A Regulatory Directive Technical Framework for Sustainable Water Management in the Semi-Arid Climates

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

By

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Abstract

Sustainable management of water resources, particularly in arid and semi-arid areas, is increasingly becoming more challenging, due to a combined effect of a rapid population growth associated with overexploitation of water resources, and impact of climate change. Climate change is projected to intensify frequency and severity of extreme events, particularly drought episodes in arid and semi-arid climatic regions. The combined effect is placing a considerable strain on the already limited water resources and has been increasing the pressure on water managers and decision-makers. A key challenge ahead is to develop measures for sustainable management of water resources. The overarching aim of this thesis is to develop a technical framework that supports the management of water resources in arid and semi-arid. The importance of the developed technical framework is to respond to these challenges through an integrated multi-objective approach for water management. Besides, there is a definite need to cope with rapid social changes and economic development, and ever-increasing water demands in a continuously changing environment. Erbil province in Iraq was chosen as a representative case study of dozens of arid and semi-arid areas, where low water-use efficiency and excessive use of water resources, particularly groundwater resources are ruling trends. Also, statutory, and legislative pressure as jurisdictions strive to implement water resources statutory standards appropriately, and the frequency and severity of drought events are projected to intensify. A novel research strategy established including a combination of a critical analysis of relevant literature, a survey including questionnaire analysis and focus group discussion, in-depth analysis and evaluation of a case study, and a critical appraisal of statutory, regulations and archived legislation documents. The study embraced interacted and interdisciplinary themes to build up a supportive framework that focused on the influential factors for sustainable water management in terms of conservation, provision and availability, and equity water allocation. Results revealed that there are an overall downward precipitation trend and upward temperature tendency across the investigated area. Two dry spell periods were observed: 1999-2001 and 2007-2008. Findings showed that there is a significant drop in groundwater levels that can be attributed to the over-exploitation of groundwater and the impact of climate change. The amounts of abstraction during dry seasons considerably exceeded the one during the wet seasons. It also exceeded both recharge and safe yield of the aquifer system. Local communities at extreme risk of water shortages as 91% of the observation wells were associated with significant drops in groundwater levels. The degree of vulnerability of the local communities to water shortages

is expected to increase. Considering that the current practices of over-abstraction of groundwater cannot be addressed appropriately in the foreseeable future, together with the impacts of climate change, represented a decrease in precipitation and increase in temperature and potential evapotranspiration rates. Rainwater harvesting ponds have a significant role in flood risk reduction. The harvested rainwater volumes mostly are not sufficient for a long drought season for watering livestock and farm irrigation; it can be regarded as a mitigation measure. The rainwater harvesting ponds as a (SuDS) measure can be employed for recreation in a certain season where the climate is moderate. As for biodiversity, despite there was not a satisfactory result, but joint actions are needed to involve Tourism Board, Environment Agency with Water Resources Management. More hydro-geological studies are needed to manage groundwater recharge properly. The outcomes show that retrofitting rainwater harvesting system in the case study area will have gain affirmative returns in the perspectives of environment, economic and amenity if invested properly. The reviewed documents of laws and regulations do have their weaknesses; the major flaw noted is the lack of practical and technical details by most of them in guaranteeing the achievement of the obligations regarding the proper management of water resources. Besides that, the drafting of some of the laws follows a general style, with some provisions overlapping one another; others lack detailed mechanisms and scientific dimensions. Further, due to diverse political assessments by statesmen and politicians at this stage, lack of funding and weak monitoring procedures has also acted as factors hindering lawmakers and academic institutions from having a useful contribution to the matter. Decision-making process encounter challenges, the highest rate was given to conflicts accounting for nearly 46%, while the lowest proportion was linked to social poverty (12%). About 23.1% and 19.8% were associated with health and economic growth, respectively. Results indicated that nearly 85% of the total water-related risks were linked to financial and physical attributes. Approximately 15% of the risks were linked to both regulations and business reputation features. The development of a local groundwater database linked to regional databases is strongly recommended for sustainable management purposes. Mapping of recharge areas and groundwater protection zones are crucial and should be considered as an integral part of long-term integrated watershed management Groundwater in shared aquifers should be regarded as common to all parties. It is recommended a resilient strategy, which increasingly introduces more restrictive policies in alliance with traditional local systems of water delivery. Joint consolidated planning is seen as a pivotal requirement among the water resources authorities, agriculture, municipalities, environment agency, climatology monitoring departments in terms of; planning, implementing, legislation, and good governance at a high level. Actions are required to apply rainwater harvesting system sustainably. Moreover, to revise and amend the environmental acts, laws, and regulations to promote water conservation and investments in integrated water resources management.

Dedications

This thesis is dedicated to the Parents' soul, their prayers and the continual encourage along with my life when they were alive. Also, to the wife, and children for their love, understanding, patience and support besides throughout the study.

It also dedicated to all who link the knowledge to surge the sciences to built-up better.

The researcher message is:

May all of us accept each other!

May all of us avoid living to bother!

May all of us strive for greatness together!

Let great minds flourish even better!

Let there be neither sick nor hunger!

Let targets be love, peace, and no horror!

The Holy Qur’anic verse

In the name of Allah, the Most Gracious and Merciful

Oh Muhammed, say: "Have you considered: if your water was to become sunken [into the ground], then who could bring you flowing water?"

(The Holy Quran, Chapter 67, Surah Al-Muluk, verse 30)

أعوُذُ بِاللهِ مِنَ الشيطان الرجِيمْ

بِسمِ اللهِ الرحمن الرحِيمْ

{قُلْ أَرَأَيْتُمْ إِنْ أَصْبَحَ مَاؤُكُمْ غَوْرًا فَمَن يَأْتِيكُم بِمَاء مَّعِينٍ}

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Publication's list (Appendix B)

Peer-reviewed journals

1. Nanekely, Mohammed, Scholz, M., & Al-Faraj, F. (2016). Strategic Framework for Sustainable Management of Drainage Systems in Semi-Arid Cities: An Iraqi Case Study. *Water, 8*(9), 406. https://doi.org/10.3390/w8090406
2. Nanekely, Mohammed, Al-Faraj, F., & Scholz, M. (2019). Estimating Groundwater Balance in the Presence of Climate Change Impact: A Case Study of Semi-Arid Area. *Journal of Bioscience and Applied Research, 5*(4), 437–455.

Conference papers (adapted post-conference into journal papers)

3. Nanekely, M, & Scholz, M. (2017). Sustainable management of rainwater harvesting systems: A case study of a semi-arid area. *European Water*, *60*, 279–285.
4. Nanekely, M, Scholz, M., & Qarani Aziz, S. (2017). Towards sustainable management of groundwater: A case study of semi-arid area, Iraqi Kurdistan region. *European Water, 57*, 451–457.

A collaborated research work outside the PhD thesis was conducted and published in the following peer-reviewed journal

5. Mohammed, R., Scholz, M., Nanekely, M. A., & Mokhtari, Y. (2018). Assessment of models predicting anthropogenic interventions and climate variability on surface runoff of the Lower Zab River. *Stochastic Environmental Research and Risk Assessment*, *32*(1), 223–240. https://doi.org/10.1007/s00477-016-1375-7

Conference papers (abstract only)

6. Nanekely, M, & Scholz, M. (2015). The Potentiality to Retrofit the Sustainable Drainage System in A Semi-Arid Area of Kurdistan. *College of Science and Technology Research and Innovation Showcase, Salford, Manchester, the UK.*

Peer review record collaboration

7. Saeedi, I., & Goodarzi, M. (2018). Rainwater harvesting system: a sustainable method for landscape development in semi-arid regions, the case of Malayer University campus in Iran. *Environment, Development and Sustainability*, *22*(2), 1579–1598. https://doi.org/10.1007/s10668-018-0218-8

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Acronyms and Abbreviations:

ACSAD	The Arab Centre for the Studies of Arid Zones and Dry Lands
ASCE	American Society of Civil Engineers
CDM	Collaborative Decision Making
CFSR	Climate Forecast System Reanalysis
CPA	Coalition Provisional Authority
EC	European Commission
EPIB	Environment Protection and Improvement Board
EPID	Environment Protection and Improvement Directorate
EWDF	European Water Directory Framework
GAP	Southeastern Anatolia Project, Güneydoğu Anadolu Projesi (in Turkish)
GWP	Global Water Partnership
IGC	Iraqi Governing Council
INBO	International Network of Basin Organizations
INBO-GWP	International Network of Basin Organizations and Global Water Partnership
IP	The Iraqi Parliament
IPC	The Iraqi Presidency Council
IPCC	Intergovernmental Panel on Climate Change
IRCC	The Iraqi Revolutionary Command Council
IRWM	Integrated Regional Water Management
IUCN	The International Union for Conservation of Nature
IUWM	Integrated Urban Water Management
IWRM	Integrated Water Resources Management
KRG	Kurdistan Regional Government
LTMAP	Long-Term Mean Annual Precipitation
LTMAPET	Long-Term Mean Annual Potential Evapotranspiration
LTMAT	Long-Term Mean Annual Temperature
LTmaxAP	Long-Term Maximum Annual Precipitation
LTmaxAPET	Long-Term Maximum Annual Potential Evapotranspiration
LTmaxAT	Long-Term Maximum Annual Temperature

LTminAP	Long-Term Minimum Annual Precipitation
LTminAPET	Long-Term Minimum Annual Potential Evapotranspiration
LTminAT	Long-Term Minimum Annual Temperature
LTMMPET	Long-Term Mean Monthly Potential Evapotranspiration
masl	Meters above sea level
MCDM	Multiple-Criteria Decision Analysis
MCM	Million Cubic Meters
MoWR	Ministry of Water Resources
MS	Meteorological Station
NCAR	The National Centre for Atmospheric Research
NCEP	National Centres for Environmental Prediction
NGO	Non-Governmental Organizations
PET	Potential Evapotranspiration
RSuDS	Rural Sustainable Drainage Systems
RWHP	Rainwater Harvesting Pond
RWHS	Rainwater Harvesting System
SDGs	United Nations Sustainable Development Goals
SPI	Standardised Drought Index
SuDS	Sustainable Drainage Systems
SWM	Sustainable Water Management
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNWC	United Nations Watercourses Convention
USAID	United States Agency for International Development
USBR	United States Department of the Interior Bureau of Reclamation
USEPA	United State Environmental Protection Agency
USuDS	Urban Sustainable Drainage Systems
WCED	World Commission on Environment and Development
WIN	Water Integrity Network
WSM	weighted sum model

Chapter 1: Introduction

1.1. Background and motivation of research

Water is a business driver and a substantial source of both risk and wealth. It is one of the most precious but least valued common property resources also. Efficient ways of water resources management are considered as an indispensable instrumental for decision-makers and planners. They are vital to social-economic development and the overall thrust of social stability.

Under the well-known slogan ‘think global, act local,’ regions in the 21st century encounter the tremendous challenge of intensifying, catalysing, and accelerating sustainable transformations, which can be known in two dimensions: first, drivers of ‘radical’ shift, like planning and governance, competitiveness and regeneration, and consuming and lifestyle; and, the second, ‘multi-dimensional’ sustainable structures, that include resource management and climate alleviation and adaptation, transport and accessibility, and the spatial environment (McCormick et al., 2013).

Water shortage hits the Kurdistan region in Iraq's northern part, i.e., the Kurdish-inhabited region, fast urbanization, and economic expansion are visible everywhere. Monitoring and water management schemes are necessary to conserve water availability to prevent aquifer over-exploitation.

It is worth to know that “Nearly 70 percent of the World’s freshwater is locked in ice. Most of the rest is in aquifers that we are draining much faster than the natural recharge rate. Two-thirds of our water is used to grow food. With 83 million more people on the earth each year, water demand will keep going up unless we change how we use it” (National Geographic Magazine, 2010) cited in (Meyland, 2011). Therefore, the utilisation of sustainable water and drainage systems in arid and semi-arid water scarce areas is gaining growing attention worldwide in particular, due to increasing consequences of the combined impacts of man-made activities and climate change.

Prior to initiating the core topic of this work, it is first necessary to introduce the term of sustainability, there are many definitions, but the most common is that put forth by the Bruntland Commission: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [World Commission on Environment and Development (WCED, 1987)]. Concerning water, a nation with water self-sufficient, it is characterised by sustainable management, ensuring enough water to meet its multiple needs for domestic, industrial, and agriculture uses. Also, its water supply will remain consistent, despite climate change impacts, such as drought and a lack of rainfall, or plenty rains and being flood resilient (Aquatech, 2019). Therefore, effective, and holistic management of water resources called water sustainability. There are now multiple demands on water resources, which drive the need for sustainable, integrated, and comprehensive water management. Sustainable Water Resources Management presents the most current thinking on the environmental, social, and political dimensions of sustainably managing the water supply at local, regional, or basin levels (Ojha et al., 2017).

Water systems need to be able to satisfy the changing demands placed on them, without system degradation, for the current and future periods. To create these sustainable systems, a more holistic and integrated lifecycle approach to water resources planning, development, and management should carry out. Such an approach should lead to plans, facilities, and policies that will be environmentally, ecologically, economically, physically, and socially acceptable and helpful by current and future generations (ASCE & UNESCO/IHP, 1998).

This research deals with a few major components and their concerns and challenges raised to the concept of sustainability applied to water management. Various pieces of literature have been reviewed, including the extent to which they applied in the development and management of water resources.

This study focuses on the contribution to assist water managers, engineers, policymakers, and planners can make, recognising that the institutions and public stakeholders should also contribute through a supportive technical framework to efficient and sustainable water management.

1.2. Problem statement

Water shortage is becoming the number one problem in the world today. The ongoing drought and the increasing demand of the growing population reduce water reservoirs. Moreover, water scarcity is not firmly connected to water sustainability well, particularly in arid and semi-arid regions. Climate change and alteration are the most influential factor that has exacerbated water availability and management today. That is why there is a belief that the severity of current climate change that is facing the globe is more serious even than the threat of terrorism (King, 2004).

Like many other countries, Iraq has long-practised the consequences of a changing climate (F. Al-Faraj et al., 2014; Pereira et al., 2014). Since 2010, the Iraqi people have witnessed severe droughts and extreme rainfall events combined with flash floods that have adversely impacted on the existing water supply and sanitation systems. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013), more frequent and more extreme weather events are anticipated in the years to come. Moreover, peoples' life has threatened due to unsafe floods and drought episodes, unsustainable drainage manners, non-rational water management, and lack of a generic platform that supporting national policies, and put-in-place strategies towards sustainable water and drainage systems

Currently, Iraq is dramatically disturbed by complex political and socio-economic problems. In its northern part, i.e., the Kurdish-inhabited region, fast urbanization, and economic expansion are visible everywhere. Also, the negative impact of climate change in the future would significantly affect surface water flows. Annual flows are projected to generally decrease below the current average annual flow (Osman et al., 2019). Thus, Monitoring and water management schemes in the region are necessary to prevent surface and sub-surface water over-exploitation in association with drought monitoring schemes in the light of legitimised water regulations.

Many semi-arid districts and provinces worldwide are experiencing the common issues; the Northeast semi-arid region of Brazil is characterising severe climate conditions and socio-economic that require specific care aiming at water resources use and conservation. Along with the water stress condition, water resources incorrect usage intensifies the susceptive to desertification. Impacts of possible climate change may also negatively interpose in the health conditions, productivity, water availability quality of life (Cirilo et al., 2017). Also, the water resources and groundwater basin in the semi-arid Mujib basin, central Jordan, has been affected by climate change and led to about 20 to 50 % reduction in annual precipitation and surface runoff. In addition to these, the Ahmednagar and Jalna semi-arid districts in the Maharashtra state in India have been suffering from mismanagement and non-sustainable groundwater utilisation for irrigation purposes, and for the farmers and villagers use (Bhangaonkar, 2018). Besides, the semi-arid Yobe State in Nigeria has experienced a significant loss of harvested crops and livestock due to drought and mismanagement in the water sector (Gana, 2018).

Along with what mentioned, water conflicts in different parts of low-income developing countries have further exacerbated access to water; little attention has been given to studying water conflicts at the local level when compared to international water conflicts. In Africa, control over water resources has been the root cause of many conflicts affecting millions of vulnerable communities. In Asia, water disputes occur due to development-related activities, in the Middle East, unfair sharing of water becomes a tool for military purposes (Adamo et al., 2018; Gebremariam, 2011).

Additionally, in semi-arid Portugal, public involvement in water sector management is rare. It is seen as necessary to achieve good water governance. Indeed, it is requisite to make awareness on the use of large volumes of water and substantial wastewater discharges that lead to some severe water pollution problems and depletions; these lead to an imbalance between the water supply needs and water availability (Gamboa, 2014).

Not only the regions and districts, but also some semi-arid cities around the world; such as Xàtiva and Benaguasil "Valencia region" in Spain (Perales-Momparler et al., 2013), Haifa in Israel, and Erbil in the Kurdistan region-Iraq accommodate and convey both sanitary sewage and stormwater. Nevertheless, they fail to cope with flash floods, which punctuate prolonged dry periods. Such failure is likely to cause deterioration in both quantity and quality of water. Moreover, some areas might be flooded with contaminated water causing disease dissemination problems.

In this work, Erbil province has been designated as a representative case study for many water-scarce areas. The province lacks any sustainable practice to combat the potential population growth, increased man-made activities, and climate alterations. The population of 2015 was estimated at 2,009,367 inhabitants. A considerable number of displaced people from some Iraqi provinces (approximately 200,000 people) have put an additional burden on the area's water system as well as on sanitation and drainage systems. However, it is projected that the population of only Erbil city will hit about 2,250,000 by 2035 (KSRO, 2016). There are little applications of the SuDS concept in water management.

1.3.Research questions

In view of the research focus, the following questions will guide the research process:

- What are the inter-discipline and trans-discipline themes that have a pivotal role in developing the framework?

- What dynamic and sustainable acclimation practices and attenuation actions can be adopted and developed to handle and alleviate the combined impacts of climate change, administrative, and human-induced pressures at local and regional scales?
- What are the features of the technical framework to be developed that can support water managers and policymakers?

1.4.Rationale aim and objectives

This work seeks to develop a coherent technical framework that supports the management of water resources in arid and semi-arid climate condition. The proposed technical support framework consists of a set of accessible measures that can be adopted to preserve, protect, and soundly manage the system and in a sustainable manner. A schematic plan of the research is shown in (Figure 1.1).

The specificity of Erbil as a part of this region, being identified as a good chosen as a semi-arid region of a wide range of similar cases around the world. Thus, the core aim of this study is to highlight the significance of the technical framework that would considerably and alike to successfully support researchers and decision-makers for the guidance of water planners, and water managers to work on. Furthermore, to make semi-arid areas more water-resilient to drought-prone spells.

This work adopts the following objectives to achieve the overall aim:

1. To critically review the literature on water scarcity related issues, and sustainable water and drainage systems (SuDS) management in arid and semi-arid regions;
2. To demonstrate how climate change and alteration had potential adverse impacts on water availability;
3. To examine the climate change effects on groundwater resources, and investigating the long-term decline in groundwater levels, storage, and abstractions;
4. To assess the changes in groundwater levels responding to seasonal and annual precipitation variability;
5. To assess the related-subjects matter on the potential applicability of SuDS in the semi-arid regions;
6. To evaluate the functions and outline the necessity of retention ponds, as a sustainable drainage system measure in semi-arid areas, which mitigate the growing combined impacts of a water shortage and inter-annual climate variability;

7. To point out the critiqued statutory documents on water-related legislations, coupled with the limitations and constraints that affect the development of sustainable water management.

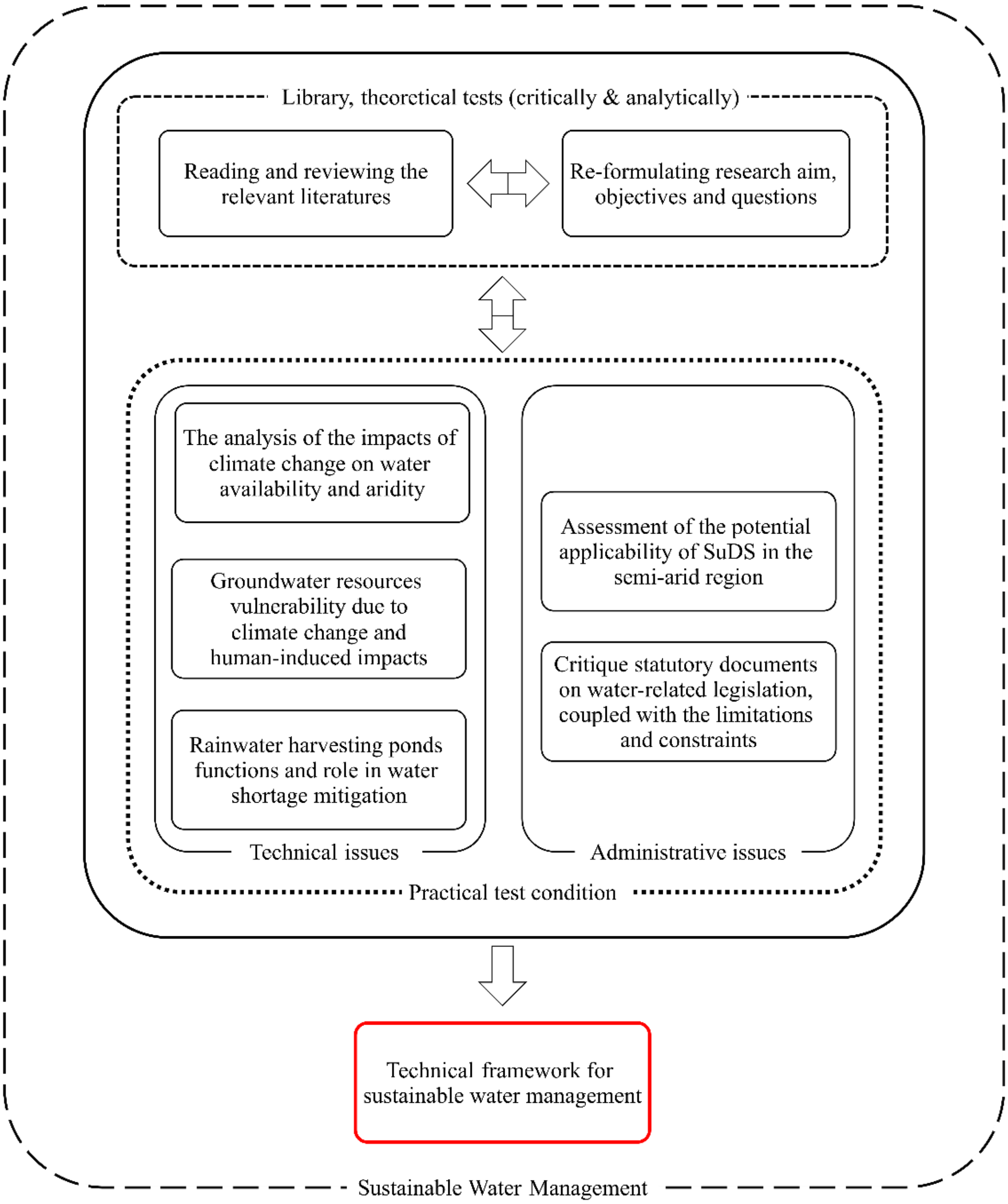


Figure 1.1 The research schematic framework (A conceptual diagram)

1.5.Research Identification and Novelty

Previous studies have tried to highlight water management either in terms of climate change, groundwater depletion, human-induced activities, or only sustainable drainage measures that attenuate the water scarcity. None of the studies has explicitly focused on the factors that have a significant and integral role in water management to develop a technical framework that sustainably supports water management for a semi-arid case study, which suffers water shortage that tends to become water-stressed areas.

Choosing this study area and focusing on common water issues is itself considered a novelty, as it passes through severe climate change, significant groundwater depletion, lack of sustainable drainage techniques, and fragile legal enacting and enforcement. Moreover, it seeks for novelty on three aspects, which is seen as a unique method that has never previously been considered; an up-to-date definition of drought, a unique research method in water resources management, and based on that to develop a technical water resources management framework to be adopted in the practice in such vulnerable regions.

Furthermore, this study is an important step to establish a nation-wide programme to achieve sustainable, rational utilization and management of water resources. It also supports the achievement of the UN-Sustainable Development Goals (SDGs) 2, 3, 6,7,11 and 15.

1.6.Approach to the research

In this work, based on the research problem nature that being addressed, pragmatism research philosophy will be adopted, which embrace the objectivism, constructivism, and interpretivism research philosophy stances. Research strategies of the survey, case study, and archival research as document reviews will be used. The approach of the research is divided into two categories:

Data collection approach: both quantitative and qualitative data will be utilised to be analysed as a mixed-method choice, quantitative data have been collected from reliable sources for climate parameters, groundwater monitoring, and sustainable drainage retention ponds. Also, qualitative archival data have been gathered from government official sources, in addition, data were being gathered from surveys as the questionnaire and focus groups, and,

The approach of data analysis; an approach of triangulation abductive laden to inductive research approach is adopted.

A comprehensive review of literature has indicated and underlined that there are remarkable knowledge gaps and calling to develop measures for assessing the climate variabilities on water availability, and its impact on groundwater resources, the potentiality of harvesting rainwater as a measure to tackle water shortages, scarcity, and stresses. Further, the statutory statements that are concerning water management have needed to be reviewed also. It highlighted the importance of developing adaptation options for sustainable management of water resources in the semi-arid case studies. Therefore, the study embraced interacted and interdisciplinary themes to build up a theoretical framework that focused on the influential factors for sustainable water management in terms of conservation, provision and availability, and equity water allocation.

1.7.Thesis outline

This thesis has been consisted and set out of five chapters and is organized as follows:

Chapter 1: Introduction

The introduction represents the basis of the thesis as it presents the focus points of the research. The chapter covers the following sections and their sub-sections: Background and research motivation, Problem statement, Study area, Research scope, Research questions, Aim and objectives, the novelty and research identification, and Thesis outline.

Chapter 2: Critical Literature Review

Chapter two presents literatures survey that have been critically reviewed. The chapter covers: Overview, Sustainable water management, Sustainable drainage system, Arid and semi-arid issues, Climate change in semi-arid regions, Groundwater issues, sustainable water management frameworks, and Water management Statutory status in the case study area.

Chapter 3: Methods

This chapter explains the methodology and the materials that been applied. It encompasses the following sections and sub-sections: Overview, Data availability and collection, Tools implemented, Methodology (qualitative and quantitative research methods), (Climatic data trend analysis, Potential Evapotranspiration estimation, , Drought and aridity identification, Trend analysis, Weighted Sum Method, Survey, Document review analysis).

Chapter 4: Results and Discussion

The chapter shows the results the main findings and discussed in detail. It consists of the following sections: An introduction, Strategic framework for SuDS, Climatic data trend analysis, Drought identification, Drought index sensitivity analysis, Impacts of Potential Evapotranspiration, Standardised Drought Index as a Climatic Index, Drought and Aridity trends, Groundwater balance and storage volume, Groundwater level trend analysis, Rainwater harvesting assessment, Technical framework, Strengths and weaknesses of statutory issues and articles.

Chapter 5: Conclusions and Recommendations

This chapter finalizes the thesis by conclusions and recommendations: Conclusions (Drought Analysis, Strategic framework, Groundwater storage depletion, Rainwater harvesting significance, Statutory issues), Recommendations and Future research, and the Limitations of the study.

Chapter 2: Critical Literature Review

2.1. Introduction

The importance of this chapter that lies to this research as it provides the initial information for sustainable water management (SWM) management in general and the components that affecting and role-in SWM that support for developing technical framework for sustainable water management in semi-arid areas in particular for further advance broadening the view and comprehension on the topic, and also to best practicing the water management by decision and policymakers, and planners. To present this chapter, it has been employed NVivo version 10 software (QSR International, 2012) that is developed by (QSR International Software Company Pty Ltd.) and it is widely being used for literature's review and qualitative data analyses, the purpose is to gather the relevant pieces of literature from various sources as dissertations, recently published journal article papers, books, the reliable internet web pages and organisations reports, and even conference proceedings. The review of literature has been organised based on domains as a thematic format, not the chronologically based. The highlighted citations, quotations, summary of results, and recommendations have been organised based on coding called ”Codes” into containers called ”Nodes” (Figure 2.1). The utilising of this software facilitates the review of each domain that need to be compared or contrasted spatially or temporally. To understand the concept of water sustainability in particular in the semi-arid region and its management, it is necessary to review the existing pieces of literature in several domains as listed below:

- The first domain explains the sustainability concept and sustainable water and drainage systems and management water management and sustainable drainage system.
- The second domain of this chapter will focus on the issues being challenged by arid and semi-arid regions.
- The next domain is included in the description of climate change and alteration.
- Following that, the fourth domain will illustrate the groundwater management and depression with its relation to climate change.
- The fifth domain will present the rainwater harvesting systems as a sustainable technique to tackle water shortages.
- Lastly, the sixth domain presents the legal affairs that belong to water management.

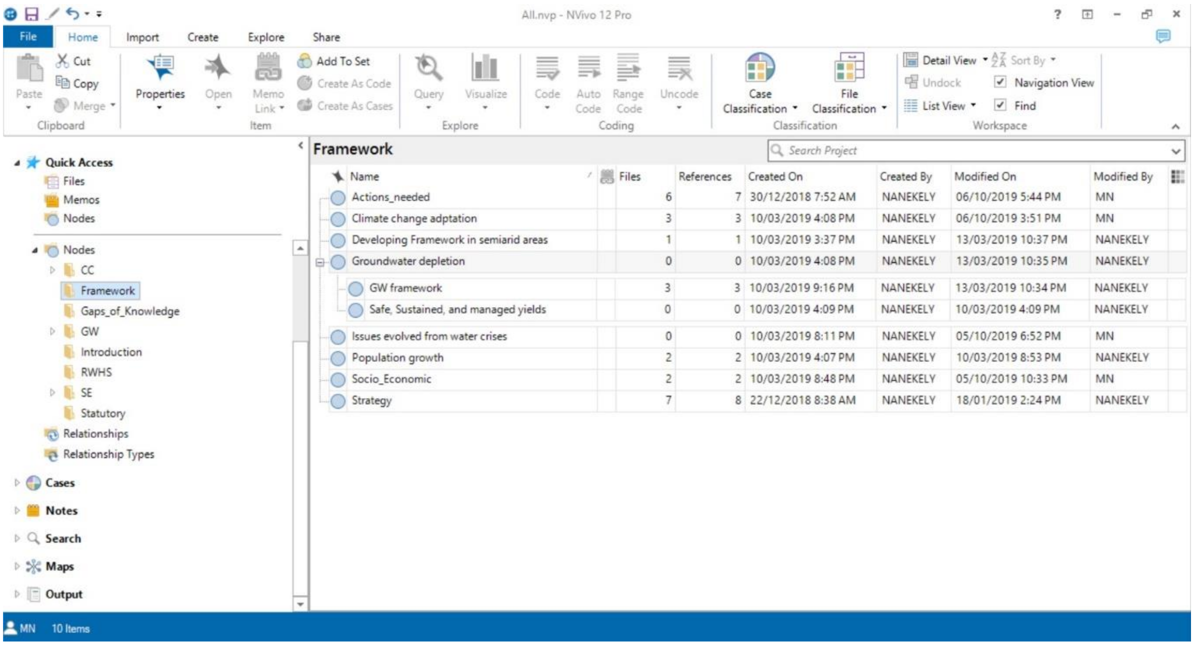


Figure 2.1 A screen-shot example of nodes tree and coding in NVivo 10

2.2. Study area

2.2.1. Choosing the study area justification

Decades of wars combined with economic sanctions, armed conflicts, and the current insecure atmosphere has left deep scars on Iraq’s arid and semi-arid environments, socio-economic features, and infrastructure.

A large proportion of the water supply and sanitation services are malfunctioning, which greatly intensified water-related challenges and exacerbated the size of water issue problems (Al Obaidy & Al-Khateeb, 2013; JICA, 2007). It has been threatened human life, the environment, and safe access to water supply and availabilities. Most people have limited or inadequate access to safe drinking water and necessary sanitation facilities. The problems of the water-related service delivery systems have been intensified, particularly the sustainable governance of drainage systems This is due to several issues: including poorly trained personnel, an intermittent power supply, a sharp decrease in spare parts availability and chemicals needed to maintain the safe running of water treatment plants, inefficient operation and maintenance programs, and a prolonged tendency that relies on curative rather than long-term sustainable solutions (N. A. Al-Ansari, 2013; JICA, 2007; US Government Accountability Office, 2005).

Management of the water supply and provision in a sustainable manner in Iraq has become a crucial issue. Al-Faraj et al., (2015) indicated that the level of water issues vulnerability has been exacerbated by the negative implications of decades of conflict and the associated unstable economic situation and political crisis, which weakened and delayed stakeholders' responses. Moreover, some vital hydraulic structures (i.e., barrages and regulators) on the Euphrates, Tigris and Diyala rivers have been controlled by "Daesh" (also known as Islamic State) several times, which impaired the daily operational policies and water resources management strategies (The guardian, 2015; Washington Post, 2016).

Due to the aforementioned issues of decades of armed conflicts and violence associated with loss of skills and institutional weakness, Iraq became one of the vulnerable and water insecure countries that have fragile water services (Furat A. M. Al-Faraj et al., 2015). Therefore, appropriately designed and operated drainage systems associated with the proper operation of other water facilities such as domestic water supply, are fundamental parts of healthy and safe environments (Maksimovic, 2001).

The main drivers adding to the elevated vulnerability include but are not limited to: (a) growing water demands at local, country-wide and transboundary levels due to climate change and alterations; (b) a considerable decrease in yearly flow volume entering the case study in Iraq from upstream riparian countries (in particular, Turkey and Iran); (c) an impairment of water quality due to effluents of untreated contaminated wastewater and considerable return flows from large-scale irrigation projects that discharge directly into watercourses; (d) non-rational water consumption use in different sectors (particularly in agriculture); (e) inadequate water supply and sanitation practices; (f) fragmented responsibilities between different actors; (g) weakness of dynamic and functional coordination among relevant stakeholders; (h) a lack or even absence of transparency in the exchange of information including data; (i) a significant and drastic decline in groundwater level; (j) legislations like acts, regulations, instructions that have not been being updated to be coped with real life situation, besides, the administrative weakness to implement such laws concerning water sector development; and (k) the absence of water withdrawal monitoring networks (Furat A. M. Al-Faraj et al., 2015; Maksimovic, 2001; US Government Accountability Office, 2005).

A semi-arid climate is the climate of a region that receives precipitation below potential evapotranspiration but not extremely. There are different kinds of semi-arid climates, depending on such variables as temperature, and they give rise to different ecology classes. A more precise definition is given by the (Peel et al., 2007) climate classification, which treats steppe climates (BSk and BSh) as intermediates between desert climates (BW) and humid climates in ecological characteristics and agricultural potential (Irlapati, 2017).

In Iraq, the semi-arid Kurdistan Region is suffering from water shortages problem. Erbil, the capital of the autonomous Kurdistan Region, has been chosen as a representative case study. As like many semi-arid climate provinces, they suffer from water shortage, climate variability, and the consequences of drought due to low precipitation, air temperatures, and high rate of evaporation. Figure 2.2 is showing the aspect of drought and water shortage in the case study area.

(a) (b)

Figure 2.2 climate change impact and drought severity in the case study area

In conjunction with the recent shortage of water, abrupt torrential downpour rains of 28 mm, 59 mm, and 42 mm in Erbil on 9 November 2015, 30 December 2015, and 29 March 2016 have resulted in flash floods (Directorate General of Meteorology and Seismology, 2016). Many sewers overflowed, which led sewage to escape and mix with stormwater. Flooding also contributed to more power outages as many local, and small power generators were flooded. Roads were damaged, and drainage systems got blocked even days after it had stopped raining. Figure 2.3 shows photos that demonstrate the failure of the drainage system in Erbil city between 1936 and 1970, and Figure 2.4 portrays sewer overflows due to recent climate change and alteration.

Figure 2.3 Historic drainage system under-performance in Erbil

(a) The city centre of Khanaqah in1936 (Erbil Governorate archive); (b) City centre of Tayrawain1960 (Erbil Governorate archive); (c) City centre of Tayrawain1967 (Erbil Governorate archive); and (d) City centre of Tayrawain1970 (Erbil Governorate archive).

(a) (b) (c)

(d) (e) (f)

Figure 2.4 Failure scenarios of the sewer overflow of the conventional drainage system in Erbil

Additionally, Erbil province like other semi-arid regions has been going under an intensive groundwater depletion so far due to intensified water demand for multipurpose uses, as it has been revealed by (Famiglietti, 2014) that the groundwater depletion has become a global water security threat, especially in arid and semi-arid regions.

Therefore, the study area encounters: (a) groundwater is over-exploited (Issa, 2018); (b) climate change results in an increase in temperature and potential evapotranspiration rates and reduces precipitation (Fadhil, 2011; Lück et al., 2014; Zoran Stevanovic & Iurkiewicz, 2009); (c) there is a lack of solid and consistent application of groundwater artificial recharge systems (UNDP, 2011); (d) integrated land-use planning is insufficient and rapid urban growth (Hameed et al., 2015); (e)) laws and regulations regarding the drilling of wells and enforcement of groundwater development regulations are absent or weak; and (f) there is a shortage of financial provisions needed to implement and/or rehabilitate relevant infrastructure (Erbil Governorate, 2018; MoAWR-KRG, 2016; MOP-KRG, 2011; UNDP, 2011).

2.2.2. Study area description

The Iraqi-Kurdistan Region, which is located in the north of Iraq, is made up of the three provinces of Erbil, Dohuk and Suleimani. Erbil is called for the province and the capital city of the region also known as “Hewler”. Erbil Province that covers an area of 15,089 km^2 (3.5% of

Iraq) has been chosen as an example case study. It lies between latitudes 35˚ 30´ and 37˚ 15 N, and longitudes 43˚ 22´ and 45˚ 05´ E. The Erbil province border extends to Iran in the East and to Turkey in the north. Erbil is located between two rivers, the Greater-Zab River to the north northwest and the Lesser-Zab River to the south-southeast. The study area varies in elevation from 175 meters above sea level (masl) south of Makhmur to more than 2500 masl in the north of the province (Figure 2.5). It consists of seven districts (Erbil, Makhmur, Koisnjaq, Shaqlawa, Choman, Soran and Merqasur). The topography of Erbil is a semi-plateau area, the plains in the south of Erbil province are important parts of the agricultural production, it has an area of 15,089 km^2 as a province and 491 km^2 as a city, Erbil city is so small compared with the total area of the Province, it account around 3% of the total area of the province (Knoema, 2016). Figure 2.6 shows an administrative map of the case study province.

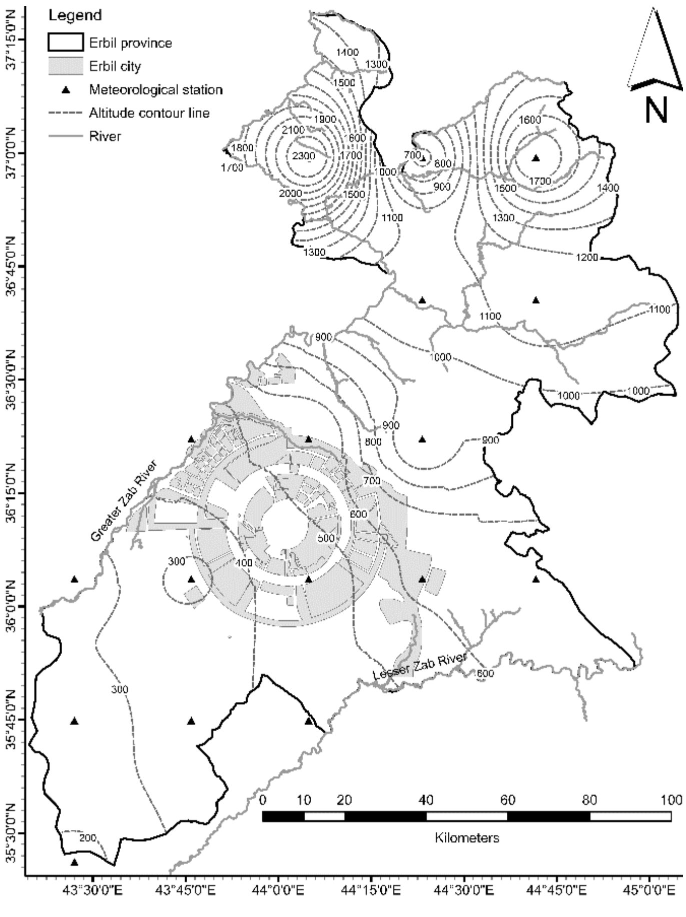


Figure 2.5 The topographic map of the case study

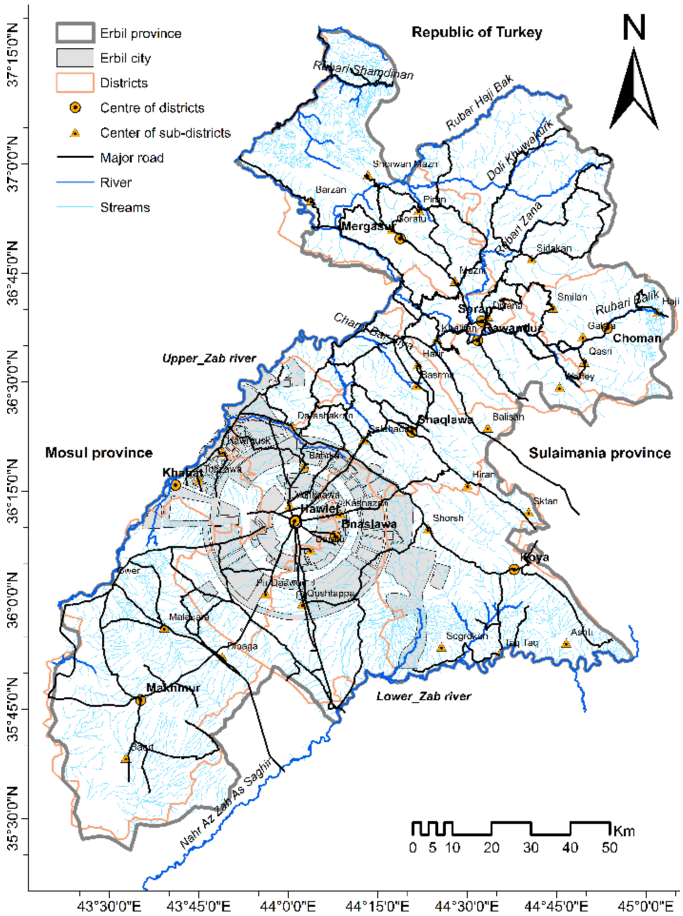


Figure 2.6 The administrative map of Erbil province case study

The City of Erbil is an economic, agricultural, and administrative centre with a predominantly Kurdish population in the Kurdish region in the north of Iraq. It is one of the world's oldest continuously settled towns. The ancient Sumerian and Assyrian city of Urbillum was on this site. Modern Erbil is on an artificial mound surmounted by an old citadel. Since 1992 Erbil has been one of the main towns of the so-called "Kurdish Autonomous Region".

This region is affected by climate change, in such cases as happened in 2006 where 112 mm of rain fell in few hours, with such a profuse rainfall no intakes can catch that huge amount of water, which leads to combined sewer overflow. The climate of the Kurdistan Region is semi-arid continental: very hot and dry in summer, and cold and wet in winter. Spring is the most beautiful season in Kurdistan. Mean high temperatures range from 13-18 °C (Celsius degree) in March to 27-32 °C in May. The summer months from June to September are very hot and dry. In July and August, the hottest months, mean highs are 39-43 °C, and often reach nearly 50 °C. Autumn is dry and mild, and like spring is an ideal time of year to travel in the region. Average temperatures are 24-29 °C in October, cooling slightly in November. Winters are mild, except in the high mountains. Mean winter high temperatures are 7-13 °C, and mean lows are 2-7 °C (KRG, 2016).

This region was affected by severe drought weather in recent years, especially between the years 2007-2008. Studies have shown that in this period vegetative areas decreased by 56.6%, as well as there being a significant reduction and shrinkage in the water bodies' surface area in the region (Fadhil, 2011).

For the collection of domestic wastewaters, timeworn and outdated sewage system exists. Wastewater discharged from households either runs in the street gutters or is connected to the stormwater sewerage system, working as a combined system.

As this situation is not satisfactory, the Municipality of Erbil, supported by the financing of the Ministry of Municipalities of the KRG, has launched a comprehensive project in order to improve the situation and bring it up to an internationally acceptable standard.

The scale of a proposed project is comprised of both, the design and construction of a complete sewerage system, which is planned to be a separate system, as well as the design and construction of a new waste water treatment plant (WWTP) (Vössing, 2005).

Wastewater is combined with stormwater is one of the environmental issues that the local authorities have not paid good attention to addressing especially during wet seasons that causes inundations. In most cases, this has led to increased health problems and financial burdens on the state (Hassan, 2010; H. Jassim et al., 2013). There is not a WWTP yet, and the reuse of wastewater for non-domestic uses is limited because of the wastewater contents (Bapeer, 2010; Saeed et al., 2010).

According to Erbil general directorate of water, in 2012, it had been produced about 61,000 $m^3.day^{-1}$ and every person in the city could receive more than 400 $litre.day^{-1}$ for domestic consumption. Therefore, the quantity of sewage discharge differs from one time to another, as a mean, it may reach 77,760 $m^3.day^{-1}$ during dry season and 108,000 $m^3.day^{-1}$ during the rainfall season (Shekha, 2016).

Erbil is one of the provinces of the Iraqi Kurdistan region. Erbil city is the capital of the Kurdistan Region and the centre of Erbil province. The location of Erbil province is extending from latitude 35˚23´55" to 36˚ 58´ 21" N and longitude 43˚ 11´47" to 45˚ 09´53" E, that is located 382 km north of Baghdad, the capital of Iraq. It has a population of 2.113 million inhabitants in 2017 (KSRO, 2019). The Erbil border extends to Iran in the East and to Turkey in the north. The predominant plains in the south of the province are important parts of the agricultural production (KRG, 2016; KSRO, 2019).

According to the Köppen–Geiger climate classification, the northern part of Erbil province is of the Mediterranean semi-arid (CSa) climate class (Kottek et al., 2006; Peel et al., 2007), which characterised by mild, and generally warm and temperate, with clear dry summers, whereas the mid and southern part is classified as (BSh) class, as a subtropical semi-arid (Hot Steppe) climate (Rasul et al., 2015). The district is almost influenced by hot-summer Mediterranean climates, that is with long, extremely hot, sweltering summers, and with cold winters. Summer months are extremely dry, with negligible precipitation between June and September. Winters are rainy and partly cloudy, with January being the wettest month.

The average annual rainfall almost ranges between 200mm and 980mm. over the course of the year, the mean annual temperature of the study area ranges between 9.7°C and 22.3.0°C. The long-term mean annual potential evapotranspiration falls between 1295mm and 2145mm, see (Appendix D.1). The agricultural land is estimated to be 41% as arable land and 59% is non-arable land. An amount of 93% of agricultural crops depends on rainfall and only 7% of the land is being irrigated (Fadhil, 2011).

The case study has common condition and characteristics with the other similars; which they have three main climate features: very low precipitation, high evaporation rates that typically exceed precipitation and wide temperature swings both daily and seasonally, in addition to low amounts of vegetation influence the soil characteristics. Also, characterized by mean annual precipitation between 200 and 700 mm often with stormy character and clustered in alternating seasons. The main feature of precipitation is the high variability in time and space of the small amount received. These regions are a subtype of dry land with an aridity index ratio between 0.20 and 0.50, characterised by a dry and very hot climate in summer, and wet cold in winter. Climate alteration brings Flash floods that caused by high intensity, shorts duration storms with a high degree of spatial variability. In arid and semi-arid regions, drought is a constant menace, its timing, duration, and severity are ever in doubt. Fragile ecosystems, making them a critical and challenging management issue in this region, during a drought, the ecosystem degrades in the terms of water, land, and plant, which occurs at an accelerated pace, which triggers socioeconomic issues in both developed and developing countries, including northern Africa, southwestern Africa, southwestern Asia, central Asia, north-western India and Pakistan, southwestern USA and Mexico, western South America, and much of Australia, and is home to an estimated sixth of the world's population. Semi-arid and arid regions are agriculturally prosperous, are experiencing groundwater depletion due to its intensive use. besides that, it is the more dependence resource for domestic water supply and industrial uses which has been depleted due to excessive consumption, in addition to overburden losses of a high rate of evapotranspiration. Growing human population rate is another issue that encounters these areas which require more agriculture lands areas for food production and an insufficient amount of available water provision for both. Water in these regions is under increasing statutory and legislative pressure as jurisdictions strive to manage water resources more holistically by addressing both surface and groundwater together but on a more decentralized and sustainable basis. These regions are facing similar legal problems but significantly different challenges arising from their unique historical attachment to individual rights to own or use water. Jurisdictions have provision for a public trust over water, but they have placed a different level of reliance on that doctrine to reallocate the limited water supply in a way that addresses the priorities as they grow and change over time.

2.3. Scope of the study

The scope of a study demonstrates the range to which the research area will be sought in the work and specifies the parameters within which the study will be operating. Thus, this research will attempt to seek three aspects of: theory, methodology, and practice as a novelty approach and contribution to knowledge through a case study, that later results in a generic value.

This research has been taken up on a longitudinal time horizon, in a scoped period from 1980 to 2015, based on the availability of data. A comprehensive review of literature will be reviewed on remarkable knowledge gaps to call to develop measures for assessing the climate variabilities on water availability, and its impact on groundwater resources, the potentiality of harvesting rainwater as a measure to tackle water shortages, scarcity, and stresses. Further, the statutory statements that concern water management is seen to be reviewed also. It will be highlighting the importance of developing adaptation options for sustainable management of water resources in the semi-arid case studies. That is, the study embracing interdisciplinary and associated themes to foundress a technical framework that focuses on the influential factors for sustainable water management in terms of conservation, provision and availability, and equity water allocation.

2.4. Justification of case study representation

For the purpose of this research, Erbil province is being considered, the capital of the Kurdistan region that is located in the northern part of Iraq, it has been chosen as a representative case study for a large number of districts, particularly in semi-arid climate areas, lacking (SWM) where: experienced a number of drought episodes during the last decades due to severe climate condition; current practices of groundwater resources utilisation lack a solid regulatory framework and where monitoring systems are often absent; negligible sustainable drainage systems (SuDS) represented as a rainwater harvesting system (RWHS) measures; water scarcity in decision-making processes; ineffectual legislations and incomplete legal regulatory framework to achieve the targets of (SWM); and the adverse effects of climate change on the water systems. Arid and semi-arid regions are spread through all continents as shown below in (Figure 2.7), Erbil province is one of the provinces that has the same climate pattern as its counterparts as shown in (Figure 2.8).

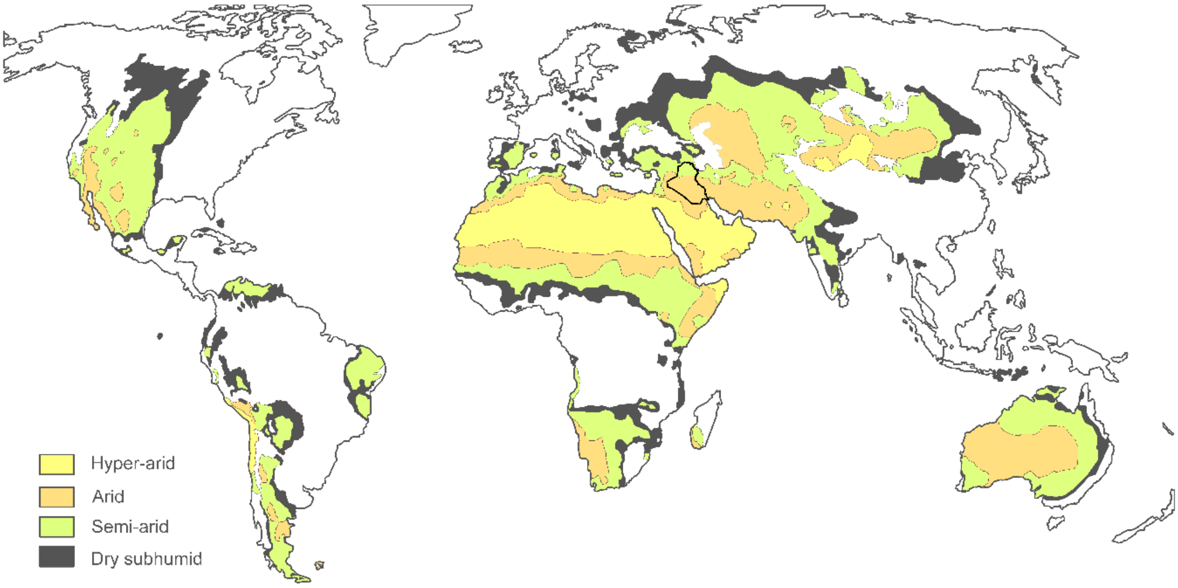


Figure 2.7 Arid and semi-arid regions in the world, the location of Iraq

Source: (Millennium Ecosystem Assessment, 2005)

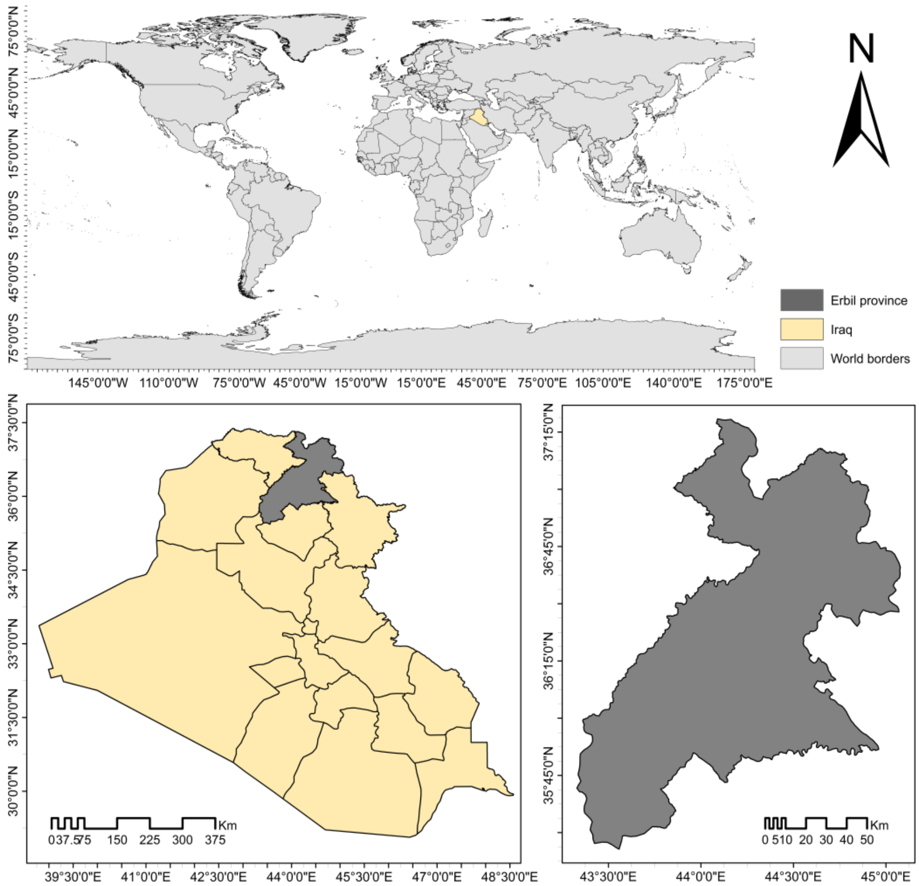


Figure 2.8 Location of Erbil province with respect to Iraq and the world

2.5. Sustainability concept

Sustainability is a concept that tries to take out from its restricted frame to more measurable state that makes human-ecological relationships better, there is still non-compatible indices for sustainability due to lack of clear methodology (Mayer, 2008). It is essential for governments to use of sustainability indices to get the optimal choice between activities benefits and costs (Ness et al., 2007).

There are two indices for environmental sustainability of regions, the ecological footprint and the environmental sustainability (Esty et al., 2008). There are a number of indices in addition to those have previously adopted. Despite of all efforts to bring out a unified index for environmental sustainability, there is not a complete satisfactory index yet, but making a junction between ecological footprint and renewability emerge index could be better (Mori & Christodoulou, 2012; Siche et al., 2008).

For improvement in fields of environment, economy, society, or technology, the performance of such related organisations needs a reliable tool of indices for urban sustainability for policymaking (R. K. Singh et al., 2009). While developing sustainability index enables institutions/governments to assess/compare sustainability performance, which guides the authorities toward it, this increases sensibility about the impact of cities on the globe through the triple bottom line (Mori & Christodoulou, 2012). However, there is not a unified urban sustainability index yet, but it seems to be normal, since it is concerning the environment, economy and society, and there are unexpected upcoming events due to rapid development of the world, if there were indices, it would need continuous updating (Cohen, 2017).

2.6. Sustainable water management

Sustainable water management (SWM) requires allocating between competing water sector demands, and balancing the financial and social resources required to support necessary water systems (Russo et al., 2014). The provision of water in urban and suburb areas as part of the sustainability of the infrastructure has gained importance recently. The fact that cities house a substantial part of the world population indicates why the consumption of water resources is extensive (Q. Zhou, 2014). The concept of sustainable development as applied to the context of water management has redefined the efforts of different organisations to meet the needs of the present generation of consumers. That is, it should be noted the importance of sustainable development which aims at improving the quality of life as well as supporting ecosystems (Gallo et al., 2013). As a result, the provision of sustainable services should occur in an environmentally friendly manner. To meet SWM objectives there should be: all forms of water must be considered usable, and reusable, water resources; and increasing agricultural crop water production represents the largest opportunity for reducing total water consumption and will be required to meet global food security needs. Additionally, the level of regional development should not dictate sustainability objectives, however, local infrastructure conditions and financial capabilities should inform the details of water system design and evaluation (Russo et al., 2014).

Brown et al., (2015) have suggest that current water systems analysis is prevalent and treats the most challenging water issues, including climate change, drought and water shortage, water provision for food production, decision-making among competing objectives, and economic incentives investment to bear on water use. An opportune moment to reorient to meet the complex, interdependent, interdisciplinary, and global nature of today’s water challenges can be taken from the emergence of public recognition and concern for the condition of water resources. Currently, low scientific and academic visibility limits the analysis of water resources systems relative to its influence in practice and bridled by focused findings that are uneasy to generalise. Of course, an integrated approach is needed to address major issues of water management (López-Pomares et al., 2015).

At the same time, a significant concern represented in drainage systems refers to water originating in urban areas (Q. Zhou, 2014). Many cities in arid and semi-arid regions are suffering from an increase in population that puts stress on water demands, in addition to water shortage and scarcity due to climate change, meanwhile, a high-density population requires urbanisation, which as a result leads to change in land cover that leads to an increase of flood risks and high rate of pollution (Yang & Cui, 2012). Therefore, the main objective of this literature review is to explore the multi directional topics that affecting the sustainable water concepts in arid and semi-arid regions.

2.7. Sustainable drainage systems

Traditional drainage frameworks are divided or merged in which both waste and rain stormwater use the same technique, and the main idea of which is to get rid of excess water or contaminated water or both (McDonough & Braungart, 2010) cited in (Armitage, 2011).

Sustainable drainage systems have been increasingly considered as promising techniques to alleviate three major water-related challenges. The problems are: (a) flash flooding; (b) imbalance between water demand and supply; and (c) water pollution (Ghani et al., 2008; N. Zakaria et al., 2007).

The (SuDS) try to copy the natural operations involved. By application SuDS techniques water pollution and flooding can be prevented in urban areas. Also, SuDS create green spaces and habitat for wildlife in cities, towns, and rurales. The methods include the: detention, retention, storage of water and infiltration, as the respective water control treatment results in a considerable decrease of the peak level of flow to avoid flooding, enhanced water quality and an opportunity to utilise rain stormwater as a source and as a component of sustainable amenity (Li et al., 2014). Yet the resources of executing the philosophy of this technology in sustainable drainage systems in a particular environment should be properly integrated despite success in some countries, such as in Portugal, Brazil, or Israel (Almeida Samora et al., 2014). That is why, it can be seen that the legalisation of SuDS has to be a requirement for all new developments in arid and semi-arid areas, at single-unit dwellings up to town planning and even within the development and planning for rational water resources management at institutional scale.

In order to succeed in terms of sustainability in both traditional and modern drainage structures, better knowledge of the physical operations is needed, along with forming connections between the structures and settings under specific environmental conditions. It is recognised that the river basin has been measured as an entity that establishes both the level and achievement of individual activities with respect to water in both prehistoric and current societies (Tortajada, 2005).

Researchers indicate that the integrated outcome of all rainstorm drainage systems plays a significant role in the stability of surface water and the instability of balanced sediments (Almeida Samora et al., 2014). Other contaminants have to be taken into consideration at the point of river basin or sub-basin process of the point under account, particularly in remote populated regions. In that context, incorporated management, controlling, planning and designing of drainage frameworks require that both outcomes are examined and an impartial evaluation is made in all stages of the water planning and administration process (Jung et al., 2015). The general objective of incorporated water administration is a sustainable usage of water sources with respect to the sustainability, social, economic, and ecological interests of the local populations. Taking into consideration the connection between the public and economy, the initial two groups are generally combined into socio-economic matters.

It should be acknowledged that the core aims, and objectives of integrated water control are prepared at various spatial levels, involving different elements. According to research, there are institutional aspects which need to be covered in order to integrate water management resources and practices (Vojinovic et al., 2014). Following are the aspects that should be considered: expansion of enhanced informatics support mechanisms for controlling, planning, designing and operational administration based on enhanced capacity and quality of facts; integration of more appropriate elements and stakeholders into the water management and decision-making processes (e.g. sustainability, public views). Establishment of research methods is needed to assess the uncertainty and ambiguity linked with future water control policies. Professionals in the field pay adequate attention to the assessment on how to discuss and instruct the public concerning the significance of metropolitan water issues (Haghighi, 2013). Introducing appropriate organisational/institutional frameworks is crucial to integrate incorporated, holistic framework management support. Endorsing suitable water management legislation and principles is expected as well (CIRIA, 2015).

The primary qualities of incorporated water control management are its holistic setting, which identifies the framework complexity, and inter-linkages of its components, replacement of information, energy and substance, and the style of control actions (Li et al., 2014). The holistic practice also similarly involves local/metropolitan and regional institutions, civil engineers and scientists, environmentalists and executives, politicians, government, and opposition, as well as the individuals affected. Sustainable water control management is guaranteed regardless of the loss of power, or inappropriate functioning of revival (Maurer et al., 2013). In the metropolitan drainage sector, it is important to ensure an extensive application of foundation control in terms of industrial water sources.

The most relevant instances of water utilisation refer to water supply (harmless, safe, reliable, and reasonable), drainage and overflow protection, hygiene with maximum recycling, recreation (promoting public health), creative and cultural principles, and environmental health. Solutions implemented at the metropolitan catchment level have to be examined in terms of the effects produced on upstream and downstream users (Bodík & Ridderstolpe, 2007). The role of rainstorm drainage systems in the variances of water sources might be examined by taking into account the approaches in which the current metropolitan structures function. It is essential to explore those structures' characteristics, and the newly designed drainage components, especially how they might influence aspects of balance and quality in a particular metropolitan region (Arnbjerg-Nielsen et al., 2013). In this sense, the major variation between metropolitan and countryside parts of a river basin is the decreased infiltration potential of metropolitan regions and the quick response in creating a surface overflow. The major variation in techniques to incorporated solutions is specified by the percentage of the metropolitan maximum flow to the flow in the downstream. The types of metropolitan flooding caused by other artificial and natural disasters, such as rainstorm or hurricane, might correspond to heavy rain and dam breakage, which also should be taken into consideration (Beeneken et al., 2013).

Although (Heal et al., 2004) see that the acronym "SuDS" contains the word "sustainable" SuDS will never be totally sustainable if drainage problems are not tackled and solved at source. Indeed, SuDS have never been viewed as completely sustainable, as the definition of SuDS: demonstrate: a sequence of management practices and control structures designed to drain runoff in a more sustainable fashion than some has been described as "a journey and not a destination" and this description applies equally well to SuDS.

2.8.Sustainable management of rainwater harvesting systems

In the World Economic Forum 2017, it has been pointed out that Environment-related risks also stand out in this year's global risk landscape. The most frequently cited of these being the pairing of "water crises" as well as "failures to climate change mitigation and adaptation". Furthermore, The World Bank expects that water stress could cause extreme societal overstrain in regions like the Middle East, where the economic effects of water scarcity could reach at risk 6% of Gross Domestic Product (GDP) by 2050 (Heijden et al., 2015). Water shortages problem can affect the daily life needs in its various forms, agricultural, industrial and then to varying degrees the economic activities.

Amin, Alazba, & ElNesr, (2013) have pointed out that an increasing maximum rainfall with decreasing annual rainfall has been observed for the cities signifying the more extreme rainfall events and resulting floods for short durations. The assessments of any systematic changes in view of the increased rain intensities and extreme climate events are viewed to demonstrate the harvested rainwater value and management as a local adaptation to the climate variability and extreme.

Bitterman, Tate, Van Meter, & Basu, (2016) have explored that there are a number of components that are basic components which govern water security, the components are; Land use/land cover, Hydrology, groundwater, socio-economic, social equity, ponds functionality as ponds capacity and management, and agriculture productivity. Therefore, considering further variables such as livestock's watering, area of ponds, biodiversity value, bio-retention consideration, recreation aspects, groundwater recharge, and beneficiaries support, those additional variables would give more comprehensible outcomes for the same studied period.

2.9.Rainwater harvesting systems in semi-arid areas

Water shortages problem can affect the day life necessities and requirements in its various forms, domestic, agricultural, industrial, and then to varying degrees the economic activities.

In large cities, rainwater storage tanks can be used to save rainwater, but in peri-urban development and suburb areas, different rainwater means such as tanks or ponds are used as a unique water supply for many households and families to support agricultural livelihoods, mitigate water insecurity, and enable ecosystem services.

The (RWHS) can be utilised in both areas; urban, outskirts, and suburban rural areas. In urban areas as it is common in different climatic regions, it is used as rainwater tanks, detention, or retention ponds, whether in rural areas it can be used as rainwater harvesting ponds or as wetlands.

2.9.1. Urban sustainable drainage systems

The design of Urban sustainable drainage systems (USuDS) involves many different disciplines and multidimensional criteria (Fryd et al., 2012). Nevertheless, most specialists and professionals tend to focus on and prioritize their own fields in the decision-making process (R. R. Brown & Farrelly, 2009). An integrated and trans-disciplinary approach will be necessary to incorporate the many disciplines in a common platform to facilitate innovative and sustainable solutions (Q. Zhou, 2014). It is essential for stakeholders to comprehend the broad scope of sustainable design and consider the urban water cycle as a whole planning unit. Meanwhile, climate change and urbanization changes need to be incorporated into the design in order for (USuDS) to adapt to future changing conditions (Gomes et al., 2012). In such a context, the future of sustainable drainage design is most likely a mix of both high- and low-tech solutions to seek a balance between investment cost and performance efficiency within a solid technical framework.

Bastien, Arthur, Wallis, & Scholz, (2010) have shown that the use of a treatment train as ponds allows approaches differing from the traditional use of single (SuDS), either source or “end-of-pipe” to be proposed to treat and attenuate runoff. The outcome provides a more flexible solution where the footprint allocated to (SuDS), costs and water quality can be managed differently to meet stakeholder objectives more comprehensively.

As for the Location and type of SuDS techniques depend on the specificity of the local conditions, as this is determined through a flexible decision-making process (Ellis, 2013). Thus, planning and implementation of drainage systems, principally (SuDS), is in line with the entire concept of water management. The use of (SuDS) should meet particular criteria, such as site characteristics, water quality, groundwater protection mechanisms, geological sensitivities, and emerging environmental issues

The reduction in regional land take can be achieved based on water quality performance or source and site control attenuation. Despite the problems associated with offsetting regional land take with source and site controls, results reveal that a different footprint for SuDS can be achieved by using (SuDS) in series rather than as an end-of-pipe control. It can be seen in the context of several SuDS related considerations which will vary greatly between catchments: land value in urban areas; increased amenity and biodiversity in urban areas; better management of accidental pollution; and improved pollutants degradation.

Further work will comprise investigating the potential value of (SuDS) source and site controls from the point of view of people living in proximity. This will enable the definition of preferred treatment trains for urban areas depending on land use, catchment characteristics and stakeholders' objectives.

2.9.2. Rural sustainable drainage systems

Rural Sustainable Drainage Systems (RSuDS) are not a new concept, but they are not widespread in the rural environment and could present many opportunities for improving our management of water at the source. They are a collection of physical structures used to mimic natural processes. In rural environments, it is an approach for managing the detrimental impact of rainfall on fields where run-off is a major threat to the flora, fauna and chemical status of our surface waters (Avery, 2012).

The (RSuDS) slow down or prevent the transport of pollutants to watercourses by breaking the delivery pathway between the pollutant source and the receptor. in addition to reducing flood risk and adapt to climate change, there is a further benefit that is the ability to provide valuable aquatic habitats in the form of micro-wetlands for farmland wildlife and will encourage the downward movement of water to recharge aquifers. There are different types of detention ponds, trenches, buffers, and wetlands.

Zakaria et al., (2013) have seen that the application of Macro (RWHS) helps to minimize the water crises in rural areas, indeed, thereby the (RWHS) techniques are encouraging and helps to minimize the water crises. On the other hand, the use of watershed modelling system (WMS) and linear optimization programming for the last two decades gives hopeful results (N. Al-Ansari et al., 2015). This had been conducted based on variables of; volume of harvested water, water surface area, catchment areas, and the minimum cost of small dams. While adopting different research methods and taking into account further variables such as livestock's watering, area of ponds, biodiversity value, bio-retention consideration, recreation aspects, groundwater recharge, and beneficiaries support, those additional variables would give more comprehensible outcomes for the same studied period and would modifies the results if different periods had been taken.

Hajani & Rahman, (2014) have examined the performance of a rainwater harvesting system (RWHS) in suburbs in semi-arid regions. Findings discover that a 5 m^3 tank can meet 96% to 99% of water demand for family daily needs. However, 5 m^3 tank can meet 69% to 99% of that demand in the driest year. Based on the results of life cycle cost analysis, the outcomes indicate that a 5 m^3 tank has the highest ratio of benefit-cost (ranging from 0.86 to 0.97) among different size tanks. Interestingly, this size of the tank, with a combined use (i.e., irrigation, laundry, and toilet), gets back a positive socio-economic value for people by decreasing water consumptive, leading to low water prices. Nevertheless, what has been resulted, but based on the developed regression equations, it can be given different values in different locations around the world, as there are many factors are governing; rainfalls frequency, dry and wet seasons pattern, water prices in the country, people behaviours in using water, water laws and regulations that adopted in the country.

A number of numerical models can be used to investigate the potentiality of RWHS, whether there are utilisations or not. ArcGIS and watershed modelling system (WMS) have the wide range uses among sorts of models. Ramakrishnan, Bandyopadhyay, & Kusuma, (2009) assert that ArcGIS gives 80-100% accuracy for the optimum selection of sites in semi-arid areas in India. Whereas (Ammar et al., 2016) have identified three main sets of criteria for selecting RWH locations and the main characteristics of the most common RWH techniques used in arid and semi-arid regions. There are diverse methods ranging from those based on only bio-physical criteria to socio-economic criteria that are more integrated approaches, especially after the year 2000. For the selection of suitable sites, the most important criteria of (RWHS) were soil type, land cover and land use, and slopes, cost, rainfall, and distance to settlements/streams. Thus, the success rate of (RWHS) projects tend to increase when these criteria are considering, but these selection methods evaluation objectives is still lacking. However, most of the current research selects the sites of (RHWS) using geographic information systems (GIS) in combination with hydrological models and multi-criteria analysis. Thus, the inclusion of a risk register for the implementation of (SuDS) in arid and semi-arid regions is recommended as well because such a measure would ensure that specialists in the field had considered uncertainties in terms of system performance and overland flood flow routes. To address the risk of flood in the respective areas, experts of water management are expected to provide a strong foundation of hydraulic design, which has the goal to minimise the physical stress on the watercourse.

2.10. The SuDS triangle

The SuDS triangle, forms the basis for a better environment, opening the possibility to introduce water as a value to be preserved and combined. This trend is seen worldwide, with different levels of engagement (Heal et al., 2004). Sustainable Drainage Systems (SuDS) involve consideration of three aspects: water quantity, water quality and amenity, known as the "sustainable drainage triangle". Sustainable development, defined in the Brundtland Report " Our Common Future" (Brundtland, 1987) as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" is based on the "sustainability triangle" and aims to balance environmental, economic and social considerations.

The main principle behind the philosophy of SuDS is that the functioning of its systems contributes to maintaining a natural hydrological regime of the environment. This usually occurs using different physical devices as well as through the retention of storm discharges. Researches indicate that SuDS usage lead to decreased flood risk and natural pollutant degradation taking place through volatilisation, absorption, and plant uptake (Quinn & Dussaillant, 2014).

These systems tend to differ in relation to specific performance indicators and the benefits they offer. Although most SuDS techniques offer multiple advantages, some perform more optimally in relation to flow attenuation, while others demonstrate adequate performance in regard to water quality remediation, or ecological performance (Jose et al., 2015). Researchers have stated that specific approaches related to the implementation of SuDS might be focused on building robustness into the precise way in which stormwater is treated (Almeida Samora et al., 2014) that serves sustainable water management.

SuDS have become an integral part of the primary objective to develop sustainable drainage, which indicates the achievement of various goals to include maintaining an appropriate public health barrier, decreasing flooding and pollution risks (Jose et al., 2015). As recognized, more integrated solutions are needed to ensure optimal source control in relation to drainage in arid and semi-arid regions. The use of SuDS might contribute to the use of multiple sources and tools, as this indicates the hope that more sustainable drainage systems might be delivered to consumers.

2.10.1. Water quality

Rain stormwater overflow becomes contaminated when it washes off rigorous and dirty pollution sources extended across the catchment. Besides soil attrition caused by rainstorm impacts and cut off force actions, two major factors contribute to rain stormwater pollution in moderate climate regions: dirty sources, which are mainly initiated from environment fallout and carbon emissions "the effect of those sources is mostly clear in the vehicles and airstream", and rigorous sources, originating typically from individual activities "inappropriate organisation or maintenance, as well as manufacturing wastes, chemicals used in industrial areas". It has been argued that both approaches tend to create soluble and balanced substances (Todorovic & Breton, 2014). Throughout the development of transport, depending on hydraulic settings, resolving and re-balancing occurs on the surface and in drainage pipes, as well as provokes certain organic and chemical responses. These approaches are frequently considered stronger and more apparently expressed in the first stage of the rainstorm; however, due to chronological and spatial unpredictability of rainfall and overflow of water, initial rainstorm effects are more definite in drainage pipes rather than in the streets. In fact, substantial amount of contaminants might be seen throughout the overflow process (Dearden et al., 2013). The success of overflow quality of water is directly dependent on the quality of forming strategy, referring to its dependability to practically replicate processes arranged in nature.

The implementation of SuDS implies direct positive effects on water quality in arid and semi-arid regions. Water quality problems might be solved with the use of SuDS. As a main driver for urban and suburbs drainage, water quality can be achieved in such environment if strict procedures for addressing the problem are considered. The techniques designed in SuDS are intended to improve the environment in terms of controlling flow and volume simultaneously (Roinas et al., 2014). The qualitative use of SuDS mostly refers to ensuring that runoff passes through various stages prior to achieving the goal of infiltration into the ground or water course.

Different values, such as runoff volume and flow rate, are dependent on the intensity of the surface water. The management of the runoff occurs in an efficient manner in the sense that the rain water should be returned back to the water environment so as to be closer to the source (Khabba et al., 2013). By selecting hard surface or soft landscaped design, experts of SuDS are focused on improving the quality of water coming in particular site, this through SuDS components application like detention ponds, swales, pervious pavement, and wetlands provide water quality improvements by reducing sediment and contaminants from runoff either through settlement or biological breakdown of pollutants (Fletcher et al., 2015). Also, this can improve the quality of downstream water bodies such as streams, rivers, lakes.

2.10.2. Water quantity

Researchers have indicated the importance of quantitative control taking place at the source site in order to decrease excessive runoff (Mguni et al., 2015). Another quantity technique which is found feasible for transferring of the sustainable drainage concept to arid and semi-arid regions is the possibility to limit peak discharge to an initially agreed runoff rate. The storm return period also should be agreed as part of the implementation of similar quantity parameters of SuDS. In this way, water quantity elements are treated in a different manner depending on the precise physical characteristics and conditions of those arid and semi-arid regions (Bressy et al., 2014). There should be an equal balance between water quality, water quantity and biodiversity, as those elements comprise the SuDS triangle, which is considered feasible for the implementation of the concept in the respective regions. Research shows that the planning stage is quite important for the incorporation of fundamental SuDS techniques into drainage systems (Uzomah et al., 2014).

Changes to the urban landscape should be properly addressed as part of planning processes involving the use of SuDS techniques. Yet arid and semi-arid regions are mainly represented by existing sites instead of new developments. It is not necessarily, as it has been seen, the rate of development in arid and semi-arid regions can be affected by many factors: government policy, economic situation, legal issues, individual’s income. SuDS are also plagued by practical barriers such as the difficulty of precisely quantifying their hydraulic and water-quality improvement performances in the management of run-off, especially at a city-wide level (Goldenfum et al., 2007; Walker et al., 2012). Also, the need for costly, high-skilled maintenance and regulation of SuDS elements presents a significant barrier, especially when considering that such skills and resources may be unavailable in developing countries

(Armitage, 2011) cited in (Mguni et al., 2015). The aforementioned assumptions should be considered when planning to improve drainage systems in arid and semi-arid regions, as the effectiveness of SuDS is closely linked with a decrease of flood risk in the built environment. Thus, the process of designing SuDS into the built environment should be completed in a way to correspond to the urban areas' objectives efficiently, as indicated in research (Bressy et al., 2014).

2.10.3. Amenity and biodiversity

The implementation of SuDS techniques is valued for deriving certain amenity and biodiversity advantages. Opportunities for biodiversity enhancement should be explored as part of the entire process of implementation of the respective measures. Amenity benefits might relate to particular SuDS features that might be adapted to arid and semi-arid areas, such as rills, canals and cascades (Everard & McInnes, 2013). This implies a solid focus on the creation of places that might be used for recreation purposes. As a significant design principle, SuDS techniques should be kept in proximity to the surface because of the required integration into the landscape. The SuDS design process is associated with the application of high-quality engineering and design principles. As researchers argue, the features should be safe and easy to maintain (Bell, 2015). Future adaptations might be considered at the design stage as well.

The overall value of developing and improving urban drainage systems in arid and semi-arid regions might be derived upon the inclusion of aesthetic and sustainable SuDS design features. The local population in those regions should possess adequate awareness and ensure thorough understanding of the goals and functions of SuDS (Bell, 2015). It is recommended to use quite gentle slopes sides and methods of barrier planning in order to limit access to the water, which is associated with avoiding of persistent problems at the water site. Other challenges that might be addressed with the development of the amenity and biodiversity functions include shallow water depths and avoiding of suddenly occurred depth changes in the water (Ellis, 2013). Additional benefits for the wildlife might be achieved through ensuring optimal water treatment and sufficient ecological design. Researchers claim that it is essential to copy some of the qualities of the natural ecosystems (Everard & McInnes, 2013). Thus, a relevant question presented in the literature is related to how amenity and biodiversity benefits might translate in practice. For instance, researchers claim that sustainable urban drainage might contribute to the substantial amenity value of different regions, particularly in semi-arid areas. This would further lead to a significant improvement of the general quality of life, the advantage of open water areas should be optimally utilised through constructing detention ponds (Voskamp & Van de Ven, 2015), particularly in moderate climate conditions, as spring and autumn seasons in these regions. Direct benefits might be generated for land values and house prices with locations in proximity to SuDS water features.

2.11. Arid and semi-arid regions issues

The governments' policy play a remarkable role in supporting any plan that they predict to be successful, however, in some countries which are situated in arid and semi-arid regions challenging gender differentiation, migration, political, environmental, and economic issues due to drought consequences (K. Schwabe et al., 2013). Countries like Ghana, North East Brazil, , Iran, India, Afghanistan, and Ethiopia are countries have experienced in this matter (Ahmed et al., 2016; Barbieri et al., 2010; Saatsaz, 2020).

Faram et al., (2010) have seen that the implementation of SuDS requires clear determinations and actions that climate change issues can be tackled by the contribution of SuDS in the portfolio approach of climatic problems. It has to be focused on the climatic portfolio approach through enhancing the stakeholders and political interventions, In addition, (Silveira, 2002) has examined the fact that socio-economic factors in arid and semi-arid developed countries are much easier than the developing countries.

Factors preventing the adoption of such solution (Barros Ramalho Alves et al., 2020; CIRIA, 2015; Ellis et al., 2002; Silveira, 2002) include: (1) there are land capturing that limits the space to apply the modern sustainable solutions in both formal and unauthorized settlements like Campina Grande city, Paraiba state, in the semi-arid region of Brazil; (2) due to the socio-economic growth, the disposable trash increase, besides, the harsh climatic alterations as the continuous rise in temperature rate, both favour the growth of epidemics in retention and detention ponds where runoff is retained, which adversely impacts the environment; (3) appropriate drainage management and design require the technological basis, which necessitates an allocation of budget to maintain its implementation and management that positively affect the environment and water availability, along with less expenditure on the health sector on the other hand; (4) administrative-base and community-based interactions almost non-existent that is necessary to obtain modern solutions to urban drainage problems, these problems can be improved through synergic efforts from both sides like public participatory projects, public awareness, institutional systematic of drainage management.

These impediments have to be realised well to achieve modern and viable solutions appropriate for developing countries. Furthermore, the problem of mass exoduses in some of these areas, because of political and military actions events, will put the host community under the pressure of both socio-economic and water as well as drainage system problems.

2.11.1. Drought issues

Drought is a common phenomenon in arid and semi-arid regions, on average, once every ten years these regions experiencing notable droughts. Climate projections for many arid and semi-arid regions propose a future with more aridity, longer periods of less precipitation, and more frequent and intense meteorological drought (Seager et al., 2007) cited in (K. A. Schwabe & Connor, 2012). Across the past four decades, warm-season span, as measured by warm periods without significant rainfall, it has increased by approximately % 3.5 in the Southwestern United States, and by 6.4% within California and Nevada (Groisman & Knight, 2008), whereas between the late 1990s to 2009 is deemed the driest on record in southeaster Australia (CSIRO, 2010). With rising demands of water due to growth of population, the frequency and degree to which the water supply falls short of its demand will increase too. For instance, the estimated impacts of drought include agricultural production losses assessed of US$670 million in Spain between 2004-05 and losses from the reduced production of hydropower that resulted in US$123 million (K. Schwabe et al., 2013). The impacts of drought can be far-reaching and affect the industry, energy, municipalities, recreation, and residential households, in which the impacts are severe and minor (Lord et al., 1995; Wilhite, 1993). The impacts of the drought range over time and location. Other factors impacting the severity of impact include the vulnerability of the hydrologic system, the exposure level, and the ability of stakeholders and institutions to respond, mitigate, and adapt to the drought (Wilhite et al., 2014).

Al-Faraj, Scholz, & Tigkas, (2014) have shown in their study on a transboundary river basin the semi-arid north of Iraq, that there is a wide range of changes in the amount of precipitation (a decline between (0% and −40%) and in the potential evapotranspiration rate (an increase between 0% and +30%). Additionally, the comparison between two drought indices (Reconnaissance Drought Index - RDI) and (Streamflow Drought Index- SDI), coupled with the current and future conceivable man-made changes in the river basin, and taking also into account the effects of climate change, results were shown at the cumulative drought effects on climate during recent multi-year droughts episodes (1999–2001 and 2008–2009), which crippled the socio-economic activities and influenced the environmental system in Diyala river basin, Iraq (Furat A.M. Al-Faraj & Tigkas, 2016). Contrary, those indices have been used in this context, but for non-transboundary cases, it can rely on both widely used indices the SPI and RDI approaches (NCAR, 2019).

Therefore, the combined impacts of multi-year droughts and the water management pattern have significant effects on water availability, with impacts on the security of the irrigated agriculture and public water supply, contributing to displacement and tribal conflicts. The expected climate change conditions along with the water usage schemes, which will put into operation in the foreseeable future, are expected to increase the vulnerability of water security in the areas around.

2.11.2. Ecosystem services

According to (Moll & Petit, 1994) an ecosystem can be defined as "a set of interacting species and their local, non-biological environment functioning together to sustain life". Ecosystem services are the benefits provided by ecosystems that contribute to making human life both possible and worth living.

Bolund & Hunhammar, (1999) have claimed that the locally generated ecosystem services such as "street trees; lawns: parks; urban forests; cultivated land; wetlands; lakes; sea; and streams" have a substantial impact on the quality-of-life in urban areas and should be addressed in land-use planning. They also claim that ecosystem services such as lawns/parks, urban forests, cultivated lands and wetlands in urban areas are contributing to protecting the rainwater from loss and pollution while just wetlands are contributing to the treatment of sewage water.

The soft ground of vegetated areas allows water to seep through and the vegetation takes up water. In vegetated areas, only 5–15% of the rainwater runoff on the ground, with the rest evaporating or infiltrating the ground. In vegetation-free cities, about 60% of the rainwater is instead lead-off through stormwater drains (Bernatzky, 1983). This will of course affect both the local climate and the groundwater levels. The valuation of this service depends on the local situation. Urbans with a high risk of flooding will benefit more from green areas that take up water than do other cities.

In many urban areas, wetlands are being used to treat sewage water. The wetland plants and animals can assimilate large amounts of the nutrients and slow down the flow of the sewage water, allowing particles to settle out on the bottom. Up to 96% of the nitrogen and 97% of the phosphorous can be retained in wetlands, and so far wetland restorations have largely been successful, increasing biodiversity and substantially lowering costs of sewage treatment (Ewel, 1997).

(Gill et al., 2007) suggested that increasing green space would reduce runoff by 4.9%, increasing tree cover reduces runoff by 5.7% and that green roofs would have a significant effect in reducing runoff by 11.8-14.1%. A study by (Mentens et al., 2006) concluded that the rainfall retention capability of green roofs on a yearly basis may range from 75% for intensive green roofs to 45% for extensive green roofs. Above all, those studies have been undertaken in Sweden which has a different climate with arid and semi-arid areas, the green roof techniques might not be successful in such an area as an ecological service, because of long drought periods, which could be an opportunity to undertake research on them. Despite this, it is noted that another benefit of green roofs over traditional green space is that they make use of previously unused space and do not impact the demands of people for open space on the ground. Additionally, (Shen & Chen, 2009) have confirmed that the hydrologic cycles and water balance in arid basins are characterised by strong evapotranspiration and in water use sectors irrigation consumes a large amount of water, resulting in the degradation of native vegetation. That is why from the ecohydrology perspective, a thorough study of hydrological and ecological processes of water utilisation in semi-arid areas is urgently needed.

(Lundy & Wade, 2011) strongly claim that urban water components contribute to the delivery of ecosystem services in all categories of it, such as supporting services, provisioning services, regulating services, and cultural services, and support the view that urban water bodies should be seen as multifunctional components of urban space. However, in arid and semi-arid regions it is different; not all services will be delivered, just likely most of them.

2.11.3. Socio-economic, population, and political issues

The feasibility of transferring the sustainable drainage concept to arid and semi-arid regions is associated with the exploration of specific socio-economic and political issues pertinent to such areas. A significant problem that might emerge in these regions is environmental factors represented as climate change interact with socioeconomic, cultural, and political processes to shape migration decision-making (McLeman & Hunter, 2010). Challenges are standing toward decision-making process, (Mohammed Nanekely et al., 2016) have assessed that the impacts of conflicts and political issues accounting four-fold of social poverty in semi-arid areas. It is essential to note that vulnerability is perceived as the direct product of the combination of socio-economic and political factors. Insufficient socio-economic indicators dominated by periods of drought and demographic tensions usually result in persistent migration from arid and semi-arid regions. It is apparent that water is fundamental for the facilitation of socio-economic development in arid and semi-arid regions as well as for the maintenance of healthy ecosystems. The constant increase of the population corresponds to the urgency to efficiently allocate groundwater and surface water for different sectors functioning in those areas.

Another issue related to socio-economic and political factors is identified as water scarcity. In the process of allocating scarce water resources in arid and semi-arid areas, the local authorities are advised to implement the efficient tool of evaluation in order to recognise important dimensions for stakeholders in the field (EWFD, 2006). As part of socio-economic and political interventions in such regions, the use of integrated water resources management framework is appropriate since it represents a solid framework that emphasises the need for action at regional and national levels. Thus, it can be stated that the government plays a significant role in validating efficient measures to improve and regulate water use in arid and semi-arid regions. The utmost goals outlined in the socio-economic and political landscape of those areas refer to decreasing losses related to water and increasing recycling of water. Priorities should be given to basic human needs, along with restoring the balance in ecosystems (Postel, 2003).

The role of groundwater in socio-economic and political development has been extensively recognised in the last few decades. An emerging advantage of groundwater is its ubiquity, but such a characteristic demonstrates significant challenges in its rethinking and proper management (Carrard et al., 2019). The management of groundwater as a socio-economic issue might be complex since an appropriate technical perspective is needed as well (D. Mustafa & Qazi, 2007; Salameh, 2008; Sarkar, 2011). The aspect of social mobilisation has been underlined as a priority by many organisations, which are responsible for the management of groundwater resources (European Communities – Commission, 2009). In this context, the issue of sustainable drainage applied to arid and semi-arid regions had received substantial attention in the research because of the possibilities to ensure sustainability not only for human beings and organisations but also for the environment. The adoption of a social perspective on technical information is important in the context of understanding hydrogeological processes. Aspects of access and system dynamics should adequately be explored by the respective authorities, in order to ensure compliance with strict principles of the socio-economic and political government of such resources (Nassery et al., 2017).

2.11.4. The challenges facing SuDS in semi-arid developing countries

The most important challenges to sustainable drainage in developing countries have to do with the incompetence of local government to provide appropriately serviced areas for the specific sites within the cities (Armitage, 2011). Subsequent “crisis management” fails to address the needs of the residents who are compelled to live there. Whilst that the technical solutions are available, thus, in the absence of adequate social and institutional planning and support, success is rare. Services are often implemented without due regard to consequences. The real obstacles to sustainability are the lack of adequate numbers of skilled personnel who are able to plan and implement urban drainage in a timeous and comprehensive manner in some semi-arid countries like South Africa, coupled with the lack of funding needed to pay for the work (Armitage, 2011; Armitage et al., 2013). Given historical problems with aid to developing countries, probably the best way is that developed countries can help with achieving sustainable urban drainage is by providing professional support to local authorities. NGOs have also shown themselves to be a considerable asset in mediating drainage solutions (Armitage, 2011). For instance, in most developing” countries people living in slums in dire conditions, the associated problem with these slums is poor drainage resulting in ongoing contact with contaminated water and flooding. Additionally, the failure to comprehend that every drop of rain fall has to be safely managed otherwise it becomes a health threat. Also, insufficient attention has been paid by engineers to the debilitating impact of weak social and institutional structures. Authorities in such countries fail to look at the problem of urban water management in a holistic manner, they fail to look at the importance of “Stakeholder participation and partnerships” and to devote a chapter to “Policies and institutional frameworks".

2.12. SuDS and SWM in arid and semi-arid regions

As has been pointed out in many research publications, the global semi-arid region's imminent water problems currently are aggravating. In general, these problems are complex not only due to policy and institutional framework, human resources development and socio-cultural reasons but also due to technical and economic parameters (Prinz & Singh, 2000).

Arid and semi-arid regions are identified as quite vulnerable to adaptation efforts made in relation to climate change. That is why the following topics need to be addressed:

Firstly, the assessment of water resources. This by the treatment of water, that is required as an asset of the economy and the nation that the regional stakeholders and local users get benefit from it by robust planning and development (Hu et al., 2014; Prinz & Singh, 2000).

Secondly, the effect of climate change. The regional water resources under uncertain effects of climate change considering climate change predictions at global and regional scales. Water scarcity caused by climate change and increased competition for water between agriculture, industries and the rapidly growing cities (Kahil et al., 2015).

Thirdly, groundwater and surface water conjunctive use. By adopting this the overuse problems could be mitigated. Beside the conjunctive use, the interactions of surface and ground waters are governing the artificial recharge. Strengthening basic research is needed for different regions on understanding these interactions and technologies identification for easy measurement of water quality, surface water flow, and parameters of soil and aquifers (Foster & van Steenbergen, 2011; Sahuquillo, 2009).

Fourthly, utilising rainwater harvesting systems (RWHS) and water conservation. This by adopting a technical approach to rainwater harvesting, groundwater resources planning development and in conjunction with other water sources, and watershed management. Additionally, the establishment of (RWHS) management and community based needed to make the delivery of irrigation water more efficient, ensuring sustainable food security and equity in water sharing (Kim et al., 2016; Mupangwa et al., 2006; Vohland & Barry, 2009). It is worth mentioning that RWHS can be applied to both urban areas and rural areas.

Fifthly, issues of water policy and institutional. The philosophy of water should be promoted by legal framework and policy as water rights and economic interests to be encouraged as a viable commercial proposition in a regional context. Moreover, precious water resources misusing can be decreased by adopting a mechanism of pricing policy through proper regulation. Not only these but also the adoption of the water resource approach of an integrated watershed-based is needed to utilise water and land resources optimally and sustainably in chosen agro-ecological areas through a developed program of national water resources (Song et al., 2010; Young, 2010).

Finally, the inclusion of a risk register for the implementation of SuDS in arid and semi-arid regions is recommended as well because such a measure would ensure that specialists in the field had considered uncertainties in terms of system performance and overland flood flow routes. In order to address the risk of flood in the respective areas, experts of water management are expected to provide a strong foundation of hydraulic design, which has the goal to minimise the physical stress on the watercourse.

2.13. Climate change and variability in semi-arid regions

"Climate change is the most severe problem that we are facing today-more serious even than the threat of terrorism," said the UK government chief scientific adviser (King, 2004). Recently, the World Economic Forum 2017 within its global risk report has pointed out that Environment-related risks also stand out in the year's global risk landscape. The major risk interconnections of Global Risks Perception Survey (GRPS) involve environmental risks, the most frequently cited of these being the pairing of "water crises" as well as "failures to climate change mitigation and adaptation". The World Bank expects that water stress could cause extreme societal overstrain in regions like the Middle East, where the economic effects of water scarcity could reach at risk 6% of gross Domestic Product (GDP) by 2050 (Heijden et al., 2015).

The climate change and alteration have been the concern issue that both the climatologists and the hydrologists have concerned about in all classes of drylands, and the continual changes of climate areas toward the aridity. Studies have revealed that the largest expansion of drylands has occurred in semi-arid regions since the early 1960s. This expansion of semi-arid regions accounts for more than half of the total dryland expansion. The area of semi-arid regions in the years of nineties is 7 % larger than that during the years of fifties (Huang, Ji, et al., 2016). The consequences of climate change and drought can be focused-in through a number of issues, specifically: the areas' aridity expansion, the effects on water resources, poverty and socio-economic, and the necessity to drought risk management.

2.13.1. Expansion of semi-arid regions

Results from studies indicate that the areas of semi-arid regions have increased rapidly during recent years globally, for instance, in China with an increase of 33% during 1994–2008 compared to 1948–62. Studies have found that the expansion rate of semi-arid areas over China is nearly 10 times higher than that of arid and sub-humid areas, and is mainly transformed from sub-humid/humid regions (Huang et al., 2019). Moreover, dust aerosols in semi-arid regions may have altered precipitation by affecting the local energy and hydrological cycles. Above all, globally semi-arid regions are projected to continuously expand in the 21st century, which will increase the risk of desertification in the near future. Therefore, projecting the areal change in drylands is essential for taking early action to prevent the aggravation of global desertification (Reynolds et al., 2011; Thomas & Middleton, 1997)

Despite that there were underestimation in the Fifth Coupled Model Intercomparison Project (CMIP5) climate analysis simulations (Feng & Fu, 2013) considering the past 58 years (1948–

2005), but dryland areas projected under Representative Concentration Pathways (RCPs) RCP8.5 and RCP4.5, will increase by 23% and 11%, respectively, relative to 1961–1990 baseline, equalling 56% and 50%, respectively, of total land surface. The increasing aridity, enhanced warming and rapidly growing human population will exacerbate the risk of land degradation and desertification in the near future in the drylands of developing countries (Huang, Yu, et al., 2016)

2.13.2. Climate effect on water resources

(Fadhil, 2011; Khayyat et al., 2019) have found that the semi-arid Iraqi Kurdistan had been affected by severe drought condition in between the years 2007-2008, a significant decrease in the vegetative cover (56.7%) and a decline in soil/vegetation wetness (29.9%) of the total study area. Likewise, the surface water resources also suffered a strong reduction and it was significant in the region, which lost between (32.5 - 40) % of its surface area in comparison with the previous year, 2007. The study results showed that the soil moisture content was the most effective actor on the vegetative cover, land surface temperature, and drought status in the study area. Thus, the water bodies and vegetation are the two sources that the agro-economics rely on, which directly affects the socio-economic situation and would have an adverse impact on poverty.

By using a high-resolution hydrologic model studies showed that water supplies forced by global climate model in semi-arid western United States. The results show that up to 60% of the climate-related trends of river discharge, winter air temperature, and snow-pack’s during the second half of last century are human-induced. It is expected that water shortages, lack of storage capability to meet seasonally changing river flow, transfer of water from agriculture to urban uses, and other critical impacts of climate variations (Sheng, 2013).

In arid and semi-arid regions such as the study area, people live in a drought environment most of the time. Groundwater from the regional aquifers serves as sole source of water supplies or supplements to limited surface water resources. In addition to impacts of groundwater pumping, a prolonged drought period can further lower groundwater level to the point at which shallow wells may go dry and result in non-reversible effects such as land subsidence. Therefore, use of groundwater resources for mitigating effects of droughts is likely to be more effective with advance planning for drought contingency. Thence, efforts need for developing regional water plans

2.13.3. Poverty

The semi-arid areas in general; ecologically are diverse, characterised by relative proportion of poor residents with limited access to eco-services. In addition to environmental disasters such as flooding or droughts, and there are conflicts that associated with the lack of water resources, which raises agriculture problems, on the other hand, leads to socio-economic matters.

One of the examples is the arid and semi-arid mountains of South America, which the climate change is projected to have a strongly negative effect on water supplies, significantly impacting millions of people. As one of the poorest countries in the region, Bolivia is particularly vulnerable to such changes due to its limited capacity to adapt. Water security is threatened further by the glacial recession with Bolivian glaciers losing nearly half their ice mass over the past 50 years raising serious water management concerns (Rangecroft et al., 2013). while (Lema & Majule, 2009) have carried out a study on semi-arid villages in central Tanzania, they found that poor villagers only perceived changes in climate patterns. The changes have affected crops and livestock in a number of ways resulting in reduced productivity. it is seen that farmer has should form a foundation for designing agricultural innovation systems to deal with the impacts of climate change and variability on coping and adaptation to climate change and drought. Further, development initiatives at the community level in semi-arid areas should put more emphasis on water harvesting to ensure water storage for crops and livestock.

2.13.4. Drought risk management

Drought is widely recognized as a slow creeping natural hazard; it is referred to as a slow onset that occurs due to the natural climatic variability. Droughts often do not get any global attention until they cause wildfires or famine (Antje Hecheltjen, 2020). In recent years, concern has grown worldwide that droughts may be increasing in frequency due to climate change. Regrettably, responses to droughts in most parts of the world are generally reactive in terms of crisis management and are known to be untimely, poorly coordinated and disintegrated. Consequently, worldwide drought impacts on the economic, social and environmental have increased significantly. Because of their long-term socio-economic impacts, droughts are by far the most damaging of all-natural disasters (WMO, 2020).

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007) stated that the world indeed has been more drought-prone during the past 25 years. Whether due to natural climate variability or climate change, there is an urgent need to develop better drought management strategies that are based on scientific knowledge and also to ensure broader social responses to manage the risks and mitigate the effects of droughts.

In 2011, the 16th World Meteorological Organisation (WMO) Congress established the Global Framework for Climate Services. For better management of droughts, and to address the drought issues, two initiatives implemented by WMO: a high-level meeting on national drought policy in 2013 and the Integrated Drought Management Program (IDMP). Both of the drought initiatives contribute by engaging users of drought information including policymakers, in order to highlight areas where drought information needs to be improved (WMO, 2020).

Decision-makers have continuously asked for better tools and resources to help them assess their risks related to climate variability and extremes (Jacobs, 2002). Understanding how droughts develop (and have developed), evolve, propagate, and affect us is vital to knowing how to better prepare and plan for them and mitigate their impacts. Whereas, Rangecroft et al., (2013) have stated that in most semi-arid regions were being faced to drier and warmer conditions in recent years, multiple political and financial barriers which prohibit successful adapting to climate changes like as in Bolivian arid mountains. Drought risk mitigations should imply strategies, which need to be planned and implemented correctly by developing long-term solutions to regional water challenges, which requires the use of inter-disciplinary approaches that maximize academic and local knowledge and community involvement. indeed, community-based resource management adaptation strategies have been seen to empower users and provide a potential way forward to effectively strengthen their capacity and resilience to climate change and water scarcity.

According to the (Parry et al., 2007) and (Arnell & Charlton, 2009), four important barriers to cope with the change of environment in terms of water quality and quantity have been recognised: (a), there may be physical barriers that restrain the performance of a particular adaptation measure; (b), there might be economic restrictions, in case if costly measures are considered for some adaptations; (c), there may be socio-political barriers to adaptation in the stakeholders attitudinize to proposed measures; and (d), water management institutions capacity could shorten the capability to implement or promote adaptation strategies.

Therefore, proposing a technical platform analysis for drought management in semi-arid countries necessary, which supporting decision-makers in drought risk management (DRM). Additionally, the uncertainties about the precise magnitude of climate change and its possible impacts, particularly on regional scales, measures must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects (Kumar, 2012). A novel platform should be embedded within a framework covering both national drought plans and policies that all relevant stakeholders can follow in to shift from the emergency mode to a risk-based management paradigm (Furat A. M. Al-Faraj et al., 2015). Appropriate mitigation measures can be taken to minimize the vulnerability of the system and build resilience in case of future episodes of drought worsened by climate change. it is essential to move toward a more risk-based approach to drought management. However, even if the drought patterns do not noticeably change in the future in terms of frequency, severity and duration, the current difficulties of coping with most droughts strongly suggest the need for a risk management mode (Furat A. M. Al-Faraj et al., 2015). The development of a national drought policy should be viewed as a continuous process. Policy coordination also requires institutional change and management of possible conflicts among different governmental bodies. Therefore, the coordination and cooperation between stakeholders are vital for achieving integrated water resources management (Furat A. M. Al-Faraj et al., 2015). Accordingly, researchers are enthusiastic and encouraging for the development of a national drought policy for climate alterations should support sustainable water resources planning. And without a harmonized national drought strategy and institutional flexibility, which includes wide-ranging meteorological monitoring networks, early warning and information systems, impact assessment procedures, risk-based management measures and drought preparedness plans, such areas will continue to respond to drought in a relief crisis-based management mode. And yet, the attempts to characterize such areas with the potential risk of climate extreme events will serve as a useful resource for assessments of the potential impacts of climate change on human and ecosystems, and in turn enhance regional adaptation, hazard preparedness, planning strategies, and decision-making (Adeyeri et al., 2019).

2.13.5. Drought monitoring

Wilhite, (2000) has suggested that drought monitoring consists of the compilation and analysis of data from natural variables associated with the onset, persistence, and termination of droughts (e.g., precipitation, runoff, and soil moisture) to quantify drought indices and communicate them to decision-makers and the public, while, (Real-Rangel et al., 2020) have seen that drought monitoring is a critical activity for drought risk management; however, the lack of ground based observations of climatological and hydrological variables in many regions of the world hinders an adequate follow-up and investigation of this phenomenon.

Early detection of droughts is important for managing emerging crop losses to prevent or mitigate possible related famines, and for dealing with increased fire risk. Satellite imagery as a tool helps to monitor precipitation, soil moisture, and vegetation health to support drought early warning systems. It is used to feed monthly drought bulletins and to issue warnings (Antje Hecheltjen, 2020).

Water management in semi-arid areas necessitates drought monitoring for best drought management, evidence-based decisions are essential for its management. Objective assessments are the basis for evidence-based decisions, which need reliable information. The obtained reliable information is taken from adequately processed data that been generated from a well-designed monitoring system. Thus, superficially and uninformed drawn inferences can guide to partial or inappropriate solutions. Additionally, establishing an updated and expanded Drought Risk Atlas (DRA) as a decision support tool for the semi-arid areas needs to be developed, regular drought indices should be calculated and mapped, and to be housed at an established National Drought Mitigation Centre to be put at the hands of decision-makers and policymakers (Svoboda et al., 2015).

Therefore, policymakers, scientists, communities, NGOs, and decision-makers should have a role to tackle the drought severity in a proactive manner rather late reactive solutions in response to the situations, especially in semi-arid climatic condition areas.

2.14. Groundwater issues in semi-arid areas

Groundwater has a substantial role in agriculture, water supply and health, and the elimination of poverty in both urban and rural areas, thus, it is regarded as a vital and the sole resource in most of the studied semi-arid regions

Recent research studies have shown that by employing various research methods including GRACE-based (Gravity Recovery and Climate Experiment) groundwater change, it has revealed that there are significant aquifer depletions over large semi-arid regions, such as the Middle East, the northwest India aquifer, the North China Plain aquifer, the Murray-Darling Basin in Australia, the High Plains, and the California Central Valley aquifers in the United States of America (Frappart & Ramillien, 2018). On the other hand, the scarcity of data in many arid regions, especially in the Middle East, has necessitated the use of combined mathematical models and field observations to estimate groundwater recharge (Ebrahimi et al., 2016). Not only the quantity issue of groundwater exists, but also the quality issues stands out, current knowledge indicates that groundwater pollution is not at the level recorded for many industrialized countries. The most endangering factors at this stage are considered to be the accelerated urbanization of the main cities, waste disposal, and industrial or municipal wastewater treatment. Therefore, groundwater quality must be carefully monitored, while adequate measures to remedy already existing hotspots should be enforced by responsible local authorities (Zoran Stevanovic & Iurkiewicz, 2009).

2.14.1. The groundwater depletion under climate change and human-induced interventions in the studies area

Researchers have become convinced that water supplies forced by global climate model in semi-arid regions reduce surface water delivery and in turn increase groundwater pumpage to complement surface water shortage. Studies show that up to 60% of the climate-related recession trends of river discharge, raising winter air temperature, and snowpack's melting during the second half of the last century are human-induced. It is expected that water shortages, lack of storage capacity to meet seasonally changing river flow, transfer of water from agriculture to urban uses, and other critical impacts are of climate variations consequences (Sheng, 2013). Additionally, the impacts of groundwater pumping, a prolonged drought period can further lower groundwater levels to the point at which shallow wells may go dry and it intensifies the issue much more.

2.14.1.1. Human intervention effects on water depletion

Famiglietti, (2014) has said that "*Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledge*", therefore, semi-arid regions as part of the global scale are also threatened by the diminution of groundwater availability. As a substitutional water resource in areas that are exposed to water shortages, and that have large groundwater aquifer; the groundwater often used as an alternative source of water supply. Groundwater overuse or continuing depletion occurs, whenever the abstractions of groundwater surpass its repletion (Wada et al., 2010).

The total global groundwater depletion is quite substantial, totalling an estimated 39 (±10) % of the global yearly groundwater abstraction, 2 (±0.6) % of the global yearly groundwater recharge, 0.8 (±0.1) % of the global yearly continental runoff and 0.4 (±0.06) % of the global yearly evaporation. This makes groundwater over-abstraction a term of the global water balance that cannot be neglected (Wada et al., 2010). Moreover, studies on semi-arid regions have seen the semi-arid regions are not excluded while the crisis is being exacerbated by the over-demand for water. Continued groundwater depletion will be unsustainable, with potentially dire consequences for the economic and food security (Famiglietti et al., 2011). The global groundwater depletion has been increasing since the 1960 and is likely to increase further in the near future, while the increase of impoundment by dams has been tapering off since the 1990s (Chao et al., 2008).

The rapid growth of water demands for irrigated agriculture and water supply for domestic, industrial and commercial uses has noticeably increased the pressure on groundwater resources. Groundwater is an essential source for both agriculture and public water supply, particularly in arid and semi-arid areas where the dependency on groundwater is between 60% and 100% (Margane, 2003). Large-scale pumping of groundwater can pose significant adverse impacts on both the ecosystems and the long-term socio-economic developments (J. Chen et al., 2014). An over-exploitation of groundwater and unmanaged water supply through unsustainable consumption increases the risk of water deficit and consequently exacerbates environmental hazards. A considerable drop in groundwater levels has been observed and reported in many parts of the world due to excessive use of groundwater, especially for irrigated agriculture and domestic uses (Margane, 2003; M. Nanekely et al., 2017b; Tabari et al., 2012; Warner, 2007).

2.14.1.2. Groundwater observation and data collection

Indeed, monitoring of seasonal and annual changes and long-term variability in groundwater storage is crucial for sustainable socio-economic development and a healthy environment. However, accurate measurements of changes in groundwater storage require intense networks of observation wells, continuous monitoring and good knowledge of the aquifer characteristics and groundwater replenishment process (J. Chen et al., 2014; Gale, 2005). In this case, the International Association of Hydrogeologists (IAH) (W. Alley et al., 2017) reported that there is an urgent need to strengthen current data collection protocols to develop indicators for sustainable management of groundwater resources and to achieve various UN-SDGs (United Nations Sustainable Development Goals) 2030 Agenda: Food Security; Human Health; Water; Energy Generation; Resilient Cities and Ecosystem Conservation.

2.14.1.3. Aquifer management and planning

Aquifer management is a multi-directional directory process. Its recharge and discharge rates, conserving water quality, the geological stratigraphy composition, climate alterations, socio-economic activities, the sustainable consumption of water, and the land-use are all factors affecting in the management of the aquifer. For the best planning of aquifers, all the aforementioned factors and their inter and intra relations have to be considered, associated with their consequences (W. M. Alley et al., 1999).

Gale, (2005) pointed out that the rational utilisation of groundwater and sustainable management of aquifers can play an important role in (a) poverty and drought mitigation; (b) economic and health risks reductions; (c) irrigated agriculture support; and (d) access to water in an equitable manner. Management of aquifer(s) and rainwater harvesting system(s) maintains the above-mentioned benefits, particularly, if considered and practised as a fundamental part of integrated water resources management that addresses the imbalance between water demand, supply and water quality as well as the impact of climate change.

The effect of climate change on aquifers:

The problem of water shortage resulting from excessive abstraction or unwise exploitation of groundwater is further exacerbated by impacts of climate change in many parts of the world suffering from a decrease in precipitation, an increase in temperature, and potential evapotranspiration rates (Margane, 2003; M. Nanekely et al., 2017b). Also, (Baba et al., 2011) have seen that the groundwater systems are considerably vulnerable to changes in precipitation patterns, particularly in areas where the climate change trend is towards increased temperature and potential evapotranspiration rates and reduced precipitation. Further, pieces of literatures show that drought episodes and climate change are likely to put difficulties and challenges to sustainably manage water resources, which require extensive investigations on potential impacts of climate anomalies on water availability and governance (F. Al-Faraj et al., 2014; Furat A. M. Al-Faraj & Al-Dabbagh, 2015; Furat A.M. Al-Faraj & Scholz, 2014, 2015). Conversely, climate extremes are buffered by groundwater-fed irrigation supply and are consequently essential to food security, therefore, it mitigates poverty in low-income countries by reducing harvest failure and increasing products (Taylor et al., 2013).

Climate change uncertainty:

For the climate uncertainty, in association to precipitation patterns and water availability has been ascertained by (Lorenzo-Lacruz et al., 2017), that in semi-arid Mediterranean climate conditions, an understanding of the spatial-temporal responses of groundwater systems to precipitation variability is required and decisive for sustainable use and groundwater management. Moreover, (Warner, 2007) and (Green et al., 2007, 2011) have pointed out the importance of assessing and understanding potential impacts of climate anomaly and variability to sustainably manage groundwater aquifers, while taking into consideration increasing stresses on groundwater resources due to population growth, elevated irrigation demands increased public water supplies and enhanced ecological needs. Additionally, groundwater storage has sensitivity to both: the abstraction of groundwater and drought episodes. However, understanding responses of groundwater bodies and changes of groundwater storages with respect to monthly, seasonal and annual precipitation variability is essential for rational withdrawal and sustainable management of groundwater.

2.14.1.4. Sustained management attempts

Al-Azawi & Ward, (2017) have suggested that sustainable groundwater use should be established by management institutions in concert with regional stakeholders, while considering hydrologic, environmental, and political constraints. Multidisciplinary studies supported by reliable data and integrated water resources modelling are desired ends in the basin, but full integration of the disciplines must await future research. Additionally, (Sheng, 2013) has seen that securing future groundwater availability involves a multi-spectrum of efforts, including minimising net losses from the underground reservoir, managing groundwater as an integrated part of the hydrologic cycle, developing infrastructure based on an understanding of the natural hydrologic system, using water wisely and efficiently, and allocating and monitoring water fairly for human as well as environmental and ecological needs. Therefore, M. Nanekely et al., (2017) have underlined the need to conduct detailed studies on changes of groundwater storage in water-scarce areas to achieve sustainable utilisation of groundwater resources. Besides, future groundwater recharge management and mechanisms should be incorporated within General Climate Models (GCMs) that incorporates the expected climate alterations (Smerdon, 2017). It is worth to mention that exploiting harvested rainwater and groundwater-fed irrigation have a notable contribution to replenish groundwater by 10.8% and 15.2 % of total rainfall and irrigation respectively in scarce semi-arid regions (Ebrahimi et al., 2016). Furthermore, (Ebrahimi et al., 2016) have estimated that irrigation water has more contribution than rainwater to recharge the ground in arid and semi-arid areas by one-third when using specific irrigation method like open furrows. On the other hand, the groundwater can be recharged by municipal wastewater, but still there are some uncertainties in terms of health risk considerations and have limited the use of reclaimed disposed urban wastewater for groundwater recharging, this based on the groundwater recharge criteria. The assessment and sustaining of groundwater resource can be conceived by the application of water balance approaches, that equalise the demand against abstractions (Hiscock & Bense, 2014).

2.14.1.5. Groundwater and surface water interaction

The interactions between groundwater and surface water are complex. To understand these interactions in relation to climate, landform, geology, and biotic factors, a sound hydro-geo-ecological framework is needed. Surface-water and groundwater ecosystems are viewed as linked components of a hydrologic continuum leading to related sustainability issues. The mechanisms of interactions between groundwater and surface water (GW–SW) as they affect recharge–discharge processes to be understood comprehensively, also the ecological significance and the human impacts of such interactions (Marios Sophocleous, 2002). Indeed, the commendable efforts to craft solutions to meet required surface water allocations are needed, but consideration of the ability of groundwater withdrawals to meet current and future demands remain dormant. The heightened awareness of the rates of groundwater depletion will reinforce urgent discussion on conjunctive management solutions required to ensure a sustainable water future (Castle et al., 2014).

2.14.2. Groundwater balance under climate change impact

The assessment and groundwater balance are useful to quantify the amount of groundwater that could be safely withdrawn. For this purpose, the hydrologic balance model is considered that it quantifies the surface and groundwater resources entering and leaving a specific geographic domain, it is also used to estimate the quantity of groundwater that may be safely and economically withdrawn (Delleur, 2007; Roscoe Moss Company, 1990). Therefore, the water balance approach provides methods that estimates groundwater resources reserves in an aquifer or basin (USBR, 1995).

The estimation of groundwater balance is imperative to measure the safe yield of the aquifer system and to set its sustainable management and rational abstraction (Voudouris et al., 2006). The safe yield is defined as the amount of water that can annually be abstracted without causing any undesired results (Todd, 1980). If abstraction exceeds the total annual recharge of groundwater (overdraft), the aquifer is no longer sustainable (Devlin & Sophocleous, 2005; Dewiest, 1991; Fetter, 2018; Freeze & Cherry, 1979).

2.14.2.1 Factors affecting water balance

The water multi-purpose uses, and demands are being escalated with the influences of factors, such as urbanisation, population growth, land-use change and climate alteration, that is rendering water availability uncertain in the future. Groundwater resources as one of the sources are being increasingly exploited to meet this growing demand.

Population growth stresses:

The world's population is continuously growing, so the demand for water is also, and there are limited water supplies particularly in arid and semi-arid regions. On top, the water shortage because of climate alterations, an increase in the population would also bring industrialization, agriculture, and urbanization which causes environmental problems which directly affects the provision and availability of the water. As population increase, the natural resources per capita are progressively decreasing, the rapid increments of the population against declining of water resources, water availability per capita has decreased, further, the pressure on the existing resources of water is continuously growing in temporally and spatially (Abughlelesha & Lateh, 2013; Nair, 2016; Sharma, 2003). Semi-arid regions that most of which are within the developing countries have been facing both matters, population growth and climate change impacts. Despite this fact, (Ahmad & Haie, 2018; Okello et al., 2015) show that the semi-arid climate is less sensitive to climate change impacts, implying that population growth is the potent driver of change. Not only the population growth associated with climate change, but also its coupling with related hastened social and economic activities such as expanding agriculture areas are key drivers for increased demand of water world-wide (Wada et al., 2010).

Urbanisation stress:

The urbanization process alters the natural hydrological cycle, and urban groundwater recharge component plays a vital role in urban water balance. In developing countries and along recent years, the sub-soil infiltration of rainwaters has been limited in the urbanised areas by the means of natural groundwater recharging in a harsh decreasing form, this due to rapid urbanisation and development (Jasrotia et al., 2009). Indeed, this is not only restricted to urban areas, but the industrial expansions have also added pressure to diminishing groundwater recharges, not to mention its role in deteriorating water quality as well. Significantly, one of the key problems that prevalent in developing countries, is the rapid expansion of urban areas leading in contraction of cities' agricultural lands within outskirt belts, which decreases the utilisation of irrigation waters to be infiltrated into the sub-soil. In other words, the change of land surfacing properties causes the change in hydrological characteristics of urban areas and the degree of imperviousness, consequently, the impact on the water balance caused by urban growth varies considerably through limiting recharges (Haase, 2009). Additionally, (Hameed et al., 2015) have pointed out in a semi-arid case study, that the urban areas had been developed between 2004 and 2014 by almost three folds causing declination in the groundwater level by more than 54%. Notwithstanding, (Wakode et al., 2018) has stated that the groundwater recharge in urban areas has components including water supply network and sewage networks leakages, the urban recharge component of groundwater was more than ten times greater than the natural recharge through precipitation and irrigation, bearing in mind that regarding the extent and intensity of percolation of urban contaminants into the aquifer exacerbates the groundwater quality, which is considered as losses. As can be seen, the urbanisation puts significant impact on groundwater aquifer recharges. Thus, rainwater harvesting could be considered as one of the measures by which; bores, farm ponds, and spreading basins can be utilised and contributed for replenishing and raising the groundwater reserve levels in such cases.

Climate change stress:

In arid and semi-arid regions, groundwater resources are usually non-renewable as aquifer recharge less than its discharge. Namely, groundwater can possibly relieve droughts and would be functionalised as a backer to surface water to meet the demand for water, this when aquifers have comprised great storage capacity and are potentially less sensitive to alterations in climate than surface water bodies (Aizebeokhai et al., 2017; Aizebeokhai A. P, 2012).

Although, the groundwater-residence time scales can range from days to tens of thousands of years or more, which delays and disperses the effects of climate and challenges efforts to detect responses in the groundwater to climate variability (Z. Chen et al., 2004), but for studying the sensitivity of groundwater to climate change alteration, there is a need to long-term records of groundwater data. Earman & Dettinger, 2011; Kumar, (2012) have pointed out that predicting the long-term effect of a dynamic system is very difficult because of limitations inherent with it. In fact, (Kumar, 2012) has speculated that the effects of climate change on surface water resources are widely recognised but not much is known about its effects on groundwater. The reasons are seen to be; that it requires long historical data which is not always available. Also, the driving factors that cause such changes are yet unclear. Furthermore, climate-induced changes in hydrological variables and their effects on groundwater systems are insufficient by uncertainties inherent in the assessment processes which relate to climate change effects on groundwater recharge. Moreover, human activities, such as groundwater pumping and the resulting loss of storage and capture of natural discharge, are often on the same time scale as some climate variability and change, which makes it difficult to distinguish between human and climatic stresses on groundwater (R. T. Hanson et al., 2004). Therefore, the need and the necessity for groundwater studies in semi-arid areas are considered as a mainstay of sustainable water management, as it has always considered as one of the water resources that ought to be reliable and supportive for surface water resources particularly in developing countries. Consequently, groundwater resources are exposed to changes in storage due to precipitation patterns variabilities, evapotranspiration, surface water and groundwater interaction fluctuations, and overdraft induced from climate change. And typically, in the semi-arid climates, groundwater recharge is going through a complex process due to the variability in precipitation and temperature, as well as responses of vegetation to these variations. Accordingly, the climatic anomaly may occur periodically and last for a period. Even if the required data exist, uncertainty is set in model parameters, structure and driving force of the hydrological cycle, moreover, the information about climate-related effects on groundwater resources is inadequate, especially with respect to groundwater quality and ecosystems, and socio-economic dimension (Aizebeokhai et al., 2017). Thus, a deeper knowledge of the effects of climate change on groundwater resources at both local and regional scales and over the long-term is integral for sounder planning and active groundwater management (Aizebeokhai et al., 2017; Davidson & Yang, 2007; Earman & Dettinger, 2011).

Given the above, (Earman & Dettinger, 2011) have seen that the responses of groundwater systems to climate by adopting the sustained and frequent monitoring is seen as more decisive. recognising the impacts of climate change on groundwater would help groundwater decision-makers to seek for adaptation choices, including aquifers' recharge management and conjunctive programs. Beyond this, sustainable water resources management has to address groundwater vulnerabilities under climate change projections more generally. Furthermore, (Mohammed Nanekely et al., 2016) have concluded that a generic platform has to be developed based on affected pillars, supporting the short and long-term regional and national strategies towards sustainable water systems, moreover, a maintained groundwater management in semi-arid conditions requires a solid framework development built upon sustainability notions (M. Nanekely et al., 2017b).

2.14.2.2. Groundwater and yield concepts

Safe yield:

The safe yield term was first used in 1915 by (C. H. Lee, 1915) to generally mean "*the quantity of water that can be pumped regularly and permanently without dangerous depletion of the storage reserve*". He recognised that permanent water extraction from an aquifer reduces by an equal volume of water passing from the basin by way of natural streams. To illustrate the existence of this natural discharge, Lee perceived that heavy pumping would commonly result in the drying up of groundwater bodies. Later, (Todd, 1959) made the definition of safe yield to include groundwater and extended to be known as extracting an amount of water from an aquifer, keeping the groundwater reserves at the desired condition, this had been defined as safe yield, it seems that Todd had broadened the knowledge of safe yield to what is wider than Lee's perception, but the safe margin of water reserves had not been considered. While (Marios Sophocleous, 1998) stated that there are misconceptions about "safe yield" when the supplies of groundwater are needed to be protected from overexploitation, there were the enactments of laws and regulations based on the concept of "safe yield", however, (G. Davis et al., 2003) among others, described the safe yield as "the maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effect", that does not sound as Sophocleous had identified before, it has not been made any attempt for more adjustment of groundwater yield concepts.

Thus, safe yield is defined as the attainment and maintenance of a long-term balance between the amount of groundwater withdrawn annually and the annual amount of recharge. Accordingly, safe yield is considered a management notion makes water pumping to be restricted as only the amount of groundwater that is recharged naturally through surface water seepage and precipitation infiltrations. Therefore, safe yield disregards discharge from the system. There also been asserted that there are a number of researchers who shared to the development of this concept including Banks (1953), Condling in (1946), and Meinzer and Stearns in (1920s), Banks submitted an increasingly widened view of safe yield that included groundwater quality, economic, hydrologic schemes, and legal considerations, that sounds thorough comprehend. Several researchers (W. M. Alley et al., 1999; Bredehoeft, 2002; Bredehoeftr et al., 1982; Devlin & Sophocleous, 2005; M. Sophocleous, 2000; Marios Sophocleous, 1998) have already written many definitions concerning the flaws of the concept of safe yield. Although Lohman in 1952 at the U.S. Geological Survey had already broadened the definition, yet the term safe yield is being used: "*The amount of groundwater that can be safely withdrawn from a groundwater basin annually, without producing an undesirable result*", undesirable results may include but are not limited to depletion of groundwater storage, the intrusion of water of undesirable quality, the contravention of existing water rights, the deterioration of the economic advantages of pumping (such as the excessively lowered water levels and the attendant increased pumping lifts and associated energy costs), excessive depletion of streamflow by induced infiltration, and land subsidence” (W. M. Alley et al., 1999). Moreover, (W. M. Alley et al., 1999) have seen that the simplicity in data inputs and information to recognise the impacts of groundwater system development as a myth, as the system has been changed due to human activities, the components of the water balance (inflows, outflows, and storage changes) will change as well, that has to be considered for any decision-making.

Thus, the safe yield should not exceed the average annual recharge to counterbalance for minor groundwater losses. Withdrawals that exceeds safe yield are called overdraft (Dewiest, 1991; Fetter, 2018; Freeze & Cherry, 1979). The groundwater basin safe yield is defined as the amount of water that can annually be withdrawn from it without producing any undesired results (Todd, 1980).

Sustained yield:

In consideration of the hindrances by using the traditional safe yield approach for groundwater management; it is noteworthy to mention that an updated term was coming into literature, that is "sustainable yield". Based on (ASCE & UNESCO/IHP, 1998) the American Society of Civil Engineers’ Committee on Sustainability Criteria, “sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, while maintaining their ecological, environmental and hydrological integrity”. Additionally, (Y. Zhou, 2009) has concluded that misperception of the safe development of groundwater is whenever the rate of natural groundwater recharge is greater than the rate of groundwater abstraction. That is to say; the safe yield is not dependent on the natural recharge alone; an assessment of the dynamic development impacts of the capture on society, economy, and the natural environment is required, moreover, the sustainable yield is an endeavour to overcome the weaknesses of the safe yield. Indeed, the sustainability concept highlights more the maintenance of social benefits and the natural environment, and despite adopting numerical models to assess the effects of groundwater development, but the difficulty remains how to quantify the groundwater basin sustainable yield in the absence of linkage between groundwater storage to the impacts on social benefits and ecosystems. it seems that a solid mixed qualitative and quantitative model should be adopted to overcome this process.

Therefore, it can be figured that the negative anthropogenic activities are not less important than the human development water needs, as the sources of pollution causing the groundwater reserves less usable and turn to wastage. Furthermore, it is worth mentioning, that the issues related to the administrative and legal affairs, conflicts and political situations of the countries lead to fragile conditions in water management.

Managed yield:

Based on the drawbacks of the last yield concepts, (Meyland, 2011) has suggested that throughout abstracting water from a system, the un-incorporation of other processes like climate change impact, aquifer conditions, uncertainties of precipitation and dry spells that affecting on an aquifer are seen as defective issues, therefore, a safety margin should be added as a new approach to assess the production capacity of the aquifer. This approach is called “managed yield” that is advised to be used rather than the safe or sustainable yield. In fact, this can be considered whenever the groundwater system management strategies are being developed. Additionally, (Kalf & Woolley, 2005) have seen the groundwater systems in many semi-arid and arid environments cannot be rationally developed by adopting a sustained yield policy, particularly where ecological restrictions are applied. Nevertheless, the controversy of using the best-fit term is still ambiguous that depends on the researchers’ conviction. Truly, most researchers have ascertained that the safe yield and sustainable yield are considered as a useful baseline for planning and apportion rights of groundwater, but they are not working as an operational rule at all climatic conditions due to their limitations and weaknesses (Loáiciga, 2017). On the other hand, (Holman, 2006) has ascertained that focusing on climate change direct consequences is to underestimate the implied important role of the other related issues like; policies, societal values and economic processes that play in the configuration of landscapes over aquifers. Yet, the managed yield concept is seen to be adopted whenever the groundwater balance is deeply examined, particularly in altered climate conditions and frequent dry spell dominated areas.

2.14.2.3. Yield estimation

Groundwater balance estimation is an essential process in integrated water balance and water resources management. However, it is nearly impossible to measure precisely, all various factors which are involved the balance estimation. Admittedly, groundwater comprises an essential part of water availability in any case study, whether it is a catchment, basin or a specified area. Indeed, at present nearly one-fifth of all the water used in the world is obtained from groundwater resources, agriculture is the greatest user of water accounting for 80% of all consumption (Raghunath, 2006), that is the point that cannot be overlooked in sustaining the agriculture sector development, consequently, the socio-economic progressions and even to meet the needs for domestic uses. Therefore, assessing the groundwater abstraction will give indications of water resources balances and highlights warning indices for over-abstraction or vice-versa.

2.15. SWM framework

The on-going research frontier activities on water scarcity, security and sustainability are still scattered that needs to be combined into a single source theme, which encompasses a broad spectrum of topics in water resources, including, but not limited to: The potential impact of hydro-climatic extremes; Remote sensing applications for water scarcity assessment; Climate change impacts on water scarcity and sustainability; Linkage between water scarcity, security and sustainability; Developments in management, adaptation, and mitigation tools for improving water security and sustainability; Emerging topics related to water security, for example, the nexus between water, energy, food and climate (Hussey & Pittock, 2012). Indeed, these considerations are supporting the (SWM).

Though physical scarcity of water is often given as the reason for water shortages, but it is usually is the management that can either create or resolve the problem (Emmanuel & Clayton, 2017). The constraint has been introduced by (European Water Framework Directive) as management: a lack of policy coherence and unsuccessful administration (EWFD, 2006). The limited extent and incoherence of policy regime reveal the unsustainable nature of water management, skewing towards an economic perspective, seek to align the demand and supply in a manner acceptable to the public, Government, investors and environmental interests. Therefore, establishing a theoretical framework for sustainable water resource management and frame a strategy that reconciles demand and supply of water requires considering environmental, economic and social interests, that is the sustainability and water balance approaches.

On the other hand, working through a robust framework requires measures for adaptation. These measures are often failing because of various social, economic and political reasons. There are possibilities to overcome the growing water crisis through better conservation and management. For this, there is needed better policies and better institutional mechanism to implement the policy guidelines (Nair, 2016).

2.15.1. Groundwater depletion

The availability and depletion of groundwater could be impacted by climate change. In terms of the hydrological cycle, climate change can affect the amounts of soil infiltration, deeper percolation, and hence groundwater recharge. Also, rising temperature increases evaporative demand over land, which limits the amount of water to replenish groundwater. More distinctly, the climate-driven impacts on groundwater do not necessarily reflect the long-term trend in precipitation; instead, the trend may result from enhancement of evapotranspiration, and reduction in snowmelt. The reduction in groundwater storage is mainly due to the combined impacts of anthropogenic over-pumping and climate effects (W.-Y. Wu et al., 2020)

The investigation of the relationship between climate change and the loss of fresh groundwater resources is important for understanding the characteristics of the different regions. The impact of future climatic change may be felt more severely in developing countries, whose economy is largely dependent on agriculture and is already under stress due to current population increase and associated demands for energy, fresh water and food.

The SWM needs developing adaptive management strategies for climate variability. A deeper understanding of the effects of climate change on groundwater resources over long-term is integral for better planning and efficient groundwater management (Aizebeokhai et al., 2017). Thus, there is a need to have a good understanding of hydrologic process in the regional aquifer system, groundwater availability in terms of quantity and quality, and impacts of climate change on groundwater availability. There is need to develop water management strategies to address issues related to groundwater availability and climate variability. Synergistic projects with different stakeholders and institutions should be established for providing essential new information and a scientific foundation for state and local officials to address pressing water resource challenges. For instance, United States-Mexico Transboundary Aquifer Assessment Program had been conducted by Water Resources Research Institutes in the semi-arid climatic areas of Arizona, New Mexico and Texas in partnership with the U.S. Geological Survey (USGS) and in collaboration with appropriate federal, state agencies, and stakeholders as well as Mexican counterparts through International Boundary and Water Commission. This program aimed to conduct binational scientific research to systematically assess priority trans-boundary aquifers in semi-arid New Mexico, Texas and Chihuahua (Sheng, 2013).

Semi-arid developing countries cases have to be highlighted for the necessity of water resources management via technical framework. The uncertainties about the precise magnitude of climate change and its possible impacts, particularly on regional scales, institutional measures must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects (Kumar, 2012). On the whole, a physical-base model of a groundwater system under possible climate change based on available data is very important to prevent the deterioration of regional water-resource problems in the future. Although uncertainties are inevitable, new response strategies in water resource management based on the model may be useful.

2.15.2. The directive water legislations issues

The United Nations General Assembly has adopted a resolution recognising access to clean water and sanitation as a human right, strengthening further the link between water resources, sustainable development and human rights[1]. This enhances the case for the recognition of indigenous rights in water resources management in a human rights context.

To maintain these, it is in the interests of countries to identify the potential of customary law in the context of locally-based natural resource use and management and the objectives of sustainable development and biodiversity conservation. (Craig & Gachenga, 2010) have argued on using both customary and non-customary laws in water resources management laws as pluralism legal provision. Legal pluralism provides a more effective context for the recognition of customary law in water resources management as opposed to functional recognition and other minimalist forms of recognition However, the constitutional, legal and administrative frameworks needed for the co-existence of the two systems of law in the context of water continue to be a challenge. This is an area of law and practice that needs further debate, policy, legal experimentation and careful consideration of locally specific customary laws and water resource management issues.

Whereas (Derick, 2005) has seen the issue in a different view, it has been explored that in the context of the semi-arid South Africa experience of water resources legislation, the nature of water resources management as set out in the new legislation departs considerably from water management practices of the past. As the first implies new considerations. This has had a significant impact on the ability of different government departments and institutions, to operationalise the new national orientation to Integrated Water Resources Management (IWRM). The point of departure has been to engage a variety of stakeholders in the

[1] United Nations `General Assembly Adopts Resolution Recognizing Access to Clean Water, Sanitation as Human Right' GA/10967, 28 July 2010, recorded vote of 122 in favour, 0 against, 41 abstentions.

operationalisation of the new water management policy. This means that a range of stakeholders, including government departments, private business, local government, civil society organisations all need to become together to charter a way forward for a hydrological region called a Water Management Area. That is, in order for the ideals of (IWRM) to be achieved a considerable amount of learning and subsequent collaboration is demanded.

Likewise, Sokile, Kashaigili, & Kadigi, (2003) had also claimed for networking and collaboration among various stakeholders; government agencies, private sector, NGOs, CBOs and grassroots organizations should be encouraged. Any anomaly in water management should be thoroughly discussed by all stakeholders and the due recommendations should be affected. Existing local institutions especially the informal traditional arrangements that favour water management should be proactively tapped and be incorporated in the wider management imperatives. Therefore, the deliberate encouragement of public participation in water management and the creation of sufficient awareness of the community on the detrimental effects of poorly managed water resource should be affected. Furthermore, (Tsatsaros et al., 2018) are also emphasizing that the water and environmental managers should be aiming to develop collaborative approaches and co-management opportunities with indigenous people for effective water resources management.

Not only different stakeholders participation but also the coordination and harmonising of various fragmented pieces of water management legislation has been recommended by (Sokile et al., 2003). Thus, conflicting, and contradicting institutions should be reviewed and harmonized. The formulation of new institutions and laws should not be taken for granted as a panacea. Any new formulation of law should start with a thorough inventory of existing laws; i.e. assembling the different fragments of law that are related to water management, and coordinating institutions formal and informal, and the building up of databases on institutions.

Equally important, (Ahmmad, 2012) has seen in the context of semi-arid Iraqi climate, that in many cases, both legislators and academic institutions are confronting barriers for the legal analysts and critics in the field to contribute to the discipline. for instance; overlapping provisions which are still in force, missing an in-depth, scientific dimension and detailed mechanisms. Besides, insufficient literature, unreliable texts and statutory documents proceedings on water resources management. Furthermore, the weak monitoring and follow-up procedures because of diverse political appraisals by statesmen.

In the assessing of the legal framework of water management, there are a number of factors, which may control the improvement of this legal framework, (Ahmmad, 2012) has coincided with (Sokile et al., 2003) and (Derick, 2005) in their views. For instance, cooperation and coordination between the various government organisations can serve this conclusion, especially if scientific and technical research, the exchange of information, technical means and methods for regulating water resources are vitally defined by enactment, it will contribute to the formation of a well- structured national water law, besides these suggestions, making more efforts in planning and social awareness are necessary by the means that coordinates with the communities behaviours, as water deficit has been becoming global.

It is worth mentioning, the water resources sharing among different states and countries is another raise important issues regarding legal issues on water use in transboundary river basins and aquifers, including the necessity of international water use treaties and resolving discrepancies in international water law while (Voss et al., 2013) call for amplifying the need for increased monitoring for core components of the water budget within a regulatory frame.

On the whole, the in-acted worldwide water laws and regulations are not free from flaws, it does not legalise by holy references, it is human-made, therefore, most of them need necessary rational and technical details and frequent amendments to ensure proper achievement of the obligations established for proper management in-accordance to spatial and temporal needs.

2.16. Statutory status

As a substantial source and a business driver of both wealth and risk, water in semi-arid and developing countries is also under legislative pressure and increasing statutory as jurisdictions strive to manage water resources more holistically by addressing both groundwater and surface water together but on a more sustainable and decentralized basis.

Hendry, (2009) have seen that different climate condition may similar in their approach to manage water resources and supply. For instance, Scotland and South Africa, despite their many differences in their both jurisdictions, there is a commitment to the water management by the public sector, and to finding ways to better regulate the public sector. From the commonalities, it is possible to draw out an analytical framework against which the process of water law reform may be assessed. The emphasis is on water management by the public sector, along with most water services in most countries, it has not meant and need not mean that countries with different climate conditions should utilise different sets of the water management framework.

Countries in semi-arid regions may face similar water problems but face significantly different challenges arising from their unique historical attachment to individual rights to own or use water.

An example of potential collapse of the water system is the Cape Town, South Africa that serves as a stark alarm for cities in arid and semi-arid, Mediterranean-like environments. This risk is especially true of cities like Marseilles, France and regions like California.

Stakeholder rights to use water represent an additional layer of complexity that further exacerbate the difficult political and economic decisions and priorities that must be faced. All too commonly, however, the legal frameworks provided lag behind the real-world need and continue to evolve as new challenges arise. Given this point, stakeholder implication plays a growing role in planning and decision-making processes, and governing approaches at the basin or community scale are developing. (Mechlem, 2016).

While South Africa has been most aggressive in its effort to eliminate the historical legal limitations on its authority to address the inequitable distribution of an essential and limited resource, as well as to better manage, conserve, use and develop that resource, the enlightened legal amendments are clearly not sufficient by themselves. Without these limitations, South Africa is now free to prioritize, allocate and manage water based on those equitable principles that it deems to be in the best interests of the beneficiaries-all interested stakeholders (Roe et al., 2009). Despite this apparent freedom to act, South Africa still faces political and financial limitations that have prevented the fully effective implementation of its water resource management goals including an expansion of water delivery systems to historically disadvantaged segments of the population. By contrast, California is still heavily constrained by its legal structure around water rights, as well as the political and financial obstacles that constrain innovative solutions. While California has well-developed access to water, the state has ignored the ageing condition of its water systems (Persons, 2017).

Commentators have speculated that the rapid repetition of election cycles in unstable political conditions incentivizes political self-preservation and promotes short-term thinking. Moreover, with elected officials responsible for allocating funding, it is difficult for local water agencies to recommend long-term spending plans that are sufficient to meet the long-term needs (Gianelli, 2012).

It is time to explore new and appropriate political and funding models that prioritize long-term planning and solutions. These models should permit more rapid and reliable execution of the projects that must be completed to provide the water resiliency necessary to meet the water needs during periods of drought and to improve the equitable allocation of a scarce and essential resource. The problems are clearly complex and the solutions will require a coordinated approach that addresses not only the legacy legal issues but also the financial and political dynamics that have restricted long-term and innovative solutions (Ruiters, 2013).

The decisive orientation in water legislation encompasses water resources attraction into the public domain; restrictions on the governmental authority to assign water resources; water-rights controlled trading; the water laws "greening"[2]; the land-water connection; and significance of user participation in decision-making and implementation. Hence the water law reform agenda is likely to be preoccupied with risk and uncertainty with reconciling tenure security; aiming fair and equitable resource allocation; raising the environment's profile in allocation of water resources; reactivate the linkage between land-use and water resources management regulations; empowering users; and mapping the interface between customary and statutory water allocation (Burchi, 2012). All things considering, and in the essence, the user participations that based on the (community-based water law)[3] which has strengths and weaknesses, there is a gap in water resources management reform in developing countries that have tended to overlook community-based water laws (i.e., is largely ignored by officialdom and professionals), which govern self-help water development and management by large proportions of citizens (Day, 2009). The impact of water resources management reform through a re-ameliorated analytical framework on informal water users' access to water and its beneficial uses is crucial. Impacts vary from the outright weakening of community-based arrangements and poverty aggravation or missing significant opportunities to better water resource management and improved well-being. The interventions combine the strengths of community-based water law with the strengths of the public sector. Thus, global experts on community-based water law and its interface with public sector intervention are seen that contribution to a new vision on the role of the state in water resources management is needed, which better matches the needs and potentials of water users in the informal water economies in developing countries (Koppen et al., 2007).

[2] Water laws concerning Environmental

[3] Community-based water law is defined as the set of mostly informal institutional, socio-economic and cultural arrangements that shape communities' development, use, management, allocation, quality control and productivity of water resources. These arrangements, anchored in the wisdom of time, are embedded in local governance structures and normative frameworks of kinship groups, smaller hamlets, communities and larger clans and groupings with common ancestry. In developing countries, they often exist only in oral form.

The human right to water is growingly recognized, not only at the constitutional level but also in legislations of water resources as well. There is an active trend to treat groundwater as a public and no longer as private asset attached to rights of land (Mechlem, 2016). Administrative permit-based water rights systems are becoming a norm. They tend to work best in highly formalized water economies and always have to consider local conditions, the existence of customary rules-where applicable-and existing administrative capacity. Developing countries, of which have limited administrative capacity and high numbers of small-scale users they face implementation challenges. Environmental perturbations continue to gain importance in groundwater legislation. Mechanisms that deal with the uncertainties caused by climate change are becoming ever more significant as the climate exacerbates the need to affect a balance between quality and the unpredictability of water resources availability.

Strengthening groundwater legislation and rank it on a par with surface water systems by dealing as an integrated manner. These encouraging developments with respect to law, institutions, and administration have to be supported and embedded in supportive policies in other sectors to achieve sustainable and effective improvements of groundwater management and reverse the global trend of groundwater depletion and degradation (Mechlem, 2016).

Consequently, legal frameworks for groundwater that have to form an integral part of context-based groundwater governance, which must be adapted to each country's technological, financial and institutional capabilities and to meet its political systems, customs, prevailing practices, and geography and environment.

Concerning transboundary water sharing (Timmerman & Bernardini, 2009) have alluded that the challenges that face the provident water resources management are not limited to conflicting postures between riparian countries. The conflicts may happen in small entities in terms of spatial, political, and geographical areas such as local water authorities, local governments, and tribal interests, also between the regional governorates and federal government. The beneficiaries are acting in different points of view, that may lead to conflicts due to different preferences, policies and goals. Nevertheless, the main challenge that remains is that the transboundary water resources join a group of actors in a multifaceted complex system driven by various disparities.

Every jurisdiction has provision for a public trust over water, but each place a different level of reliance on that doctrine. Thus, any jurisdictions should find an efficient and effective means to reallocate the limited water supply in a way that addresses the priorities as they grow and change over time through a coordinated themes framework. For this reason, the necessity to provide a review of the legal documents of the case study water resources-related statutes by presenting most of the applicable legislations seen needed. It further examines if those laws are reliable in the creation of a competent legal framework for the country's management of water resources.

Additionally, the metamorphosis underwent by Iraq throughout the previous century in their social, political, and economic aspects led to the beginning of endorsements for numerous laws that protected the water resources on a national level. However, the endorsements remained so until recently, when the changes took place at the constitutional level, as will be discussed in the results and discussion chapter.

2.17. Integrated and sustainable water management

Water resources shortage and scarcity continue to be a key challenge, especially in water-scarce regions, mainly due to climate change adverse impact, landscape development, and population growth. These difficulties have put the sustainable development of the available water resources at the forefront of strategies and long-term plans. To achieve sustainable water resources management, Integrated Water Resources Management (IWRM) has become a universally accepted approach.

There different manners being used for the IWRM term; no co-agreed definition is available. Moreover, different terms are utilised that reflect the IWRM components or notions, for instance; water resource (master) planning, river basin management, water development plan, shared vision planning, and watershed management (Integrated Water Resource Management and Water Sharing (M. D. Davis, 2007). Although, the contemporary definitions have become similar internationally (Table 2.1).

Table 2.1 Integrated Water Resources Management Definitions

Organization	Definitions and concepts of IWRM
World Conservation Union	No co-agreed definition is available universally. One mode; is the all water resources integrated management (i.e., groundwater, surface water, marine waters, etc.). Second mode; water integration with the other natural resources' management. The International Union for Conservation of Nature (IUCN) affirms that only through the conservation integration into IWRM can be ensured the wide range of services ongoing maintenance that provided by ecosystems and the livelihoods which depend upon them (IUCN, 2003).
U.S. Corps of Engineers (USACE)	Acting on pursuing a set of common goals through coordinated activities for the development and maintenance of water resources (H. Cardwell et al., 2004).

World Bank	The World Bank defines IWRM as a vision that ensures economic, social, environmental, and technical dimensions in the development and management of water resources (World Bank, 2004).
European Commission (EC)	“Water resources should be managed in a holistic way, coordinating and integrating all aspects and functions of water extraction, water control and water-related service delivery so as to bring sustainable and equitable benefit to all those dependent on the resource” (Moriarty et al., 2004).
U.S. Environmental Protection Agency (USEPA)	Water resource in terms of quality and quantity can be managed through the watershed approach as a flexible framework, which includes management actions and stakeholder involvement supported by appropriate and reliable science technology (USEPA, 2005).

The IWRM has been considered by The United States Agency for International Development (USAID) as “a participatory planning and implementation process, based on sound science that brings stakeholders together to determine how to meet society’s long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits”. IWRM helps to protect the world’s environment, foster economic growth and sustainable agricultural development, promote democratic participation in governance, and improve human health” (H. E. Cardwell et al., 2006).

Also, the IWRM is seen as a practical notion that been shaped and resulted from the practitioners' on-the-ground accumulated experience (Hooper & Lloyd, 2011). Whereas The International Network of Basin Organizations and Global Water Partnership (INBO-GWP, 2012) shown that IWRM is based on four principles adopted and defined by the international community since the International Conference on Water and the Environment in 1992 (that also so-called the Dublin principles). These principles are: “(a) freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment; (b) water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels; (c) women play a central part in the provision, management and safeguarding of water; and (d) water has an economic value in all its competing uses and should be recognized as an economic good”.

The Global Water Partnership (GWP) has defined the IWRM as “a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (GWP, 2004; INBO-GWP, 2012; Rogers & Hall, 2003).

Most of the definitions included in (Table 2.1) are addressing sustainability in some manner and considering multiple objectives. Whereas other institutional bodies have discerned the

IWRM in different views, they embodied a more comprehensive concept rather than pure sustainable notion.

The USACE is deliberately broadening its definition, describing the IWRM as a process, and disaggregating the specific components (H. Cardwell et al., 2004). While A typical international policy definition of IWRM that orientated towards developing countries is the GWP definition, by which IWRM is linked strongly with reduction of poverty and economic developments (Guerquin et al., 2003).

Subsequently, the GWP were later compiled the principles as: the “IWRM is based on the sustainable use of water, and equitable and efficient management. It also acknowledges that water is an ecosystem integral part, a social and economic good, and natural resource, whose quality and quantity determine the nature of its utilisation”, (Figure 2.9).

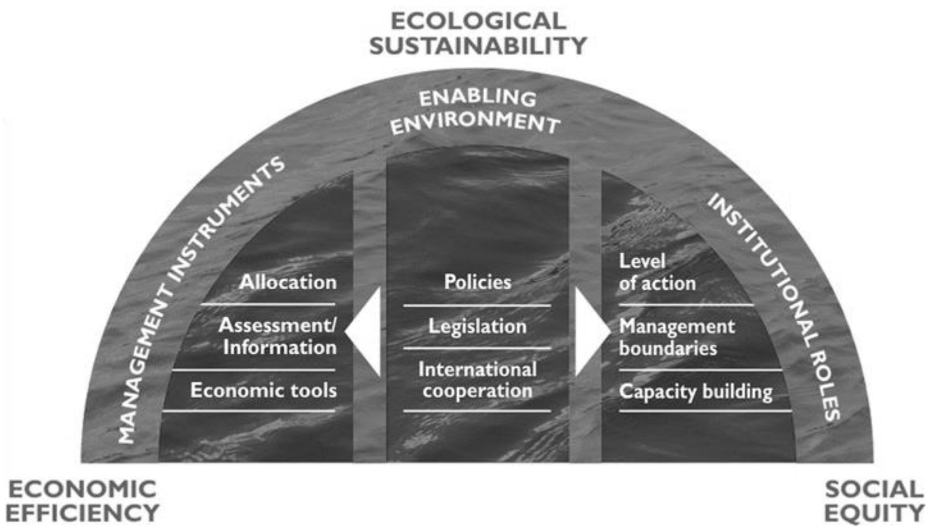


Figure 2.9 General framework of IWRM

Source: (GWP, 2017)

This emphasizes the importance of an integrated approach as well as clearly articulating the link between water resources management and the three themes of sustainable development: economic efficiency in water use, social equity, and environmental and ecological sustainability.

An Integrated Regional Water Management (IRWM) approach focuses on three pillars: an enabling environment of suitable policies, strategies and legislation for sustainable water resources development and management, putting in place the institutional framework through which to put into practice the policies, strategies and legislation, and setting up the management instruments required by these institutions to do their job (GWP, 2017).

(Hubert H G Savenije & Van der Zaag, 2000) indicated that politics, technical cooperation and institutions are the “three pillars” that supporting the sharing and management of international water resources (the roof), while the IWRM represents the foundation of the three pillars (Figure 2.10). The “three pillars” of IWRM according to the GWP (Figure 2.11) are: Enabling Environment, Institutional Framework and Management Instruments (Jønch-Clausen, 2004). Moreover, (H.H.G. Savenije & Van der Zaag, 2008) have suggested that IWRM must take account of water resources, water demand, the spatial scale and the temporal scale.

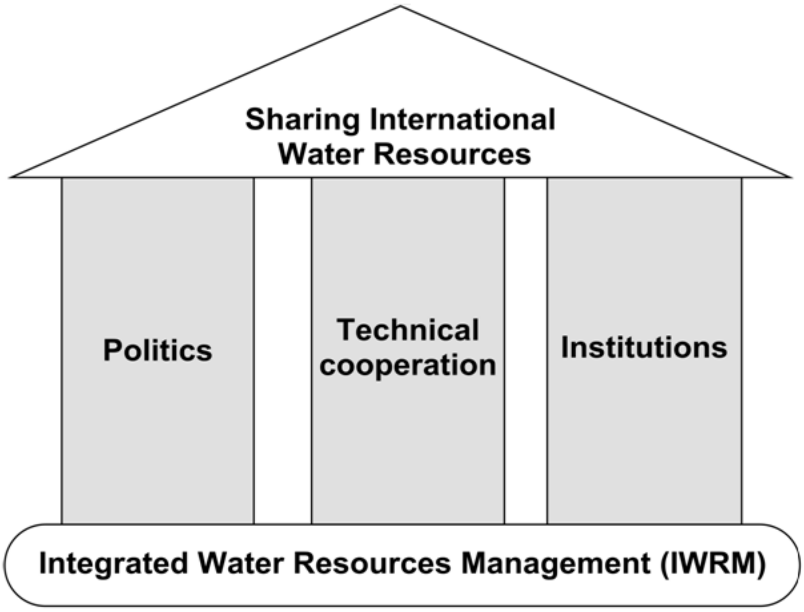


Figure 2.10 A classical temple for sharing international water resources.

Source: (Hubert H G Savenije & Van der Zaag, 2000)

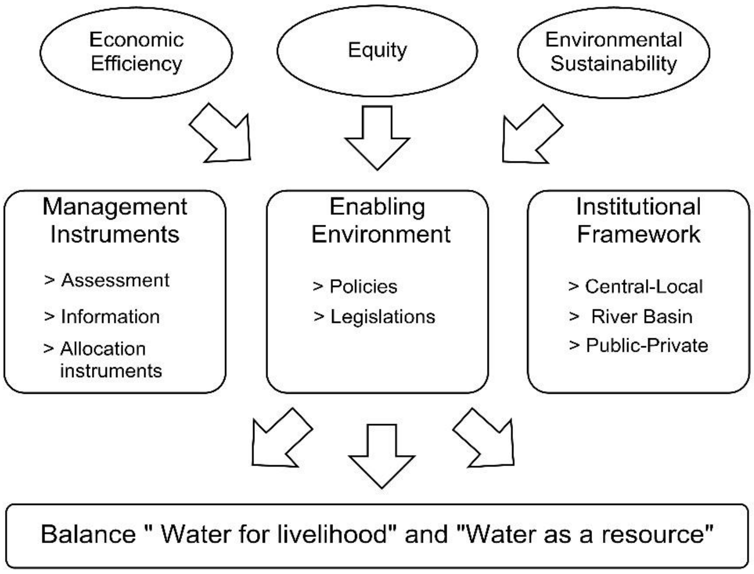


Figure 2.11 The "three pillars" of Integrated Water Resources Management: Enabling Environment, Institutional Framework and Management Instruments.

Source: (Jønch-Clausen, 2004)

(Rogers & Hall, 2003) referenced on the Collaborative Decision Making (CDM) as a appropriate and proper mechanism within the Integrated River Basin Management (IRBM) and IWRM framework. The CDM calls all parties to be participated in water resources management. The CDM described as "a joint effort among government agencies, private sectors, NGOs, the public, universities and other relevant stakeholders aimed at improving the present management system through increased information exchange among the various parties in the community and improved decision support tools" (Elfithri et al., 2008). Figure 2.12 portrays the integration framework between CDM, IRBM, and the IWRM.

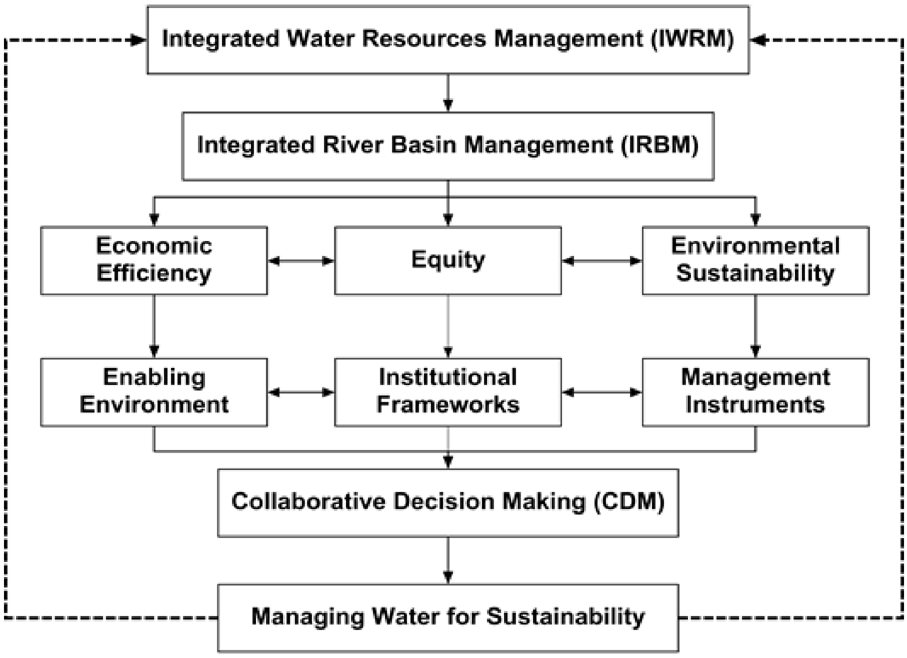


Figure 2.12 Framework of IWRM and IRBM that showed the importance of CDM.

Source: (Elfithri et al., 2008)

While the principles and concepts of IWRM have been commonly acknowledged at national and international scales, the application of IWRM has not been adequately improved in many cases (AWRA, 2011; Bateman & Rancier, 2012). The legal frameworks, governance systems, the processes of decision-making and effectiveness of institutions, often differ from country to the other. Besides, the existing evidence shows that the current popularity of the concept irrespective, its impact on water management improvement has been, at best, marginal (Biswas, 2008).

The supply-side solutions alone are not sufficient to tackle the ever-increasing demands from industry, climatic, and demographic pressures; water recycling measures and demand management are being introduced to converse the challenges of inadequate water provision (UN-Water, 2008; UN-Water and GWP, 2007). For this reason, the IWRM directs on the better portioning of water to different water users and the importance to involve all stakeholders in the decision-making process. Further, it is also acknowledged as the framework for water management adaptation to climate change that causes floods and droughts (UN-Water and GWP, 2007).

The GWP has illustrated the stages in Integrated Regional Water Management (IRWM) planning and implementation (Figure 2.13). The process starts with the national goals and continues into the actions for implementation and monitoring and evaluation progress (Jønch-Clausen, 2004).

Figure 2.13 Stages in IWRM Planning and Implementation.

Source: (Jønch-Clausen, 2004)

(Cai et al., 2002) have suggested that to achieve a delicate balance between supply and demand, new frameworks are needed that can use sustainability indicators to escort the decision-making process. The quantified sustainability criteria use ensuring risk minimization in environmental conservation, water supply, water allocation equity, and water infrastructure development economic efficiency. These also strongly satisfy the sustainable water management especially in irrigation-dominated river basins that try to ensure a long-term, flexible, and stable water supply to meet crop water demands, also the growing industrial and municipal water demands to alleviate the adverse environmental consequences.

Also, (Hemoh & Shenbei, 2014) have developed a sustainable integrated management framework for water resources for the available water resources in Africa arid regions based on the review of relevant literature. The proposed framework (Figure 2.14) highlights the foremost actors/stakeholders in an integrated water management system which is labelled along with the normal triangle and the components that are essential for successful and sustainable management of water resources in labelled regions of Africa which are also labelled along the square. The inverted triangle represents the tools for a sustainable water management framework and the circles are considered the technical system for water resources distribution and control pending the adequate assessment of the components and the involvement of all relevant actors.

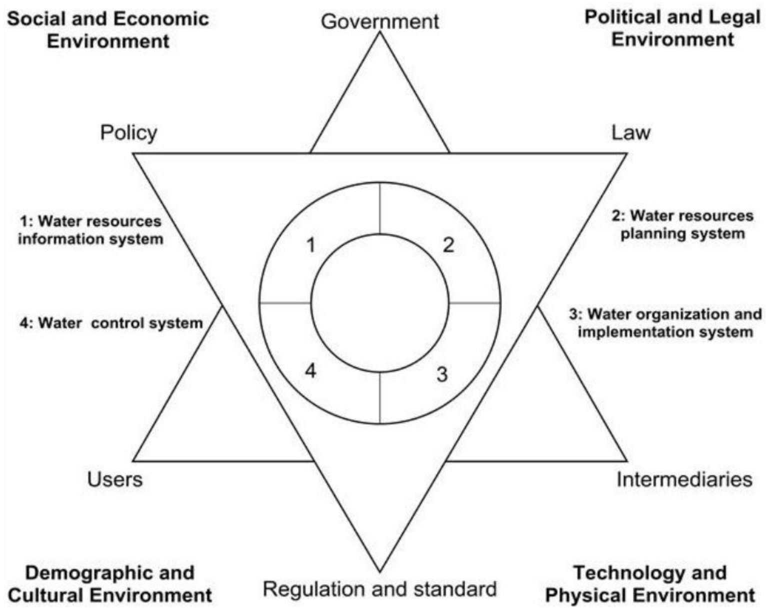


Figure 2.14 Water Resources Sustainable Integrated Management Framework.

Source: (Hemoh & Shenbei, 2014)

However, solid and active water governance is essential to efficiently put the IWRM in practice. Political volition, coherent legal framework, viable involvement of all water-related stakeholders and transparent exchange of data and information are fundamental elements to successfully implement IWRM and achieve the sustainable management of water resources.

As for the urban water management, (Parkinson et al., 2010) cited in (Bahri, 2012) has presented a framework manifesting the components of it that can be adopted in the urban areas. Urban areas need to move from the status of water users to that of water suppliers and managers. With today's technologies and management options, water quantities and qualities can be managed more effectively and efficiently for different purposes.

Integrated approaches can deliver water to specific users in appropriate quantities, qualities, and at appropriate times, without compromising the availability of the resource for others. Managers can tackle existing, or prevent impending, water scarcity by promoting water use efficiency and alternative sources of water, including wastewater and stormwater. New approaches to the collection, transport, treatment and management of sewage can improve resource recovery and mitigate the strain on water resources under challenges such as high population density, urban sprawl, and climate change (Tucci, 2009).

IUWM requires the development of planning and management for all components of urban water services (Figure 2.15). These services are interconnected and require a high level of integration. Coordinating structures and forums will ensure communication between departments, between levels of government, and with communities and stakeholders.

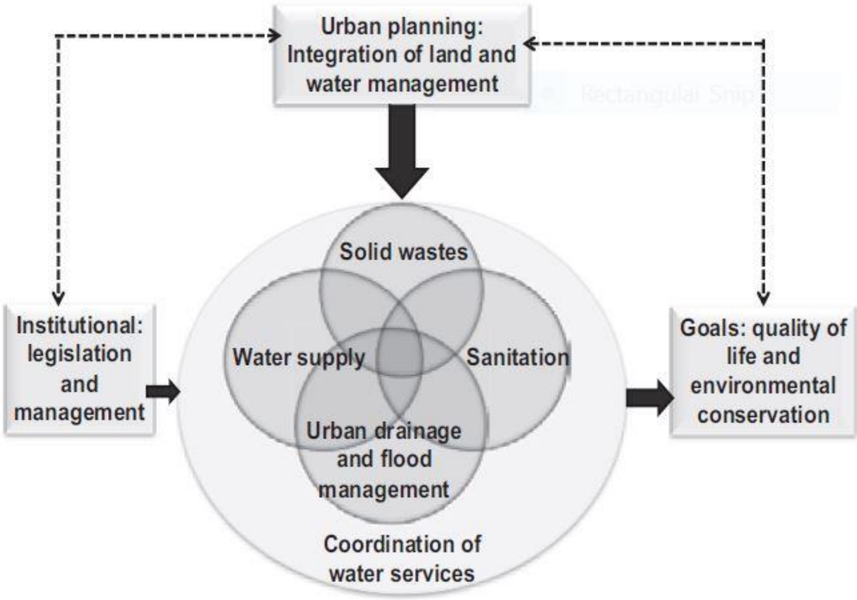


Figure 2.15 Integrated Urban Water Management.

Source: (Tucci, 2009)

Urban planners have an important role in helping governments overcome fragmentation in public policy formulation and decision-making by linking planning with the activities of other policy sectors, such as infrastructure provision, and adopting collaborative approaches that involve all stakeholders in determining priorities, actions, and responsibilities (Figure 2.16). This may involve new methods for interagency coordination and control of water use, such as a new institution or executive committee that has the authority and capacity to regulate and enforce standards and procedures.

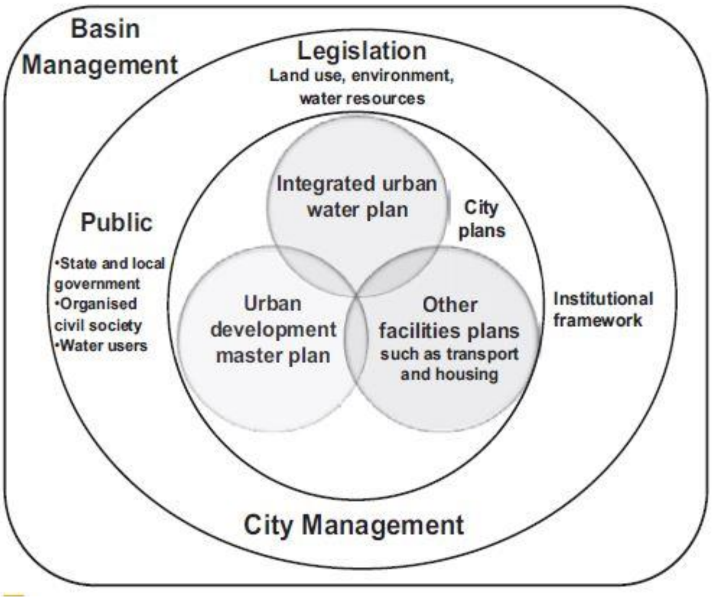


Figure 2.16 Framework for Integrated Urban Water Management (IUWM) and land use planning. Source: (Parkinson et al., 2010).

Integrated urban water policies based on participatory, democratic, and pluralistic governance can secure sustainable development, particularly if governments adopt clear urban policies as an integral part of their economic policies (UNEP, 2002). Changes will be necessary to shift attitudes and stimulate innovative, efficient, and sustainable ways to manage the water resource.

On the whole and in most cases, the IWRM can be described as a process to facilitate stakeholder for promoting coordinated activities in pursuing common goals for multiple objective water management and development joined with the criteria of the sustainable water resource systems.

2.18. Overview of the gaps in the literature

In this sub-chapter, literature gaps identification in the reviews will be summarised. The identified research problems, together with the gaps in the literature, lead to developing the framework for the study that formulated the choices of methodology and the categories of the data type. (Appendix A) includes a table of concerning reviewed studies that have been summarised.

Continuous international and regional exigency calls by organisations and institutions concerning water management and sustainability to develop a technical framework to avoid and adapt to water scarcity in the semi-arid regions. So far, sustainable water management has been studied by relying on either quantitative data or qualitative data.

Globally, semi-arid regions are the quicker changeable areas with respect to other areas due to the shrinkage of humid areas and expansion of aridity, which facing water deficiency, and therefore, there is a wide range of factors that involved in sustainable water management that can be considered with the change of economic, environmental, political, and technologic development.

Despite that water management needs a resilient frame and dynamic form to achieve sustainable water management objectives, which has to possess the ability to be easily updated and adapted to any country or region, but still, there are gaps for developing a technical framework as a novel platform for the threatened semi-arid regions, which still and continually faces an expansion of geographical aridity year by year, which involves and implies additional concerned influential factors, such as climatic parameter, surface- and subsurface-water, water-conserving measures, and regulation statements.

However, even if water resource assortments and the drought patterns do not noticeably change in the future in terms of scarcity, severity, frequency and duration, the current difficulties of coping with most droughts, but still there is a requirement for a framework management model to run water management at optimal form. Therefore, (Furat A. M. Al-Faraj et al., 2015) have strongly suggested the need for a framework management model based on the current difficulties of coping with most droughts, that is appropriate as alleviation measures, which can be taken as the action to reduce the vulnerability of the region and build resiliency in case of episodes would happen in the future caused by worsened droughts or water resources scarcity and degradation. Also, given projections of climate change impact or groundwater depletion, it is essential to move toward a more risk-based approach to more sustained management.

The alteration in precipitation and temperature creates complex recharge processes in semi-arid climates. Given this, the projected climate alterations leave many questions remaining for those interested in water resources sustainable use. The questions that might be given rise are:

1. How does the change in storage in aquifers respond to climate variability on interannual to multidecadal timescales and climate change from human activities?
2. Considering future climate change, how much hydrologic response is caused by natural variability and how much is caused by human activities?
3. Do certain time periods of climate variability necessitate time-varying groundwater-management strategies?
4. Are socio-economic issues susceptible to the recession caused by climate variability?

5. Can some trends in water quality be linked to climate variability and change?
6. Will the effects of natural climate variability on water resources over time be because of human-induced climate change?
7. What strategic role will groundwater storage play in adapting to climate change?

Yet, the current knowledge of groundwater recharge processes supports for some assessment and provides a framework for designing future research. Additionally, the amount of original pieces of literature available on this topic shows that this is an intense area of research (Davidson & Yang, 2007).

Nair, (2016) has seen that because of climate changes and a rise in population and shifting more to seasonal rainfall pattern over semi-arid climate regions in India, there is fast decreasing of available freshwater per capita in all major river basins, also, has reflected in summer water availability and groundwater recharge. By the year 2030, most of the basins will be facing water stress. Several socio-economic issues such as migration, disputes over-sharing, and pricing of water will appear due to falling water availability. Accordingly, measures for adaptation and national policies should be placed through technical frameworks to address the issues seriously, and there are potentialities to overcome the growing water crisis.

Whereas (Mohammed Nanekely et al., 2016) have suggested that revisions and amendments of environmental acts, laws and regulations are essential to promote water conservation and investments in integrated water resources management. Urban drainage systems face an increased challenge to meet the demands linked to a growing population, including an increase of internally displaced people in conflicted countries. Therefore, develop a solid action plan for short- to long-term capacity building programmes, and put into practice a coherent monitoring and evaluation process and measures to ensure that the implementation is thoroughly followed-up.

To understand the aspects of the different regions, (Kumar, 2012) has believed that it is important to investigate the climate change and loss of fresh groundwater resources relationships of the different regions. In the majority of developing countries, whose economy is mainly reliant on agriculture (World Bank, 2019) and is already under stress because of population increase and associated demands for freshwater, are more severely be affected by future climate change. Moreover, notwithstanding measures like governance management through robust framework must be taken to anticipate, minimize or prevent climate change causes and the mitigation of the adverse effects. In addition, if the potential consequences of future changes in groundwater recharge, resulting from several factors, are to be assessed, hydrogeologists must increasingly work with researchers and multi-disciplines, such as socio-economists, legislatures and climatologists.

Accordingly, and all in all, it can be summarised the above literature in the following three themes:

Lack of policy and strategy: most of the developing countries in semi-arid regions suffer from a clear and well-oriented strategy to overcome water shortage planning management.

Limited literature and knowledge: the available literature on sustainable water management in semi-arid regions is highly fragmented and confusing explanations. Much literature is available on water management in different climatic regions, but some being available on the semi-arid areas that have seen the disparity of topics discussed, none of them addressed the (SWM) in semi-arid areas through a solid, comprehensive, and resilient framework

Limited of the research methodology paradigm: most of research on water management either rely their studies on quantitative data analysis or qualitative data analysis. There should consider pragmatism philosophical stance for (SWM).to answer the research questions comprehensively.

The development of adaptation and mitigation strategies to tackle anthropic and climate changes impacts is becoming a priority in drought-prone areas. Therefore, there is a need to think of a new and resilient paradigm and framework of managing and decision-making on facing water shortage, scarcity, and stress in semi-arid areas to be adapted to climate change at global as well as national levels.

Chapter 3: Materials and Method

3.1. Introduction

The materials and methods that been used in this work will be presented generally in this chapter. It describes different kinds of methods used for conducting this research. The researcher used both quantitative and qualitative methods to collect data.

The chapter mainly is divided into twelve sections and included sub-sections. This section introduces the chapter as a whole. While sections 3.2 to 3.8 are set forth the research methodology as per the nested model that consisted and interlinked from the research design, research philosophy; research approaches, research strategies, research choice, the time horizon, data collection techniques, and research framework articulation. Whereas sections 3.9 to 3.12 present the quantitative and qualitative methods, document review, and data analyses that have been used in this study.

3.2. Research Methodological Design

It is widely agreed that the methodology of research should be set prior to undertaking any research. (Blessing & Chakrabarti, 2009) have stated a research methodology design *"should help identify research areas and projects, and in selecting suitable research methods to address the issues"*. They also have set a design research methodology as *"an approach and a set of supporting methods and guidelines to be used as a framework for doing design research"*. Despite of the potentiality of uncertainty in a research process, the failure possibilities can be lessened by using proper research design and by predicting and identifying pitfalls and hinders that the researcher may encounter. Moreover, the overall research strategy can be set by examining the philosophical research aspects using research design. In accordance, many research frameworks can be identified through the literature on methodological aspects. Many research models have been tailored and modelled so far, specifically, is the nested model which gained popularity by the researchers, which first presented by (Cooper et al., 1998) and the research onion model that been introduced by (Saunders et al., 2007, 2009, 2012, 2016). The earlier model had three basic sequential components to establish the research methodology, while the latter model composed of six components as (layers). It is recognised that one of the important features of the nested model is that shows a simple way to understand the research methodology converged layers, additionally, the research onion consists of more component layers and provides the researcher with a wider perspective of how to design the research properly through a series of a logical reasoning process.

Thus, in this research, six methodology layers have been involved, which are as per the following order: the research philosophy supports the research approach that been selected for this work. The research approaches will be pursued using a range of research strategies. Based on different strategies, the research choice has been set out, and then the time horizon of the research was specified. All these have been narrowed down, targeting toward data collection to support developing the technical framework, which is seen as a unique methodology that has never been taken up before. Figure 3.1 portrays the methodology and will be shed lighted in subsequent sections.

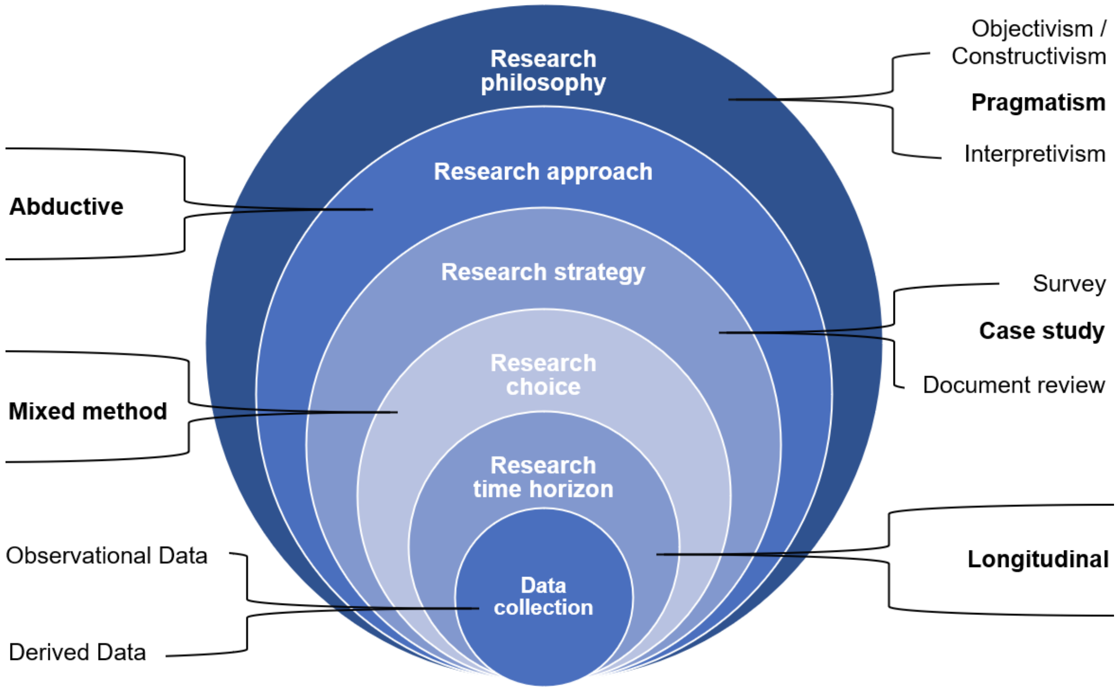


Figure 3.1 The research methodology narrow-down process

Adopted from (Saunders et al., 2016)

3.3. Research philosophy

Pursuing the paradigms of technical issues in combination with the participation of multidisciplinary and interdisciplinary stakeholders' need to embrace both the philosophical principles and technical parameters. In the first instance, the research philosophy will be outlined, and later, the research approaches will be dissertated.

3.3.1. General overview

The following subsections set forth the objectivism, constructivism, and interpretivism philosophical stances targeting the position that adopted for this research.

3.3.2. Philosophical stance

Löwer, (2006) has claimed that sophisticated research areas commonly require different research methodologies to rightly, holistically and carefully define the "real-world phenomena" and approaches of research can rely on various dimensions such as goal, data, focus, and the researched objects number.

In terms of the research focus, the line of action can be stakeholders' participation or technical or, as in this research, the integration of both targets because of the nature of the drivers of sustainable water management (SWM), as implied earlier in chapter one. The research approach goals rely on, explanation, description and recommendation, which, for this research, all will be considering during its process. The types of data are qualitative or quantitative. On the contrary, in terms of the researched objects number, this work is based on a single-case-study examination as will be explained in section 3.5.1.

The theme of this study encompasses both stakeholder's perspectives and technical aspects with a stronger laden on the later one.

3.3.3. The philosophical position of this research

Objectivism is the concept that an objective reality occurs and can be extended known through the accumulation of more complete information. In this study, the climate parameters variability has impacts on human-being life and the availability of water to be managed in a sustainable manner, thus, climate as a social phenomenon has a great effect on the social actors as human, and the surrounded eco-system.

While constructivism seeks the opposite of what objectivism says. It is a philosophical perspective, which claims that all knowledge is constructed from human-being practices as opposed to discovered self-evident knowledge or nature reality. Thus, people (as a social actor) are the ones who commit a breach, this represented over doing unfavourable anthropogenic activities and natural resources misuses, which could affect the nature and the eco-system (as a social phenomenon), which needs to be answerable for the new rules that coming from time to time. For instance, groundwater depletion is a consequence of excessive water use and unsustainable management that exacerbated more due to climate alterations and imperfection and weakened legislation that needs to be seen from both directions.

Additionally, interpretivism also recognised as interpretivist, which involves the researchers into the interpretation of components (feature, element, statement, pieces of a document) of a study, thence interpretivism integrates human attentiveness into a study. Therefore, this philosophy stance focuses on qualitative rather than quantitative analysis.

The philosophical position of this study embraces the aforementioned philosophical stances in a pragmatism position which make the researcher judge a topic from multiple viewpoints about the impact of the social actors and social phenomenon. It can be used these views to create a practical approach to research. It can also be used to come up with a solution to the problems. Additionally, the pragmatism is a deconstructive paradigm, which favours mixed-method choice in research, “sidesteps the contentious issues of truth and reality’’ (Yvonne Feilzer, 2010), and “focuses instead on 'what works' as the truth regarding the research questions under investigation” (Teddlie & Tashakkori, 2009) cited in (Christ, 2013). Moreover, it is known that pragmatism research philosophy is considered as a world view or paradigm that should support complementary mixed-methods research choices. It is a philosophy that orients the research problem toward the view that the research question can be answered effectively by the best research methods (Morgan, 2013; Saunders et al., 2009). Therefore, as the (SWM) is characterized by the bifurcating and correlation with various disciplines and aspects of science and knowledge, and also to different groups of stakeholders, thus, pragmatism is designed to be a broad paradigm, it is intended to handle any kind of situation.

3.4. Research approach

Research approach builds upon research philosophy that, in this study, will be an abductive approach and mostly depend on inference due to the feature of the study that apprehends from issues concerning water. However, as has been explained in section 3.3.2, sophisticated research areas are interested in the use of varied research approaches.

An abductive research approach seemed most suitable given the essence of the research objectives. It is worthwhile to distinguish here a subtle difference with an inductive approach, that seeks to determine general rules, it tracks from research question to observation, next come the description, and analysis, and finally it comes up with developed outcomes. While the abductive reasoning seeks for a cause-and-effect relationship, which is interesting in water issue concerning its shortage and availability.

3.5. Research strategies

In this research three strategies have been used for data collection; case study research, survey represented as (questionnaire, and focus groups), and document review, all targeted to eliciting evidence from various sources.

3.5.1. Case study strategy

There are multiple definitions and understandings of the case study. According to (Bromley, 1990), it is a "systematic inquiry into an event or a set of related events which aims to describe and explain the phenomenon of interest". The unit of analysis can vary from an individual to a corporation or even a region. While there is a utility in applying this method retrospectively, it is most often used prospectively. Data come largely from documentation, archival records, interviews, direct observations, participant observation and physical artefacts (Yin, 1994).

The case study research strategy is that investigates to answer specific research questions which seeks a range of different kinds of evidence, evidence which is there in the case setting, and which has to be abstracted and collated to get the best possible answers to the research questions. No one kind or source of evidence is likely to be sufficient (or sufficiently valid) on its own. This use of multiple sources of evidence, each with its strengths and weaknesses, is a key characteristic of case study research, that is often indexed as neither quantitative nor qualitative (Burns & Grove, 2010). Moreover, (Gillham, 2000) has seen that a fundamental characteristic is that you do not start out with a priori theoretical notions (whether derived from the literature or not) - because until you get in there and get hold of your data, get to understand the context, you won't know what theories (explanations) work best or make the most sense.

It also defined by (Yin, 2014), which is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, addresses a situation in which the boundaries between phenomenon and context are not clearly evident and use multiple sources of evidence. It is a method when the phenomenon under study is not readily distinguishable for its context (Yin, 1994).

According to (Denscombe, 2010), the case study strategy can use a wide range of phenomena as the unit of analysis, but, in order to qualify as something that lends itself to case study research, it is crucial that the unit has distinct boundaries. In the case of a province-based approach, the boundaries are those concerning to the entitie's water-related characteristics.

Importantly, (May, 2011) notes, *"the goal for many proponents of case studies […] is to overcome dichotomies between generalising and particularising, quantitative and qualitative, deductive and inductive techniques".* Research aims should drive methodological choices, rather than narrow and dogmatic preconceived approaches. Therefore, the aim of case studies is to illustrate the general by looking at the particular. The logic behind concentrating efforts on a single-case study rather than multiple-cases is that there may be insights to be gained from looking at the individual case that can have wider implications and, importantly, that would not have come to light through the use of a research strategy that would cover a large number of instances (Denscombe, 2010). Many of the features associated with a case study are not necessarily unique; however, when combined, they give the approach its unique character. The rigor of a case study should be judged by validity and reliability (Yin, 1994).

Further to the well-known use of case studies to develop new hypotheses, the case study method can serve evaluation needs by being able to assess outcomes and test hypotheses (Yin, 1994). To achieve that, a major prerequisite is the development of causal relationships, which will then become the main vehicle for developing generalisations. Thus, it is imperative in sustainable water management case studies to consider strong links to multidisciplinaries role associated to different features of studied area. On the wholecollecting qualitative or quantitative datasets about the phenomenon, the researcher gains more in-depth insight into the phenomenon than would be obtained using only one type of data. That is, it serves to provide a framework for evaluation and analysis of complex issues, tt shines a light on the holistic nature of the case (Hamel et al., 1993; Yin, 2003).

3.5.2. Survey strategy

A survey is a research strategy which can be used for data collection from a pre-determined group of respondents (the population of interest) to gather insights and information into various topics of interest (Lavrakas, 2008). It can have multiple purposes, and the researcher can conduct it in many ways depending on the methodology chosen and the study's aim, and also the researcher, therefore, uses the data and information from a sample of individual to make some inferences to be used as knowledge later and to help make decisions.(Kelley et al., 2003; Lavrakas, 2008).

3.5.3. Document review strategy

The archival research is a type of research strategy that involves extracting, exploring, and explaining official texts and archival records on the changes happening over a long-span-time through document review method. These records may be held in collecting institutions (Bronx Community College, 2019), such as in a governmental body's organization custody or in their websites, which initially issued or gathered them. As a type of primary research that extracts substantiations from original records, archival research can be compared with secondary research (either undertaken online or in the library), that involves and depending on secondary sources relating to the enquired topic. In this research, legislative documents pertaining to water management in Iraq and Kurdistan Region have been utilised for the purpose of this study.

There are three approaches in archival research, historiographic, ecological, and new archivalists approaches. Their modes vary in terms of four basic criteria: the analysis level (few/many), the methods of input (read/measure), the causality implicit approach (descending/ascending), and their measurement conception (objects/relations) (Ventresca & Mohr, 2002). Here in this research, the ecological approach has been adopted that goes through a high level of analysis, based on measured inputs, and also based on descending time horizon from the establishment of Iraqi state till the year 2018.

3.6. Research choice

In this research, mixed-methods research choice has been adopted, since sustainable water management inter-related to many concerning themes and branches of study which build upon different sorts of data types, the researcher can use both data types: the qualitative and quantitative data for study purposes. It has been enabled to use the same to collect as well as analyse the data. Complementary mixed-method research choice has also been utilised for the potentiality to find and fill easily the gaps in the information to explore more aspects of the study.

In this case study research, quantitative data have been employed to describe climate condition, groundwater monitoring, and (SuDS) measures as rainwater harvesting ponds (RWHP) assessment. and also, qualitative data that adopted on gathered data from focus groups questionnaire and interviews, in addition to document reviews of water legislation and statutory documents.

3.7.Collected data

It is known that data can be mainly sorted out into four types, based on methods for collection: simulation, experimental, observational, and derived data. The research data type may affect the way of managing such data. Here, in this research, tow types of data have been gathered as following:

3.7.1. Observational Data

These are captured through observation of a behaviour or activity. It is collected using methods of semi-structured surveys, and the use of an instrument or sensor to monitor and record information such as the use of sensors to observe climate data at meteorologic stations and at monitoring groundwater wells. The observational data are usually captured in real-time, it would be very difficult or impossible to re-create if lost.

3.7.2. Derived or Compiled Data

Derived data involves using existing data points, often from different data sources (Macalester College, 2019). For instance, archival legal documents, and also, combining area and suggested dam sites associated with a number of beneficiaries, water storage volume, reservoir size, and the construction cost. To be known, this type of data can usually be replaced if lost, it may be very time-consuming (and possibly expensive) to do so.

3.8.Research Methodological Framework

To recap the process been used in this research, this section is devoted to present the research methodological framework and identifying the three main stages as illustrated below in (Figure 3.2), through a conceptual framework showing the process of collecting data from different sources to articulate the logical steps taken throughout this study.

The research consisted of three stages; collecting data, data refining and controlling data, and analysing data that target the aim of the research. It was initiated by collecting data on; climate parameters, groundwater monitoring, rainwater harvesting, statutory documents, and surveys on SuDS. Following that, the datasets have been filtered moving toward the exploratory analyses and documents review, each based on the data types of qualitative and quantitative data. Next, the analyses outcomes have been utilised to develop the framework as the core aim of the study.

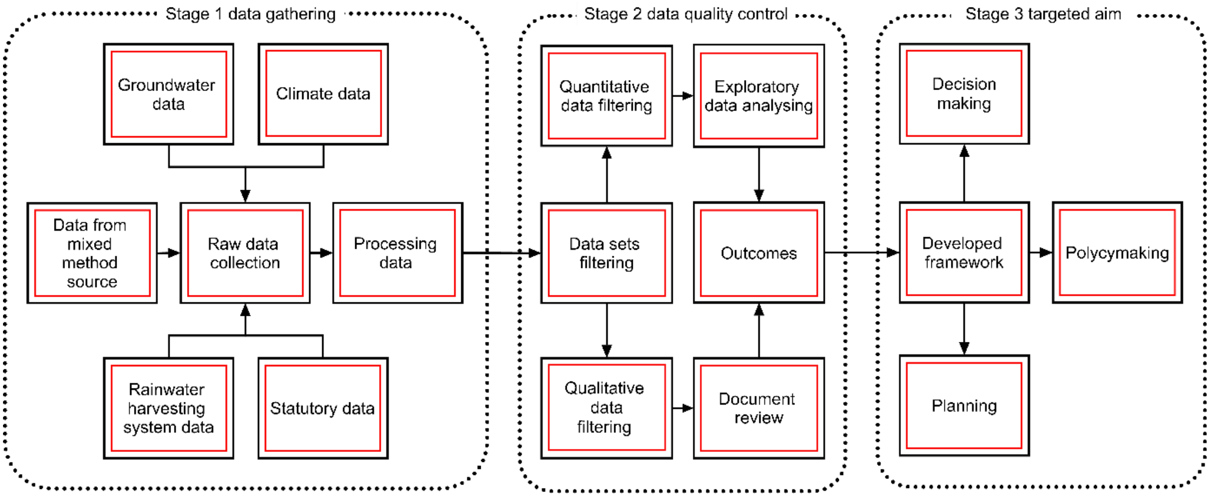


Figure 3.2 A schematic diagram of the process of data collection and research progression

3.9.Qualitative research method

In principal, the mixed-method research choice has been adopted as a preliminary survey in addition to getting data. The purpose of this research methodology is to generate the notion of SuDS and its expectation by sorting out respondents' views, in order to look for the dynamic and attainable measures to firm up the research question.

It has been stated that combining of both quantitative and qualitative approaches in research design and data collection should be considered whenever possible. Such mixed-methods research is more expensive than a single method approach in terms of time, cost, and effort, but improves the validity and reliability of the resulting data and strengthens causal inferences by providing the opportunity to observe data convergence or divergence in hypothesis testing (Abowitz & Toole, 2010).

According to (Hesse-Biber, 2010), typically, employment of research design by using both qualitative and quantitative data as mixed-methods for answering a specified research question(s), and the gathering of methods "involves the collection, analysis, and integration of quantitative and qualitative data in a single or multiphase study" (W. E. Hanson et al., 2005). The "multi-methods" term is used for mixing methods by merging a number of either qualitative or quantitative methods in a single research study, like "in-depth interviews and observation of participant" or "survey and experiment" in a single research study. This approach implies a procedure for gathering, analysing and integrating the results of both quantitative and qualitative data at some stage of the research within a single study for the sole purpose of gaining better understanding of the topic of interest. Attempts were made to test the proposed hypothesis or to check any relationship between the diverse variables as quantitative technique was appropriate for testing of hypothesis.

(R. B. Johnson & Onwuegbuzie, 2004) have stated the following phrase: “word, picture, and narrative can be used to add meanings to numbers”. This approach is considered as a substantial field of gathering data because of its positive contribution in making the phrase clearer. Alternatively, what mostly people understand is that qualitative data usually presented as a narrow scale can be merged with quantitative and numerical data at a wider scale for the same issue, giving researchers an opportunity to disseminate research results to incoming studies and examinations.

3.9.1. The design of questions form

A questionnaire is one of the research techniques for gathering information from respondents., the researcher should be assured about how to measure the variables and what is required of interest. In the beginning, it is always recommended to review pieces of literature on previously used validated questionnaires that can be administered in similar settings and capture variables that are of interest according to the hypothesis of the study (Edwards, 2010).

To develop a new questionnaire, it should be pilot tested and validated so that to judge if it is gaining what is supposed to measure and gives reliable results. The questions wording is very decisive and should be considered into account; content propriety, language sophistication level, form and type, succession and how is data inquired from the respondents. During questionnaire development, its mode of administration should be kept in mind, it has been self-administered and its design and flow have been planned accordingly (Kazi & Khalid, 2012).

The application of the questionnaire technique does not necessarily need to be checked for reliability, and results can be compared for different studies and also combined for meta-analysis.

As for the accuracy of a measure that is known as validation, what it aims to do, regardless of the responder. The valid questionnaire leads to get better quality data with high comparability that reduces the effort and increase the data credibility. the following characteristics should be included in the valid questionnaire (i) viability and simplicity (ii) precision in the words and reliability (iii) satisfy the problem intended to measure (iv) consider the underlying concept to be measured and (v) measuring the change capability (García de Yébenes Prous et al., 2009) cited in (Kazi & Khalid, 2012).

That is a survey of a semi-structured questionnaire has been selected as one of the tools for data collection. It was adopted because it enables the researcher to look at relations between and amongst different sites, categories, and characteristics (Rubin & Babbie, 2016). The appropriateness of semi-structured questionnaires can be used effectively for examinations like this study where the aim happens to be a probe for attitudes and reasons for feelings or certain actions (Kothari, 2004).

A form of 11 eleven questions has been prepared, mainly the questions were divided up into six themes. The set of themes was consisting of; the challenge to stockholders, business and management, climate alteration, water sustainability, the strategy in planning and legislations and both social with environmental issues. Figure 3.3 shows themes related to questions. The purpose behind tailoring the form is to assess; the role of SuDS as a measure in areas with a water shortage; water scarcity in decision-making processes; and the adverse effects of climate change on the drainage system.

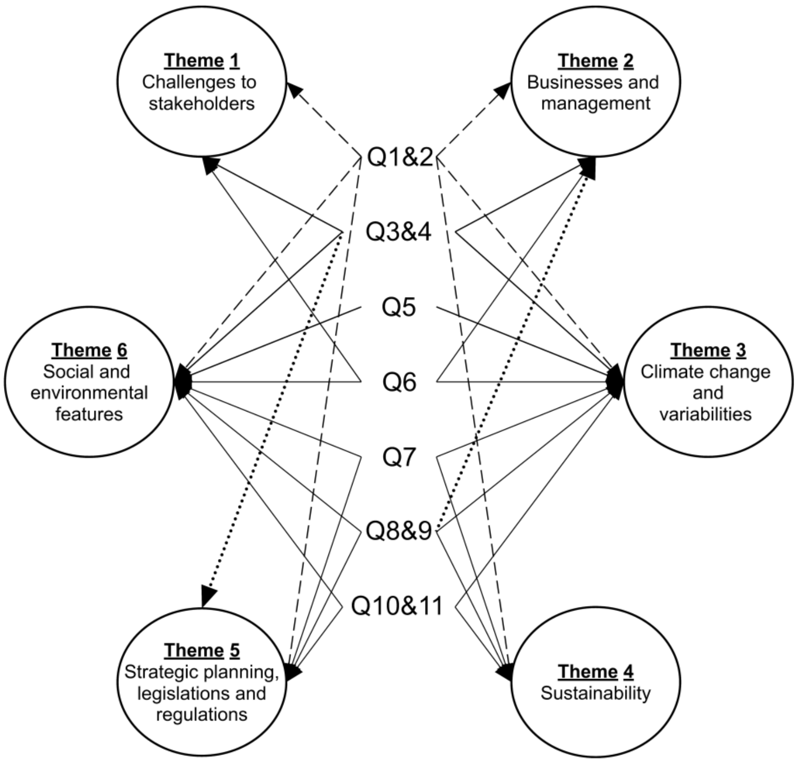


Figure 3.3 Spectrum of adopted themes

3.9.2. The rationale of using mixed-method

Only in the last twelve years has the concept of mixed-method been widely accepted, although researchers have long used this sort of research method, but not named as "mixed". This approach is useful as it relies on multiple ways to address the research problem (Biddix, 2009).

In this approach, research problems can become questions of the research/or hypotheses in accordance with findings from prior studies, experience or knowledge. Moreover, the sample size could be more than that of a single design. Researchers can overcome the limitations of a single method, meaning that they can achieve more interpretations, exploring phenomena, defeating the weaknesses of single design and getting answers for open questions from different views (Creswel, 2014; Creswell & Creswell, 2017).

3.9.3. The survey

A solid integrated and joint methodology was used to achieve the objective and appropriately demonstrate the results. A combination between a self-administrated questionnaire, face-to-face communication and interviews, and electronic media interaction. An on-line questionnaire was designed and five workshops, targeting multidisciplinary cohorts (hydrologists, hydrogeologists, civil engineers and ecologists), were conducted, both genders were invited without bias. (Mitchell & Jolley, 2012) pointed out that "*using a self-administered questionnaire can be a cheap and easy way to get honest answers*". Similarly; (MBA Official, 2015) stated that the advantages are low-cost, high reliability, time-saving and high suitability for collecting large samples. Face-to-face communication and interviews (including the exchange of ideas, information, feedback and constructive comments) and electronic media (i.e., direct e-mails and LinkedIn professional networking) were used to target a high number of potentially authoritative responders such as academics and Ph.D. students at universities, researchers at research institutes and decision-makers in relevant industries.

Seminars were undertaken on the concerning topic and concepts, and were also presented in the Civil Engineering department at the Salahaddin University, and at the Ministry of Municipality in capital city of Erbil, in addition to undertaking seminars at the general directorate of municipalities, and at the city council. Moreover, face-to-face interviews were undertaken with planners and decision-makers. (Mayor, general directors, board chairpersons', directorate managers and head of departments). A poster sheet of A2 size was printed in colour for decision-makers to illustrate the uses of SuDS techniques in some countries and its advantages in conserving sustainability. In addition, a power point presentation of 42 slides was prepared to show to the professionals.

The main reason for selecting particular categories of cohorts is that they usually comprise professionals with good knowledge and experience, and because of their speciality in the various areas of development competence. Which is likely to lead to more objective and scientific results. On the other hand, their experiences and feedbacks will contribute to the precise details and answers required by the questionnaire themes. This will crystallise the more notions of the SuDS and give an overview on it.

Questions were grouped into a solid set of classes, see (Appendix C). The statistical analyses were performed using the International Business Machines software package for statistical analysis (Wheeler, 2013) version 24 (IBM Corp, 2016) in an attempt to convert the responses to informative output.

In 2018, 337 individuals, representing 35% of “various” organisations, 30% of local councils, 17% of government commissions, 12% of the local community, and 6% from the private sector participated in the workshops undertaken for this study. Participants were involved in the project via either individual face-to-face interviews and/or telephone conversations (Opdenakker, 2006). The interviews were used to investigate current and future foreseeable water scarcity, as well as impacts of water scarcity on ecosystems, agriculture, industry and domestic users. The relationship between water scarcity and sustainable management of water and drainage practices, as well as the socio-economic drivers and their influences on water resources management in a sustainable manner, were also assessed. Moreover, the study examined the likelihood of growing conflicts among multi-water use stakeholders because of a water shortage.

The workshops were structured to identify individuals who can offer good insight and who represent a spectrum of experiences and opinions. Semi-structured interview techniques were adopted in this study (Adams, 2015; Newton & Newton, 2010; Whiting, 2008). The surveys were undertaken by a number of well-designed inter-connected specific questions (Appendix C) to effectively engage diverse groups of people and to ensure integrity, consistency and comparability of the data gained through the questionnaire, interview and workshop processes.

Prior to conducting the workshops, ethical approval as a certified formal letter from the Ministry of Agricultural and Water Resources (KRG) and Ministry of Municipality-KRG were obtained including the consents from all participants, letters addressed to a number of pertained official government departments, semi-official departments and academic institutions were inviting their representatives.

3.10. Quantitative research method

Kothari, 2004 has identified the quantitative research that is based on the measurement of amount or quantity. It is applicable to aspects that can be manifested in terms of quantity, it is also a purposeful and organised process that depends on numerical data to get information. It clearly describes variables and checks the relationships and correlation between them.

The quantitative research approach will be followed later by using specific software and numerical methodologies that could be the best option for bringing out results that will facilitate and manage the work for assessment and interrelated factors impact.

Since the climate pattern is the crucial issue to identify most research areas in environmental studies, climate alterations are highly regarded as an essential and influential factor, and some actual requirements (including accurate data collection, modelling scenarios and sensitive analyses) should be considered in such studies. Therefore, collecting data on the climate in this study area is considered necessary. For sustainable water management, the adopted parameters have to be taken into account to identify its functionality. One of the factors that have to be taken into account is climate data collection in the form of measurements over a period, and these are presented as quantitative data.

The role of groundwater is not lesser than climate change, as it is the field that strongly concerning the sustainability in water management. The data that are gathered would be the guide for further findings in this specific aspect, which have not expected into account previously. Therefore, data collection, and sensitive analyses surely would give valuable indicators on the items, which the study has been based on it. The assessment of SuDS techniques is also measured as quantitative method, most of data will have been collected as figures and numbers.

3.10.1. Climate data acquisition

Due to lack or insufficient availability of meteorological data in many areas around the world, the data from the National Centres for Environmental Prediction (NCEP), Climate Forecast System Reanalysis (CFSR) can be relied (Dile & Srinivasan, 2014; Fuka et al., 2014; Soundharajan et al., 2016).

In this research, meteorological data from a reliable source (NCEP, 2015) have been downloaded and utilised for this study, similar to actual recorded data from ground-based metrological station records or official departments archives. The reason behind using data from the website is that; there is insufficient real-data from the official departments, this is because of the precedent instability in the case study area following events experienced by the country in the last four decades represented as military actions, fragile political situations, and administrative issues.

Climate data of seventeen grided virtual data stations of altitudes ranging from about 193 masl to as much as 2764 masl within and in close proximity to the Erbil Province were examined. Interpolated daily meteorological variables such as precipitation (P), minimum (T_{min}), maximum (T_{max}), mean air temperatures (T_{mean}), radiation and humidity between from 1980 to 2014 were made available from the National Centres for Environmental Prediction (NCEP), Climate Forecast System Reanalysis (spatial resolution = 0.5° * 0.5°). Figure 3.4 shows the location of the grid climate sites and the variations in altitude.

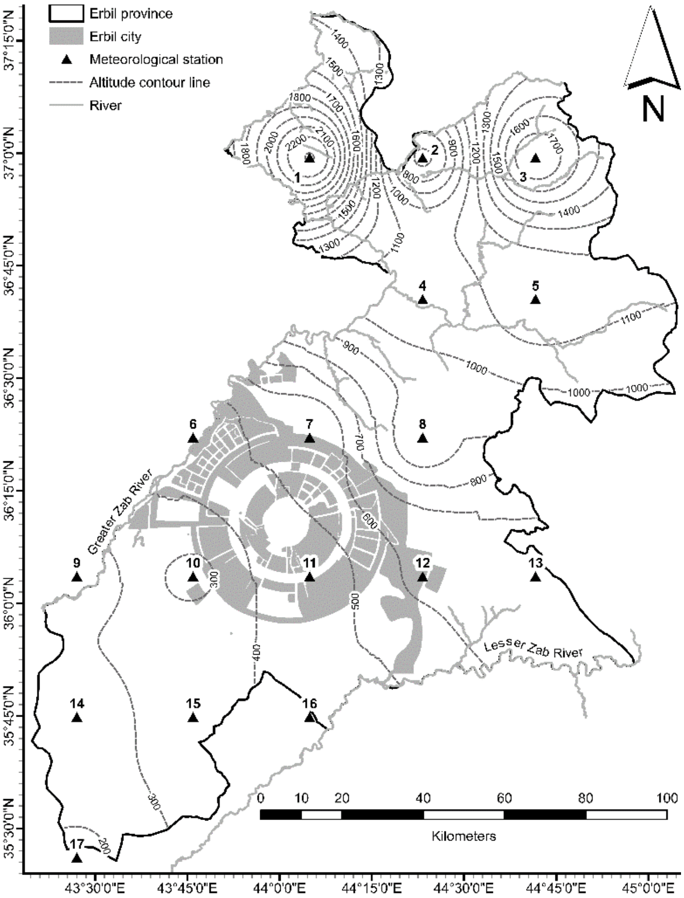


Figure 3.4 The location of the grided Meteorological Stations and the variations in altitude

3.10.2. Groundwater data

3.10.2.1. Groundwater data of observation wells

Groundwater level records at ninety-nine observation wells (OW) over the case study area were made available by the Ministry of Agriculture and Water Resources in the Kurdistan Region of Iraq (MoAWR-KRG, 2016).

Fifty-four observation wells' record have been chosen out of the total of (ninety-nine), see (Appendix D.2). The selections were according to the availability of a complete set of monthly readings of water levels from 2000 to early 2016. The recorded data of monitored groundwater levels from 2004[4] to 2015 has been considered to examine the fluctuations and trends in water levels that has been observed in the investigated observation wells. Figure 3.5 shows the observation wells across the study area.

[4] The monitored groundwater levels of this year have been considered as a reference level, this due to poor data that precede this year, and based on the availability of sufficient and reliable later data.

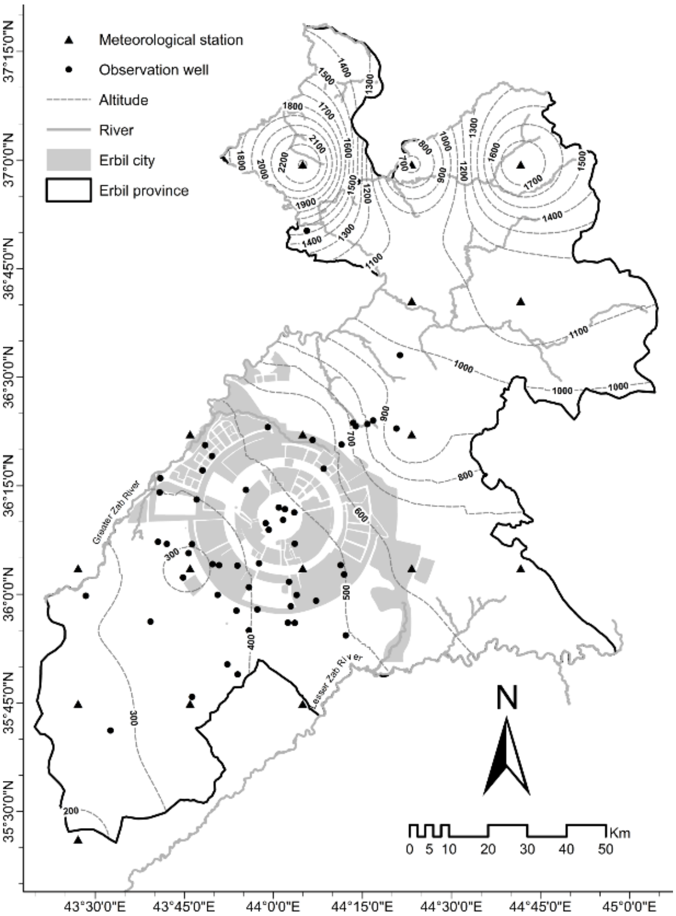


Figure 3.5 The locations of 17 meteorological stations (MS), and 54 observation wells (OW)

3.10.2.2. Groundwater data for aquifer status

To analyse the groundwater reserves in this study area, data have been gathered from different sources; the secondary research data, which have been taken from studies that undertaken before (Hameed, 2013; Zoran Stevanovic & Iurkiewicz, 2009), and the data that have been taken from official government departments (MoAWR-KRG, 2016), additionally, primary data were gathered represented as daily precipitation, and air temperature for 17 (MS) (NCEP, 2015), which have been relied by other studies (Dile & Srinivasan, 2014; Fuka et al., 2014) to find out mean monthly potential evapotranspiration across the study area. Hydrological years defined over twelve consecutive months from 1st October of any year to 30th September of the following year that can be used in the estimation as long as the changes in groundwater storage. The wet season extends from November to April, whereas dry season is from May to October that mostly the monthly precipitations were not exceeded 100mm (Murray-Tortarolo et al., 2017).

The Erbil groundwater basin is dominated of Mukdadiya Formation (That was formerly known as the Lower Bakhtiari Formation) and The Bai Hassan Formation (That was formerly known as the Upper Bakhtiari Formation (Tertiary age, i.e. Late & Early Pliocene respectively) and by almost 1000 meters thick covered by recent deposits represented as (Alluvium and River terraces) Figure 3.6.

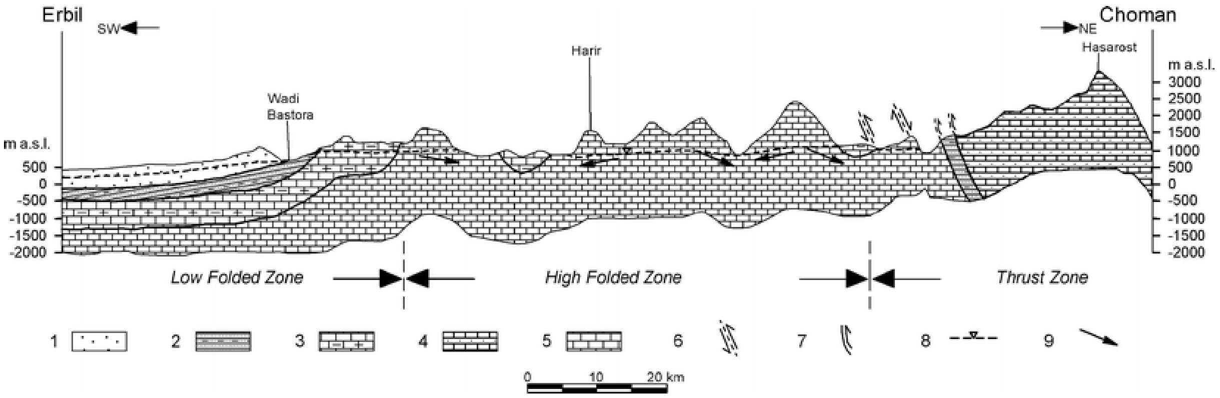


Figure 3.6 Regional hydrogeological cross-section (Choman-Erbil).

Source: (Z Stevanovic & Markovic, 2004)

1 Recent alluvial deposits, Lower and Upper Bakhtiari formations; 2 Lower and Upper Fars formations, Red beds series; 3 Pila Spi and Gercus formations; 4 Naopurdan-Walash series; 5 Shiranish and Kolosh formations, Aqra-Bekhme formations; 6 fault; 7 main thrust; 8 estimated groundwater level; 9 groundwater flow direction

While the aquifer characteristics are generally favourable, its recharge is limited by low rainfall and the absence of perennial streams (Erbil Governorate, 2018; Zoran Stevanovic & Iurkiewicz, 2009). In arid and semi-arid regions, rivers and streams typically lose their waters by, for example, recharging groundwater. However, in this case study, both surrounding rivers are acting as water-gaining streams, which is usually more typical for humid regions where groundwater recharges streams. Thus, the lower reaches of the two Zab rivers (**Error! Reference source not found.**) drain the aquifer rather than recharging it (Al-Basrawi & Al-Jiburi, 2014; Hameed, 2013; Z Stevanovic & Markovic, 2004). Figure 3.7 shows the direction of groundwater flow toward the rivers.

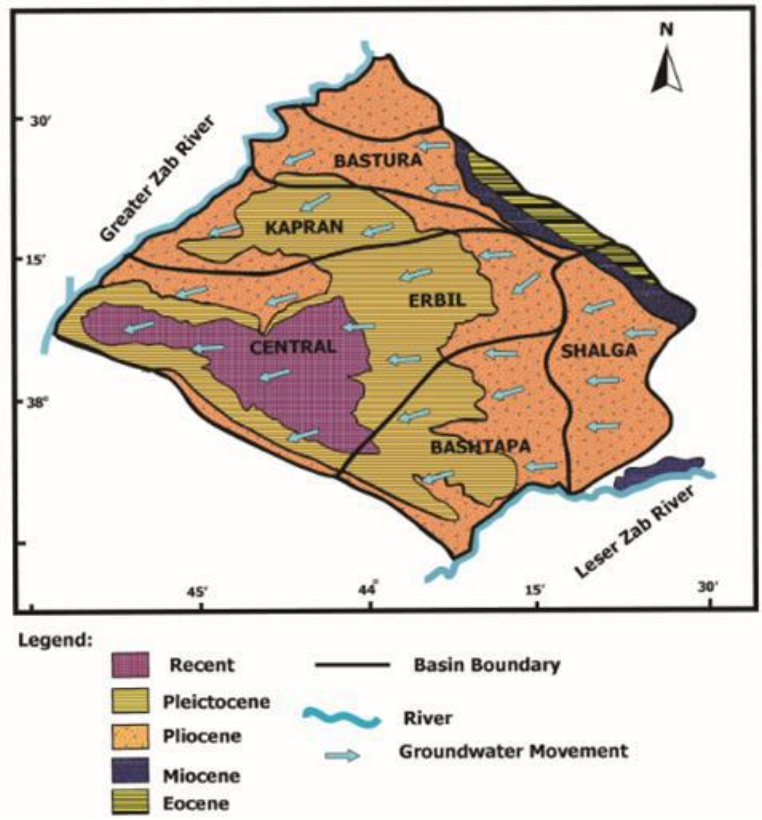


Figure 3.7 Geological map of Erbil Basin and the direction of groundwater flow

Source: (Dizayee, 2014)

The types of soil across Erbil province vary according to geographical location. Rough mountains as well as broken and stony landforms the upper part of the province (Buday, 2006; Haji & Ahmad, 2015; Zhang et al., 2015). The middle part comprises two types of brown soil, while gypsi-ferous alluvium, brown soil deep phase and lithosolic soil in sandstone and gypsum shape the lower part of the province. The soil types are shown in (Figure 3.8 a) (Hameed, 2013).

(Figure 3.8 b and c) are based on data obtained from the General Directorate of Water Resources, Kurdistan Regional Government (KRG)-Iraq (MoAWR-KRG, 2016), and (Buday, 2006), and show the formations of the ground layers represented as intergranular, intergranular fissured, karstic fissured and aquitard as well as aquifer productivity.

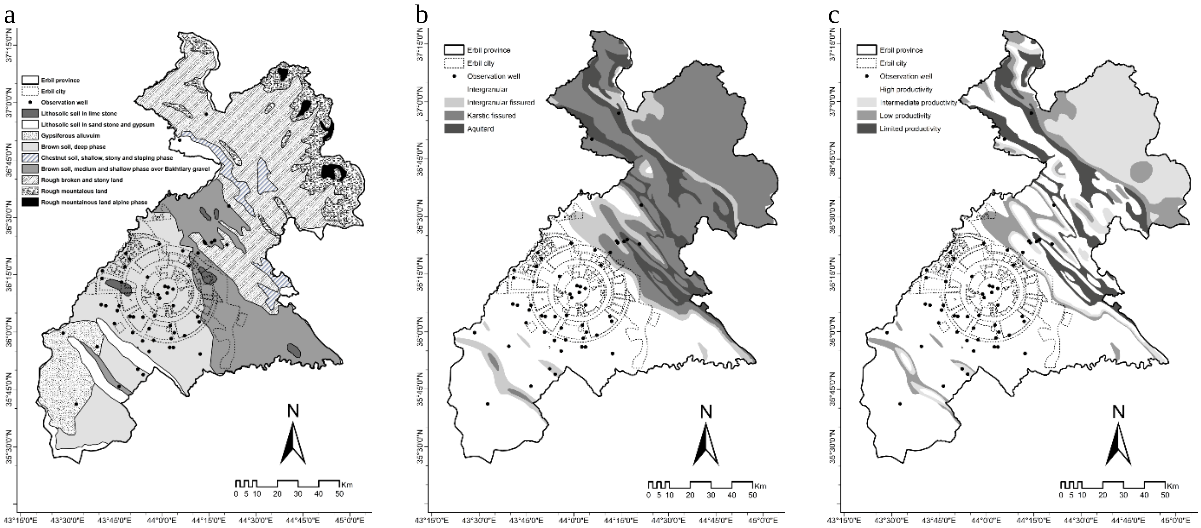


Figure 3.8 Soil and Geological characteristics

(a) Soil types across Erbil province, *After* (Hameed, 2013); (b) : Type of aquifers across Erbil province, *After* (Buday, 2006; MoAWR-KRG, 2016); (c) Productivity of aquifers in Erbil province, *After* (Buday, 2006; MoAWR-KRG, 2016)

Two main groups of significant aquifers can be distinguished in the case study area: The karstic and karstic-fissured aquifers of the extended carbonate formations (limestones and varieties) in the central high-folded zones, and the intergranular aquifers of the lowlands, in addition to aquitards between the two types of main aquifers. Well-karstified rock masses can be developed to capture the flood flush waters for later use. Construction of cut-off walls to elevate the discharge level has proved to be an effective method in this regard. Climate change will alter the sustainability conditions of most water resources Due to the impacts of climate change, most water resources will be "un-sustained". This technique contributes the sustainable use of an un-sustained resource (Baba et al., 2011).

(Payne & Woessner, 2010) pointed out that aquifers of high flow productivity have the potential to be considered a source of water supply for large-scale irrigation projects and municipal water use. Aquifers associated with intermediate flow productivity can also be considered potential suppliers for irrigation and municipal purposes, the average wells' discharge is about 9.1 (Liter/second), see Appendix D.8. However, placement of wells may be challenging to ensure a sufficient flow rate. Inter-granular or intergranular fissure formations that have little to offer could be considered suitable sources to single or a small number of households. At any rate, the achievement of a desired minimum flow rate may be difficult (Lewis et al., 2006; Payne & Woessner, 2010).

Figure 3.8 a, b, and c provide initial characterisation of groundwater and give an indication of the likely variation in groundwater yield and flow type in relation to different geological deposits. The productivity classes shown in Figure 3.8 c provide a potential measure of the expected long-term abstraction rate of groundwater.

3.10.3. Rainwater harvesting systems

A set of fifty-five detention ponds, which considered as a Rainwater Harvesting System (RWHS) has been investigated as one of the commonly used sustainable drainage systems (SuDS) in the arid and semi-arid areas (Harb, 2015; Ziller & Ertl, 2010). Ten indicators have been adopted to: (i) assess the function of the RWHS; (ii) investigate the degree of success in implementing the RWHS; (iii) explore the main problems and obstacles; and (iv) reflect on potential solutions to improve the performance of the system in the arid and semi-semi-arid areas. These indicators were: (a) the cost of construction, (b) the size of inundated area, (c) the harvested water volume, (d) proposed livestock’s watering, (e) irrigation area, (f) groundwater replenishment, (g) flood risk mitigation, (h) the number of beneficiaries and socio-economic development, (i) the appropriateness for recreation, (j) and biodiversity. A weighted scale approach has been used in which a weighted scale factor (WSF: 1 to 5) was given to each indicator. The weight scales are (1: very low impact; 2: low impact; 3: medium impact; 4: high impact; and 5: very high impact). The Ministry of Agriculture and Water Resources-Kurdistan Region Government (KRG) in Iraq (MoAWR-KRG, 2016) made data available and a number of field visits has been undertaken to some detention ponds in the studied area. Figure 3.9 illustrates the location of the detention ponds. Data have been gathered for each indicator against each detention pond, see (Appendix D.3).

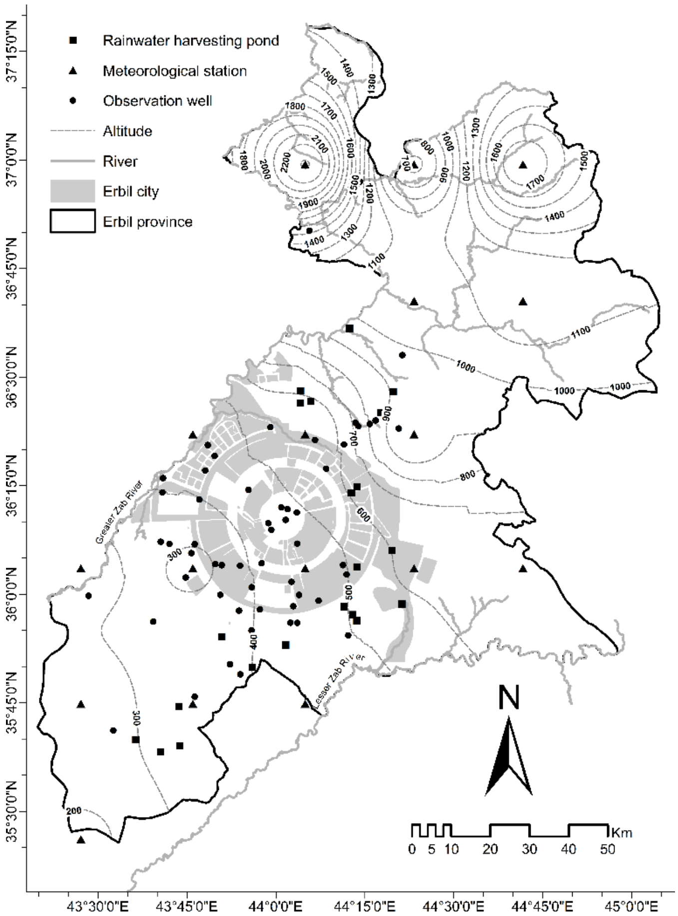


Figure 3.9 The location of rainwater harvested pond in the case study area

Since the data were collected, they consist of figures (numbers) for every indicator, and each indicator represents as an indicator of the effectiveness of the system, moreover, how the indicators data can be inducted, therefore, the approach of Multiple-Criteria Decision Analysis (MCDA) have been chosen (San Cristóbal Mateo, 2012; Zardari et al., 2015).

Multiple-criteria decision analysis (MCDA) is seen as a sub-discipline of research methods, which distinctly evaluates multiple conflicting and non-conflicting indicators for evaluation or decision-making. For complex situations, this method can be tailored well, and considering a number of criterions explicitly gives more informed and better estimation.

One of the methods that widely have considered as a sort of (MCDA) techniques is Weighted Sum Model (WSM) (Herath & Prato, 2006; Zardari et al., 2015). In decision theory, the (WSM) is well known and simple (MCDA) for evaluating a number of indicators in terms of a number of criteria (Alanazi et al., 2013; Ben-Arieh & Triantaphyllou, 2002; Marler & Arora, 2010). The common formula for obtaining the weighted score (Odu & Charles-Owaba, 2013) is shown in Equation 3.1:

$$Ii^{WSM-score} = \sum_{j=1}^{n} Sw * Rw , \quad \text{for n =1, 2, 3} \quad \ldots\ldots\ldots\ldots (3.1)$$

Where

Ii^{WSM} is Indicator score weight; Sw is Scaled weight; and Rw is Relative weight (Proportional weight).

Although, there would be a potential issue with this method; the factor values may not be an accurate representation of the differences among factors due to a researcher's choice of the extraction, whereas one of the advantages of this method is; the indicators with the highest loading values on the factor would have more effect on the factor score (Distefano et al., 2009).

3.11. Document reviews and archival research

Statutory documents were mostly available from the official website of the Iraqi Supreme Judicial Council (ISJC) for both authorities: The Iraqi Federal Government and the Kurdistan Regional Government from the year 1917 which are regularly added and updated by recently issued documents. The adopted legal documents are Laws, regulations, or instructions.

Archival research method as document reviews and analysis have partly been adopted in this research. Documents analysis is a type of qualitative research, by which the researcher interprets the documents to give voice and meaning around an assessment topic (Bowen, 2009). Therefore, it is one of the qualitative research data technique by which statutory documents can be interpreted to give view and meanings around a topic. The archival research herein is seen as a sort of research which involves seeking out and extracting evidence from legal documents. These records held as a collection of primary data from formal governmental body website, that originally generated and accumulated them. Further, it endeavours to point out the strengths and weaknesses and also to highlight them as thematic assortments for further processing to be as part of developing a framework to manage water resources in a sustainable manner. Here in this work, the longitudinal time horizon scope has been adopted for statutory documents analyses.

Additionally, communications with groundwater professionals via visits to both sites and official departments, face-to-face meetings, phone calls, workshops and small focus group interviews were carried out over the year 2018 to gather useful data and information on laws, regulations, instructions, orders and records of monitoring wells along the study area to assess current and future foreseeable groundwater management policies and arrangements. Multidisciplinary cohorts who can offer valuable insight and who represent a wide spectrum of experiences and opinions were involved in this survey. The discussions covered topics such as (a) increased reliance on groundwater; (b) lack of integrated management of groundwater resources; (c) increased number of illegal drilling of wells by individual farmers and households; (d) groundwater quality deterioration; (e) absence or weakness of implementation of the regulatory framework to control illegal drilling of wells and protect groundwater pollution; (f) lack of integrated land use planning; (g) poor protection and maintenance of wells; (h) drying-up of a large number of wells; (i) public awareness of sustainable management of groundwater; (k) absence of reliable statistics on groundwater abstractions; (l) financial provisions; and (m) impacts of climate change.

3.12. Data analyses

Tukey, (1962) explained data analysis as *"Procedures for analysing data, techniques for interpreting the results of such procedures, ways of planning the gathering of data to make its analysis easier, more precise or more accurate, and all the machinery and results of (mathematical) statistics which apply to analysing data."* Additionally, according to (Judd et al., 2011) the data analysis process is known as testing, refinement, converting and modelling data toward finding the needed information, summarising the findings and taking decisions later. Data are collected and analysed to answer research questions, test hypotheses credibility or disprove theories.

3.12.1. Questionnaire data analysis

The questionnaire consisted of several sorts of questions – including multiple choices, Likert ratings, and after collecting of 337 responses, a categorising process was carried out for the questions, before the process, coding for each answer was undertaken. The IBM SPSS package was used for statistical analysis. For this, only the frequencies, correlations, reliability and consistency were obtained as inferential analysis.

3.12.2. Climate data analysis

The obtained climatic data for the region has been organised in excel sheets, and descriptive charts have been prepared, a sensitive inferential and descriptive analysis for the climate variables will be discussed.

Daily data of seventeen meteorological stations (MS) were downloaded and analysed for all the stations of altitude ranging from about 175 masl to as much as 2306 masl within and in close proximity to Erbil Province. Daily records of precipitation (P), minimum temperature (T_{min}) maximum temperature (T_{max}), mean air temperature (T_{mean}), solar radiation, wind speed, and relative humidity for 35 years from the water years (1979-1980) to (2013-2014) were made accessible by the National Centres for Environmental Prediction (NCEP, 2015) based on Climate Forecast System Reanalysis (CFSR) which had been created and completed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over this time period on (spatial resolution = 0.5° × 0.5°). Hydrological (Water) years defined over twelve consecutive months from 1st October of any year to 30th September of the following year. The coordinates and the altitudes of the meteorological stations associated with climatic data have been tabulated, see (Appendix D.1).

Altogether, through investigating the climate alteration of a semi-arid climatic area, it is necessary to examine the drought severity status and the amounts of evapotranspiration rates for the scoped period.

It is worthy to mention, to visualise the data distribution over the studied area, ArcGIS v.10.5 was utilised to generate spatial distribution sets of maps, which show the long-term maximum, minimum and mean annual precipitations, temperature, and the potential evapotranspiration rates distribution. The spatial analysis tool for the ordinary kriging method (ESRI, 2017; Goovaerts, 2000; Jamaludin & Suhaimi, 2013) was used for the development of isohyetal lines and classified symbology maps.

In water resources researches, the spatial interpolation has been being utilised widely by employing various types of kriging techniques: They are simple, universal and ordinary kriging, among these three types, ordinary kriging is more desirable. This is because, the latest research regarding the analysis of rainfall by (Grimes & Pardo-Igúzquiza, 2010) have outlined that ordinary kriging can give good results so that to calculate the rainfall data for unmeasured locations. It is considered as the preferable method in terms of bias and accuracy. For the value estimations, ordinary kriging method concept uses are reliable. Moreover, it is dependable to use when the meteorological stations' number is limited (Gupta et al., 2017)**.**

The measured values close to the unmeasured points have greater influence. Ordinary kriging gives the best linear unbiased valuation with a minimum error variance. Assumptions for the practical usage of ordinary kriging are based on constant but unknown mean and sufficient observations to estimate variogram.

Kriging weights the surrounding measured values to derive a prediction for an unmeasured location. Equation 3.2 (Jamaludin & Suhaimi, 2013) is formulated as a weighted sum of the data. The weight **λ** depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location. The weights **λ** are calculated by finding solutions of a system of linear equations, which are obtained by assuming a real-valued function is a simple path of a random process, and that the error of prediction is to be minimized.

$$Z(S_0) = \sum_{i=1}^{N} \lambda_i Z\,(S_i) \qquad \text{………. (3.2)}$$

Where

$Z(S_i)$ denotes the measured value at the i^{th} location;

λ_i is an unknown weight for the measured value at the i^{th} location

S_0 is the prediction location, and N means the number of measured values.

3.12.2.1. Evapotranspiration

Evaporation and transpiration occur in simultaneous time, both processes depend on air temperature, solar radiation, wind speed and relative humidity (i.e., vapor pressure deficit). The rate of transpiration is also affected by environmental aspects, crop characteristics and cultivation practices. Different types of plants may have different rates of transpiration (Allen et al., 1998).

Reference evapotranspiration (ETo) is defined as the rate at which readily available soil water is vaporized from specified vegetated surfaces (Jensen et al., 1990). Then reference evapotranspiration is defined as the ET rate from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100m of the same or similar vegetation (Allen et al., 2005; Walter et al., 2001). The concept of the ETo was introduced to study the evaporative demand of the atmosphere independent of crop type, crop development and management practices.

An updated equation was recommended by FAO (Allen et al., 1998) with the FAO-56 Penman-Monteith Equation, simplifying the previous used equation by utilizing some assumed constant parameters for a clipped grass reference crop. It was assumed that the definition for the reference crop was a hypothetical reference crop with crop height of 0.12m, a fixed surface resistance of 70 s m^{-1} and an albedo value (i.e., portion of light reflected by the leaf surface) of 0.23 (Smith et al., 1991).

For this study, FAO tool version 3.2 (FAO, 2012) was applied to calculate the Potential Evapotranspiration (PET). The Food and Agriculture Organization Penman-Monteith (FAO-PM) method is adopted by the tool using the new Equation (3.3) below (Allen et al., 1998), and was used to determine the potential evapotranspiration (PET). It is worth noting that this method has commonly been used worldwide to obtain the reference crop evapotranspiration (ETo) (Bogawski & Bednorz, 2014; Debnath et al., 2015; Kwon & Choi, 2011; Sharifi & Dinpashoh, 2014; Tabari & Talaee, 2011; Vangelis et al., 2013)

$$ET_o = \frac{0.408\,\Delta\,(Rn - G) + \gamma \frac{900}{T + 273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \quad \ldots\ldots\ldots\ldots (3.3)$$

where:

ETo is the reference evapotranspiration (mm/day); Rn is the net radiation at the crop surface ($MJ/m^2/day$); G[5] is the soil heat flux density ($MJ/m^2/day$); T is the mean daily air temperature at 2m height (°C); u_2 is the wind speed at 2m height (m/s); es is the saturation vapour pressure (kPa); e_a the actual vapour pressure (kPa); (es-ea) are the saturation vapour pressure deficit (kPa); Δ is the slope vapour pressure curve (kPa/°C); and γ is the psychrometric constant (kPa/°C).

The calculations are based and in accordance with the procedures below:

Step 1: Air temperature

The (average) daily maximum and minimum air temperatures in degrees Celsius (°C) are required.

For standardisation, T_{mean} for 24-hour periods is defined as the mean of the daily maximum (T_{max}) and minimum temperatures (T_{min}) rather than as the average of hourly temperature measurements, average temperature is calculated by:

$$T_{mean} = \frac{T_{max} - T_{min}}{2} \quad \ldots\ldots\ldots\ldots (3.4)$$

where:

[5] Soil heat flux is small compared to Rn, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, based on the idea that the soil temperature follows air temperature, as the collected climatic data that were daily data and converted to monthly data, therefore, for day and ten-day periods: As the magnitude of the day or ten-day soil heat flux beneath the grass reference surface is relatively small, it may be ignored and thus: Gday ≈ 0.

T_{mean} = mean daily air temperature, [ºC]; T_{max} = maximum daily air temperature, [ºC]; T_{min} = minimum daily air temperature, [ºC].

Step 2 – Mean daily solar radiation (Rs)

The average daily net radiation expressed in [MJ m^{-2} day^{-1}] is required.

Step 3 – Wind speed profile (u_2)

Wind speeds measured at different heights above the soil surface are different. Surface friction tends to slow down wind passing over it. Wind speed is slowest at the surface and increases with height. For this reason, anemometers are placed at a chosen standard height. For the calculation of evapotranspiration, the average daily wind speed in ($m.s^{-1}$) measured at 2m above the surface is required (Allen et al., 1998).

It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ. To adjust wind speed data obtained from instruments placed at elevations other than the standard height of 2m, a logarithmic wind speed profile may be used for measurements above a short-grassed surface:

$$u_2 = u_z \frac{4.87}{ln(67.8z - 5.42)} \quad \text{………… (3.5)}$$

where:

u_2 = wind speed 2m above the ground surface, [$m.s^{-1}$]; u_z = measured wind speed z m above the ground surface, [$m.s^{-1}$]; z = height of the measurement above the ground surface, [m].

Step 4 - Slope of saturation vapour pressure curve (Δ)

For the calculation of evapotranspiration, the slope of the relationship between saturation vapour pressure and temperature, (**Δ**) is required. The slope of the curve at a given temperature is given by:

$$\Delta = \frac{4098\left[0.6108 exp\left(\frac{17.27T}{Tmean+237.3}\right)\right]}{(Tmean+237.3)^2} \quad \text{………… (3.6)}$$

where:

Δ slope of saturation vapour pressure curve at air temperature T [kPa °C^{-1}]; T_{mean} air temperature [°C]; exp[..] 2.7183 (base of natural logarithm).

Step 5 – Atmospheric Pressure (P)

The atmospheric pressure, P, is the pressure exerted by the weight of the earth's atmosphere. Evaporation at high altitudes is promoted due to low atmospheric pressure. This effect is, however, small and in the calculation procedures, the average value for a location is sufficient. A simplification of the ideal gas law, assuming 20°C for a standard atmosphere, can be employed to calculate P in kPa at a particular elevation:

$$P = 101.3\left(\frac{293-0.0065z}{293}\right)^{5.26} \qquad \text{………… (3.7)}$$

where:

P = atmospheric pressure [kPa]; z = elevation above sea level [m].

Step 6 –Psychrometric constant (γ)

The psychrometric constant relates the partial pressure of water in air to the air temperature so that vapor pressure can be estimated using paired dry and wet thermometer bulb temperature readings. Another way to describe the psychrometric constant is the ratio of specific heat of moist air at constant pressure (Cp) to latent heat of vaporization. The specific heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure. Its value depends on the composition of the air, i.e., on its humidity. For average atmospheric conditions a cp value of $1.013\ 10^{-3}$ MJ kg^{-1} $°C^{-1}$ can be used. As an average atmospheric pressure is used for each location, the psychrometric constant is kept constant for each location depending of the altitude.

$$\gamma = \frac{C_p P}{\varepsilon\lambda} = 0.665x10^{-3}P \qquad \text{………… (3.8)}$$

where:

γ = psychrometric constant [kPa $°C^{-1}$]; P = atmospheric pressure [kPa]; λ = latent heat of vaporization, 2.45 [MJ kg^{-1}]; C_p = specific heat at constant pressure, $1.013\ 10^{-3}$ [MJ kg^{-1} $°C^{-1}$]; ε = ratio molecular weight of water vapour/dry air = 0.622.

Step 7 -Mean saturation vapor pressure derived from air temperature (e_s)

As saturation vapor pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by:

$$e_{(T)} = 0.6108exp\left[\frac{17.27T}{T+237.3}\right] \qquad \text{………… (3.9)}$$

where:

$e_{(T)}$ = saturation vapor pressure at the air temperature T, [kPa]; T = air temperature, [ºC].

Therefore, the mean saturation vapor pressure is calculated as the mean between the saturation vapor pressure at both the daily maximum and minimum air temperatures.

$$e_{(T_{max})} = 0.6108 exp\left[\frac{17.27\ T_{max}}{T_{max} + 237.3}\right] \qquad \text{………… (3.10)}$$

$$e_{(T_{min})} = 0.6108 exp\left[\frac{17.27\ T_{min}}{T_{min} + 237.3}\right] \qquad \text{………... (3.11)}$$

where:

T_{max} = maximum daily air temperature, [ºC]; T_{min} = minimum daily air temperature, [ºC].

The mean saturation vapor pressure for a day, week, decade or month should be computed as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e_{(T_{max})} + e_{(T_{min})}}{2} \qquad \text{………... (3.12)}$$

Step 8 - Actual vapor pressure (e_a) derived from relative humidity

The actual vapor pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations should be used.

$$e_a = \frac{e_{(T_{min})}\left[\frac{RH_{max}}{100}\right] + e_{(T_{max})}\left[\frac{RH_{min}}{100}\right]}{2} \qquad \text{………... (3.13)}$$

where:

e_a = actual vapour pressure, [kPa]; $e_{(Tmin)}$ = saturation vapour pressure at daily minimum temperature, [kPa]; $e_{(Tmax)}$ = saturation vapour pressure at daily maximum temperature, [kPa]; RH_{max} = maximum relative humidity, [%]; RH_{min} = minimum relative humidity, [%].

Step 9 – The inverse relative distance Earth-Sun (*dr*) and solar declination (δ)

The inverse relative distance Earth-Sun, dr, and the solar declination, δ, are given by:

$$d_r = 1 + 0.033 cos\left[\frac{2\pi}{365} J\right] \qquad \text{………... (3.14)}$$

$$\delta = 0.409 sin\left[\frac{2\pi}{365} J - 1.39\right] \qquad \text{………... (3.15)}$$

where:

J = number of the day in the year, 365, or 366.

Step 10 – Conversion of latitude (φ) in degrees to radians

The latitude, φ, expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

$$\varphi[Radians] = \frac{\pi}{180}\varphi[decimal\ degrees]$$ ……….. (3.16)

Step 11 - Sunset hour angle (ώs)

The sunset hour angle (ώs) is given by:

$$\omega_S = arccos[-tan(\varphi)tan(\delta)]$$ ……….. (3.17)

where:

ώs = latitude expressed in radians; δ = solar declination.

Step 12 – Extra-terrestrial radiation (Ra)

The extra-terrestrial radiation, Ra, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [(\omega_s \ \sin\varphi \sin\delta) + (\cos\varphi \cos\delta \sin\omega_s)]$$ ……….. (3.18)

where:

R_a = extra-terrestrial radiation, [MJ m^{-2} day^{-1}]; Gsc = solar constant = 0.0820 [MJ m^{-2} min^{-1}];

dr = inverse relative distance Earth-Sun; ώs = sunset hour angle, rad; φ = latitude, rad; δ = solar declination, rad.

Step 13 – Clear sky solar radiation (R_{so})

The clear-sky calculation radiation is given by:

$$R_{so}=(0.75+2E10^{-5}z)R_a$$ ……….. (3.19)

where:

z = elevation above sea level, [m]; Ra = extra-terrestrial radiation, [MJ m^{-2} day^{-1}]

Step 14 – Net solar or net shortwave radiation (R_{ns})

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$R_{ns} = (1 - a)\ R_s$ ………... (3.20)

where:

R_{ns} = net solar or shortwave radiation [MJ m^{-2} day^{-1}]; α = albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimensionless]; R_s = the incoming solar radiation [MJ m^{-2} day^{-1}].

Step 15 – Net outgoing long wave solar radiation (Rnl)

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law. The net energy flux leaving the earth's surface is, however, less than that emitted and given by the Stefan-Boltzmann law due to the absorption and downward radiation from the sky. Water vapor, clouds, carbon dioxide and dust are absorbers and emitters of longwave radiation. It is thereby assumed that the concentrations of the other absorbers are constant:

$$R_{nl} = \sigma\left[\frac{T_{max}K^4 + T_{min}K^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right)$$ ………... (3.21)

where:

R_{nl} = net outgoing longwave radiation [MJ m^{-2} day^{-1}]; σ = Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}]; T_{max} = K maximum absolute temperature during the 24-hour period [K = °C + 273.16]; T_{min} = K minimum absolute temperature during the 24-hour period [K = °C + 273.16]; e_a = actual vapour pressure [kPa]; $\frac{R_s}{R_{so}}$ = relative shortwave radiation (limited to ≤ 1.0); R_s measured solar radiation [MJ m^{-2} day^{-1}]; R_{so} calculated clear-sky radiation [MJ m^{-2} day^{-1}].

Step 16 – Net radiation (R_n)

The net radiation (Rn) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$R_n = R_{ns} - R_{nl}$ ………... (3.22)

where:

R_{ns} = net solar or shortwave radiation, [MJ m^{-2} day^{-1}]; R_{nl} = net outgoing longwave radiation, [MJ m^{-2} day^{-1}];

To express the net radiation (R_n) in equivalent of evaporation [mm] (R_{ng});

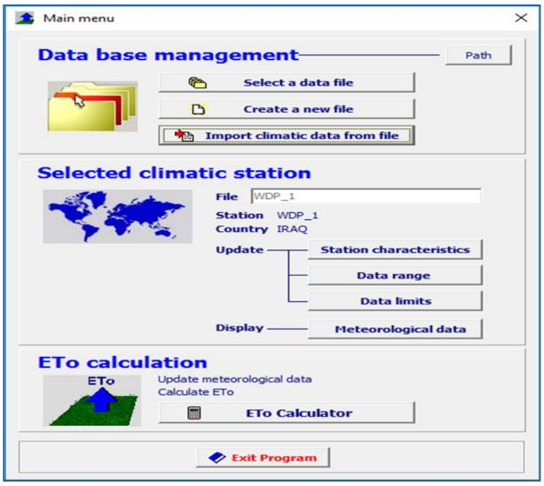
$$R_{ng} = 0.408 * R_n \qquad \text{……….. (3.23)}$$

where:

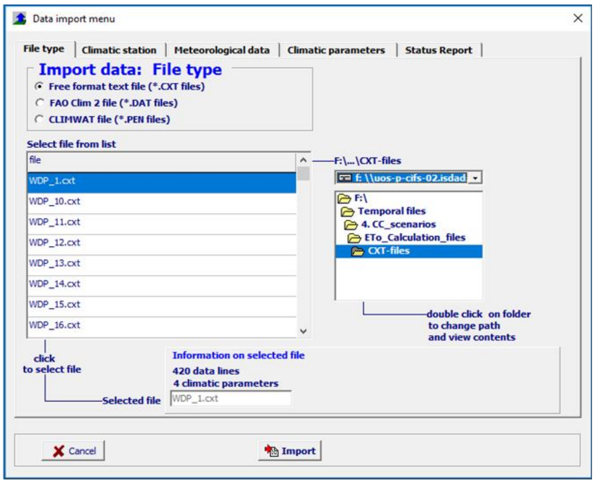
R_n = net radiation, [MJ m^{-2} day^{-1}].

Beginning with ETo-FAO software, initially, and above all, datasheets were tabulated for the climatic parameters (air temperature, wind speed, solar radiation, and relative humidity) for every single metrological station, then, the data were transferred one by one from Excel sheets to txt extension files. Subsequently, these data were imported into the software (Figure 3.10), wizard step (1-3), all related information data were assigned of locations, coordinates, and the designated names of the metrological stations for every data file.

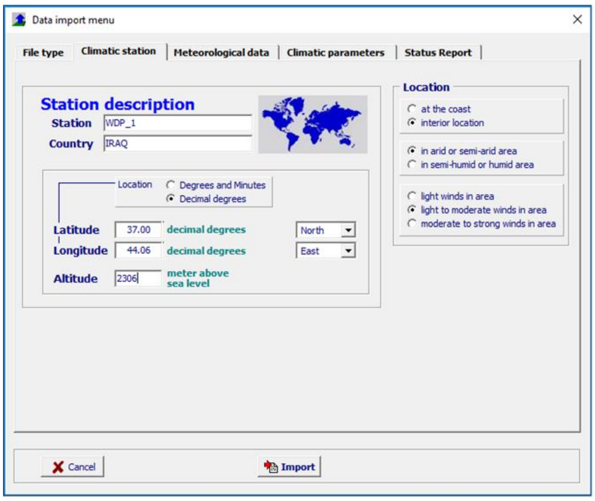
Following that, the meteorological data types have to be assigned in association with the time range of imported data, that is, the recorded start day, month, and year, in addition to the last recorded day, month, and year. Next, the climatic parameters will be checked based on the columns that are sorted in the imported data files, in addition, the units of the climatic parameters need to be adjusted that been specified within the program again. Looking at the upper/lower limits of data that need to be reviewed for the data ranges is the following step, see (wizard step 4-5). When the error messages in the status report wizard show green signals, that means the data have been properly input (see wizard step 6), thereafter, there is need to back again to the program interface to calculate ETo values (wizard step 1). The relevant data and the default units have to be selected or tick before portraying the evapotranspiration bar chart and reporting data process in the subsequent wizard. Finally, and after that, the ETo data report files to need to be destinated to an allocated folder, see Figure 3.11 (wizard step 7-10).



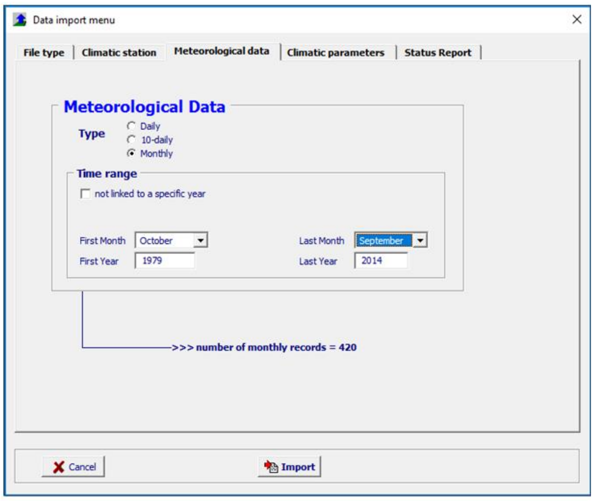
Wizard step 1



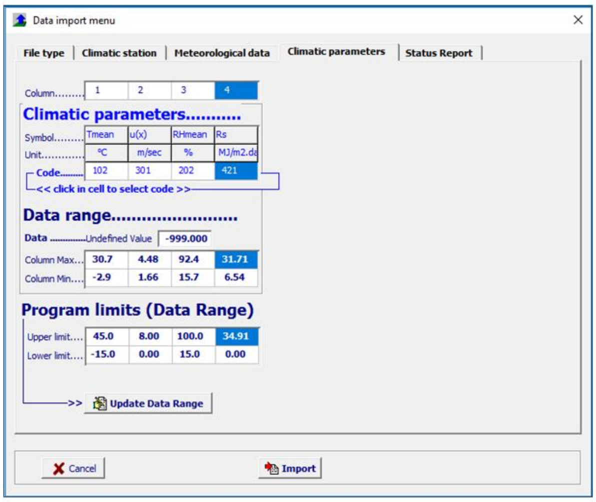
Wizard step 2



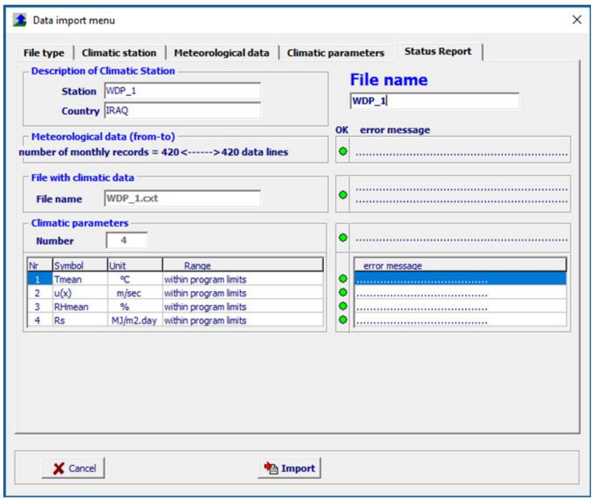
Wizard step 3



Wizard step 4

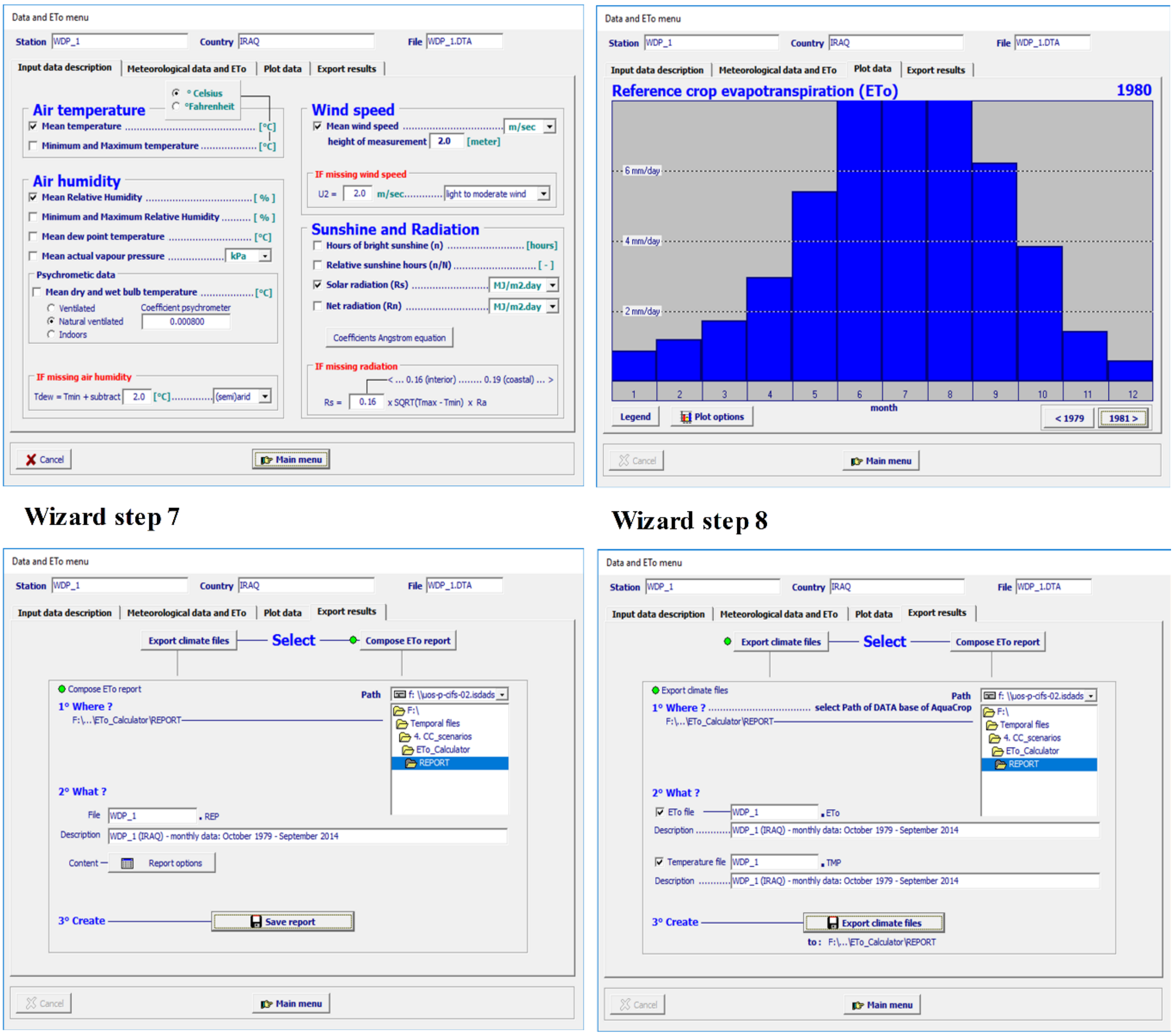


Wizard step 5



Wizard step 6

Figure 3.10 FAO-ETo tool version 3.2, PET calculation wizard steps interface (1-6)



Wizard step 7 Wizard step 8

Wizard step 9 Last wizard step

Figure 3.11 FAO-ETo tool version 3.2, PET calculation wizard steps interface (7-10)

3.12.2.2. Drought analysis

For more familiarisation with climate aspects, there is a need to investigate and discern the attributes of drought indices due to climate alteration of the study area. Drought is a multifaceted phenomenon that can be characterised mainly by its duration, severity, and areal extent. Drought severity is the principal factor amongst these three dimensions that can be used for drought analysis. To assess the severity of drought, drought indices are typically used in a meaningful way (Tigkas et al., 2015).

NCAR, (2019) defines the Standardized Precipitation Index (SPI) as a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. The SPI can be created for differing periods of 1-to-36 months, using monthly input data. For the operational community, the SPI has been recognized as the standard index that should be available worldwide for quantifying and reporting meteorological drought. Despite that, but concerns have been raised about the utility of the SPI as a measure of changes in drought associated with climate change, as it does not deal with changes in evapotranspiration.

DrinC (Drought Indices Calculator) (National Technical University of Athens, 2019) version 1.7.(90) is one of the software that determines the drought indices based on at least 30 years period of data that must be available in order to have reliable results. It is a software package that has been developed for providing a simple, though an adaptable interface for drought indices calculation.

Based on the long-term mean monthly data for both precipitations (P) and potential evapotranspiration (PET), Excel sheets were organised for the time series along 35 years starting from hydrologic year 1980 to 2014 for all the 17 meteorologic stations (MS).

Figure 3.12 depicts the windows of the processes to calculate drought index. Initially, the selected data files have been imported to DrinC software. In the first window, data files of both (P) and (PET) were defined, and also the hydrological year period, the first year of the studied time period and the beginning and last months are needed to be assigned. The next window in the same figure is showing how the ticks in the relevant boxes were selected, a single index (or all the indices at once) will be calculated. For each index, there are different output options. For the Deciles, each decile threshold may be displayed in the output file, whereas, for the Standardised Precipitation Index (SPI) each one of the different forms of the index can be selected for output. Several time steps were calculated: 3-months, 6-months, and the annual step.

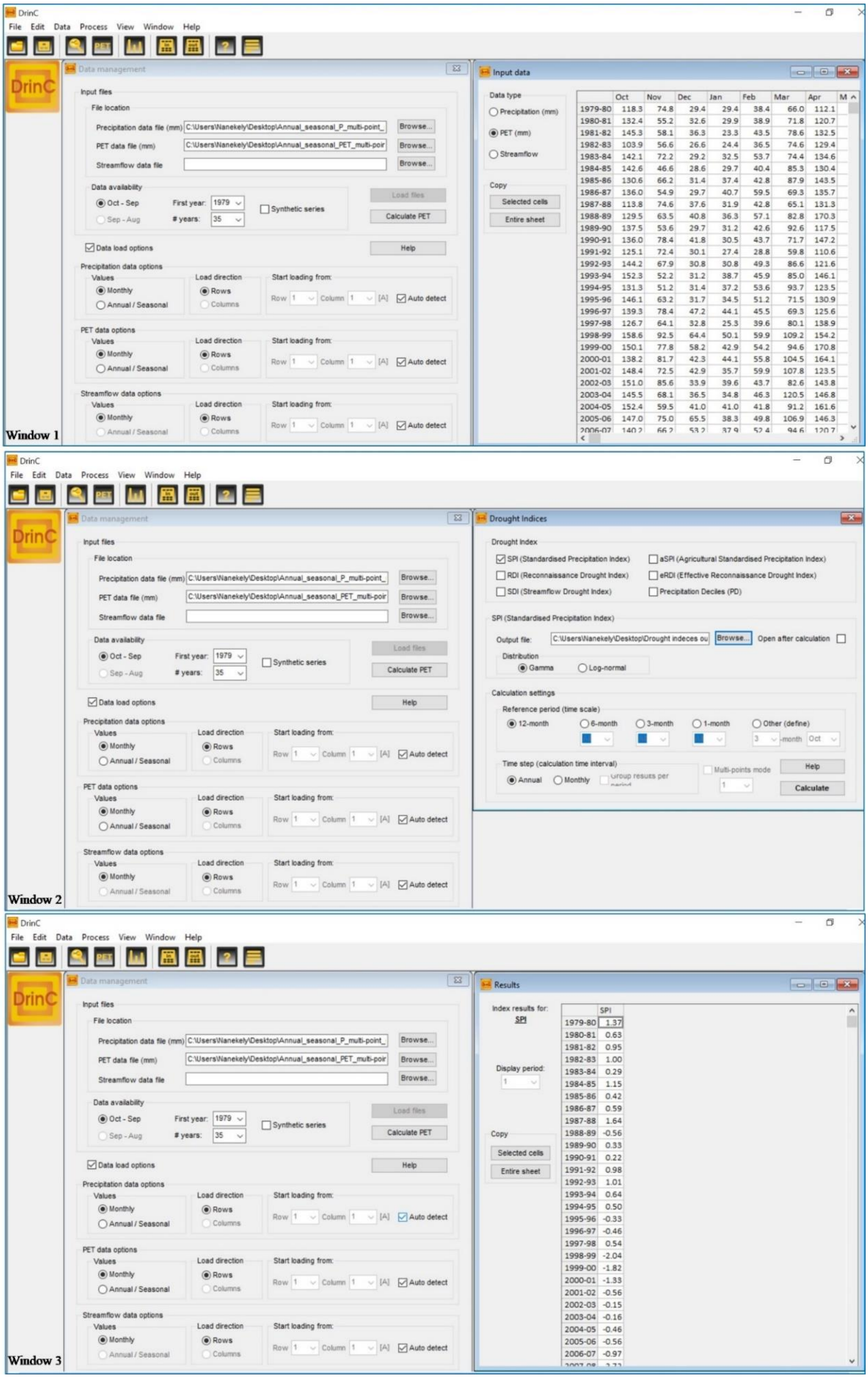


Figure 3.12 DrinC software version 1.7.(90), drought index calculation wizard steps interface

3.12.3. Groundwater data analysis

3.12.3.1. Groundwater depression analysis

Monthly records of observation wells levels have deliberately been chosen in order to represent and matches the most aquifers and soil type to represent the trend lines of water level between January 2004 and January 2016, which observed at fifty-four observation wells (Figure 3.5) in Erbil Province, and were examined to quantify the long-term gradient tendency of the groundwater level over a period of 12 years (2004–2016). The altitudes of these wells are between 258masl and 970masl and the depths of these wells are from 84m to 215m. Most of these wells are located in confined and semi-confined aquifers, and few of them are in unconfined aquifers. The Ministry of Agriculture and Water Resources (MoAWR-KRG, 2016), via the general directorate of water resources (both the affiliated directorates of irrigation management and groundwater affairs) made these data available. The groundwater level is a key parameter for evaluating spatial and temporal changes in groundwater environment and storage (Iwasaki et al., 2013). Climate change, represented by low precipitation and high-temperature rates, influences groundwater level fluctuation (Z. Chen et al., 2002, 2004). Even the confined aquifers are indirectly affected by climate alteration due to over-abstractions for over-demands, high evapotranspiration, and also human-induced factors.

Monthly readings along the twelve years have been compiled to mean annually readings, then the differences of the first and last readings were found to check whether been regressed or not, due to a large number of charts, fifty-four observation wells have deliberately been chosen to represent the trend lines of groundwater levels. They almost reflect a fair distribution and covering the entire case study area.

The data were arranged and tabulated based on what has been collected, the data are consisted of; well code and IDs, the district that the well situated, coordinates, well depth, geological formation, groundwater basin, and monthly readings of groundwater level.

The data of groundwater levels have been managed as the time series along studied period verse the depression of water in the wells, Microsoft Excel 2010 has been used to find the trend line and the regression of data. The values of trends' slope have been got, based on that a spatial distribution map of groundwater depression has been developed.

The non-parametric distribution-free Mann-Kendall (M-K) test at 5% significant level was applied to detect the long-term trend in groundwater level. The SPSS version 25 was used to carry out this analysis (Appendix D.7).

The M-K test is particularly used to check the alternative hypothesis versus the null hypothesis of no trend of the existence of monotonic decreasing or increasing trend of groundwater time series data. The non-parametric M-K test is fit for those data series where the trend might be supposed to be monotonic (i.e. mathematically, the trend either consistently decreases and never increases or consistently increases and never decreasing), and no seasonal or other cycles are present. Thus, The M-K test is commonly utilized in detecting upward or downward trends associated with the examined parameter (i.e. groundwater level) over time (Dahamsheh & Aksoy, 2007; Hussain et al., 2015; Pohlert, 2016; Seibert & Vis, 2012; H. Wu et al., 2007). However, despite the importance of groundwater to Erbil province and other areas where there is over-exploitation of groundwater, there have been insufficient measurements of groundwater fluctuations over time to properly support decision-makers and planners to sustainably manage groundwater resources (Chikodzi, 2011; M. Nanekely et al., 2017a; Tabari et al., 2012).

Appendix D.8 includes information that obtained from (MoAWR-KRG, 2016), it shows almost the total number of groundwater wells in the case study area, the number of legal wells and the purposes for which these wells are being used.

It is worthy to be known that ArcGIS software v.10.5 has also been utilised to generate spatial distribution map, which shows the long-term groundwater depletion across the studied area. The spatial analysis tool for the ordinary kriging method has also been used for the development of classified symbology maps.

3.12.3.2. Groundwater balance analysis

The groundwater storage balance is attributed to its recharge and discharge components, and can be defined as the water balance basic concept (Meyland, 2011; Scanlon et al., 2002), which is the volume of water entering a water system during a specific time period denoted as (inflow, I) subtracting the volume that leaves that water system as (outflow, O), which equals the change in the volume of water in the system (ΔS) Equation (3.24).

$$I - O = \pm \Delta S \qquad \text{………..} \; (3.24)$$

The more precise equation is the following equation that had been applied in northern Iraq for some studied basins with adequate data for balance analysis (Zoran Stevanovic & Iurkiewicz, 2009):

$$P + Sf = R + E + Q + A \pm GWR \quad \text{……….. (3.25)}$$

Where: P is precipitations, Sf signify surface flows to the basin, R is runoff and surface flow out from basin, E is evapotranspiration, Q denotes discharge of springs, A is groundwater pumping abstraction, and GWR denotes changes in groundwater reserves.

Since the study area is bounded by two rivers, the Greater Zab River to the north-southwest and the Lesser Zab River to the east-southeast (Figure 1), and based on official references both are sourcing from the outside of the studied area, and both are providing surface water and absorbing basin's groundwater, as underneath flow directions are seeps toward both, therefore, the surface runoff of rivers are not considered into the calculations, except that runoff was being triggered from rainfalls.

Effective infiltration analysis to assess aquifer status:

Effective infiltration (I_{eff}) is one of the basic hydrological parameters and the quantity of meteoric water per unit surface that annually infiltrates into the soil and recharging aquifers (Bonacci, 2001; Rossi & Donnini, 2018). Thereon, the effective infiltration approach considered as one of the techniques by which groundwater storage can be assessed and quantified.

In this case, the effective infiltration (I_{eff}) have been adopted to quantify recharge from precipitation, that is the ratio of (infiltration depth/gross precipitation) for a certain time, and based on this definition, the ranges of (I_{eff}) coeficient is between 0 and 1. It is defined by the following analytical equations (3.26):

$$I_{eff} = \frac{P_{eff}}{P_g} \times 100 \quad \text{……….. (3.26)}$$

Where: I_{eff} is Effective precipitation; P_{eff} is effective precipitation; and P_g id gross precipitation

It is worth to mention, the effective infiltration approach has limitations and might leads to uncertainty, it can be noted as; if there was a high-intensity rainfall in a specific time, the ability of soil to capture the precipitation would be less than usual that leads to less effective precipitation values, whereas, if there were no rainfall in a certain time period, the value of effective precipitation would be infinite. Thus, the more time span considered, the more reliable the results would be getting. And therefore, Equation (3.27) has been employed to minimise errors (Bonacci, 2001).

Equation (3.27) has been used to estimate the values of long-term mean seasonal effective precipitation for the whole studied area along 35 hydrologic years.

$$I_{eff} = \frac{\sum_{i=1}^{6} P_{eff}}{\sum_{i=1}^{6} P_{g}} \quad \text{……….. (3.27)}$$

Where (I_{eff}): the effective infiltration coefficient, (P_{eff}): the monthly effective precipitation, and (P_g): the gross precipitation that has fallen on the area in a specified time unit, (i): the seasonal six months' period.

Therefore, the variation of groundwater reserves are determined mainly in terms of the effective precipitation by the effective infiltration of soil cover classes corresponding to aquifers (Figure 3.13 and Figure 3.14), considering the annual character of the outcomes, all values are in 10^6 m^3/year (MCM/year).

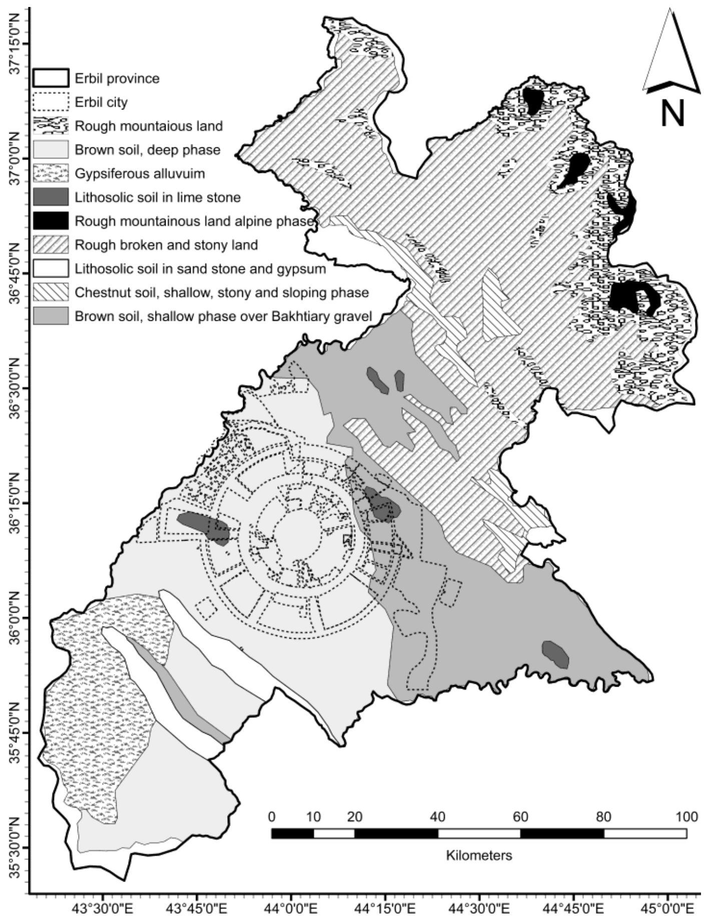


Figure 3.13 Soil cover types across the case study area

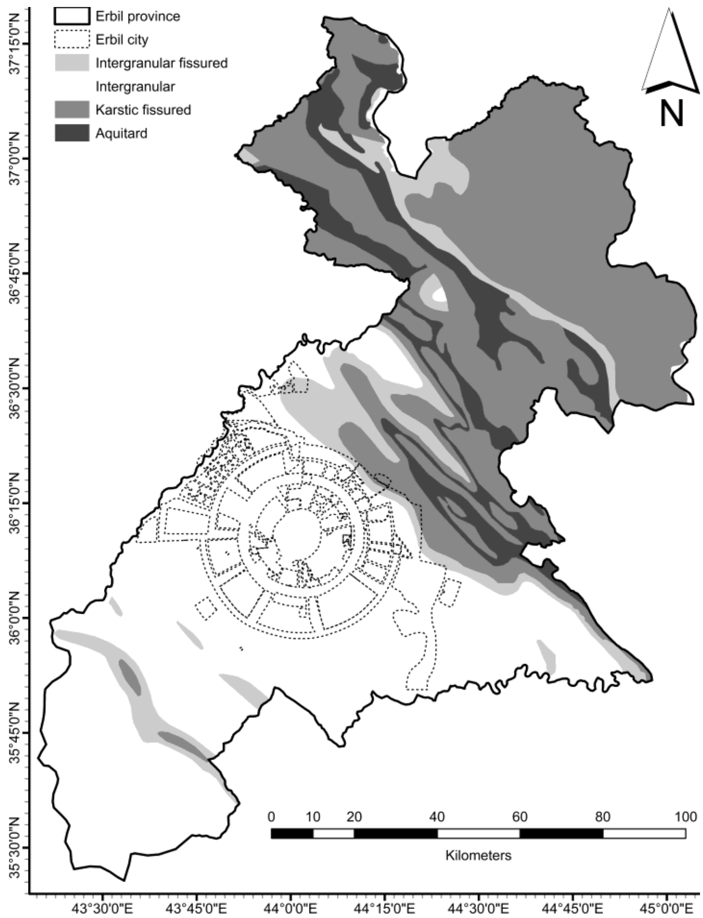


Figure 3.14 Aquifers types across the case study area

To grasp aquifers' status over the studied area for the targeted period, the groundwater recharge rates, volumes, and the permissible considered time for water extraction from wells have been calculated, see (Appendix D.9), the percentage of effective infiltration (I_{eff}) has been employed to determine those aforementioned requirements. The effective precipitation (P_{eff}) values were basically determined on the (I_{eff}) ratios for various soil classes that covering the study area, corresponding to the long-term gross seasonal precipitation (wet and dry) periods.

Different natural soil cover classes (Buringh, 1960; Hameed, 2013) have been sorted in (Appendix D.9), the areas of each soil type were determined by utilising ArcMap GIS 10.7 software (ESRI, 2019) and its shapefiles, the values of (I_{eff}) for each class have officially been obtained from the Ministry of Agriculture and Water Resources , Kurdistan Region , Iraq (MoAWR-KRG, 2016).

Long-term precipitation (LTP) and the calculated long-term potential evapotranspiration (LTPET) by using the Equation (3.3) have been tabulated and compiled in a number of spreadsheets. The monthly precipitation and potential evapotranspiration for each year and for every particular (MS) have been categorised, then the long-term monthly precipitation (P) and potential evapotranspiration (PET) have been assorted for both seasons (wet and dry).

For each soil cover type, the averages of both climate parameters (P) and (PET) were determined form the meteorological stations' data correspond to each soil class for both seasons (wet and dry), then the value of (I_{eff}) for each soil cover has been determined using Equations (3.26 and 3.27).

The aquifer formations and aquifer productivity maps helped to identify the corresponding soil classes to them (Figure 3.13, Figure 3.14, and Figure 3.15). First, the productivity of every aquifer has been set (A. I. Johnson, 1967; Lewis et al., 2006; Payne & Woessner, 2010). Following, the recharge rates in (litre per seconds), and recharge volumes for all aquifers have also been determined in million cubic metres (MCM). Later, the aquifers' statuses were assessed on condition that seasonal effective precipitation (P_{eff}) to be greater or equal than the seasonal evapotranspiration (Bonacci, 2001), see Appendix D.9 and Appendix D.10.

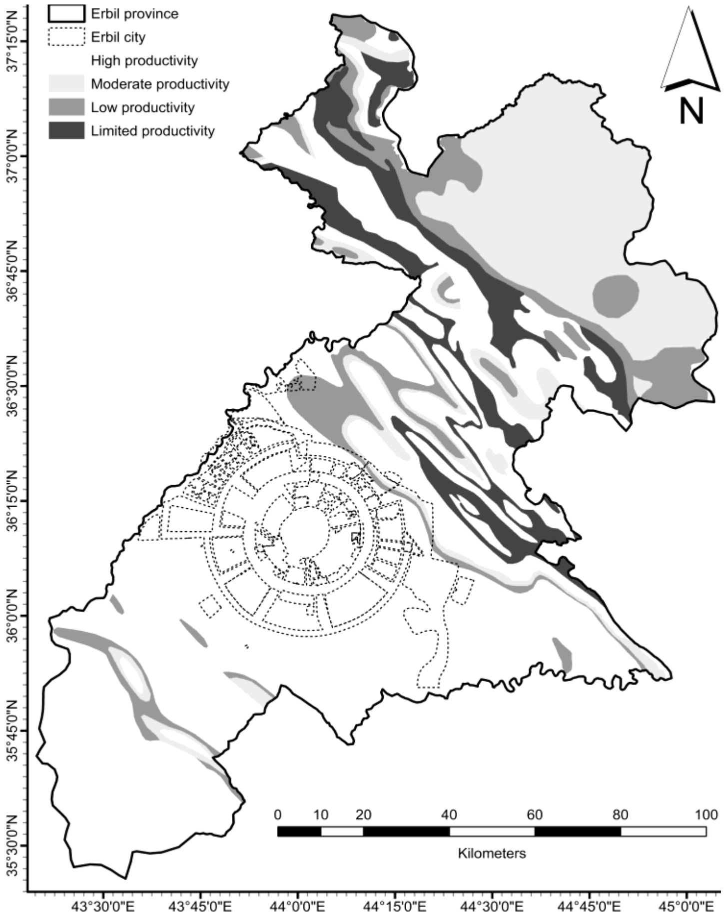


Figure 3.15 Productivity of aquifers across the case study area

To show the responses of rainfall infiltration over the studied area for the scoped time period, there is a need to look for the relation between effective precipitation and time under the impacts of climate variables**.** The mean annual precipitation (MAP) data for every meteorological station have been added to tables based on the different soil covers and the number of meteorology stations that cover the certain soil area. In the beginning, the average (MAP) was determined. Then, the effective precipitation (P_{eff}) for soil classes have been determined using Equation (3.29). Next, the average of all effective precipitations of the study area has been found verse every single water year. Lastly, the (MAP_{eff}) has been plotted as a line graph, see Figure 4.20.

Mass-Curve analysis to assess aquifer status:

Stevanovic and Iurkiewicz (2009) have critically claimed that the application of simple water balance equation is only given to the yearly disparities between balance components and groundwater level temporal falls, which results from dry spells can lead to improper inferences and might be unnecessary constraints on groundwater utilisation at certain times. Therefore, the mass curve method is preferably seen to be used. For this purpose, data in (Appendix D.10) have been set, the same procedures have been followed as in (Appendix D.9) except that the data entry was based on mean monthly precipitation to find (recharge rate and volumes) for every single year based on I_{eff}. approach as aforementioned before.

Groundwater storage change and extraction:

To estimate the safe yield and aquifers' storage capacity, there a need to find annual storage volumes. The following equation and Figure 4.21 determined the change of annual groundwater storage:

$$\Delta S_i = R_i - D_i - PET_i - Q_i \qquad \text{……….. (3.28)}$$

i = 1, 2, 3, ..., N= 35 years

The inflow is represented as R_t and outflows are represented as: (D_i), (PET_i), and (Q_i)

Where:(R_i) represents as the recharge to the basin, (D_i) is the discharge from groundwater storage to rivers, (PET_i) is the evapotranspiration, and (Q_i) is the groundwater extraction for different purposes. It is worth to mention that, in the absence of human uses of groundwater the fluxes of (R_i, D_i, and PET_i) are defined as "native fluxes", while in the presence of groundwater extraction (Q_i) by human-induced factors, it represents as "actual fluxes", the extraction flux (Q_i) is considered as the influential factor on the other fluxes (recharge, discharge, and the evapotranspiration), thus the safe yield relieson the actual flux (Heath, 2004; Loáiciga, 2017).

The actual operated well numbers and the average of water drafting volume have officially been compiled by (MoAWR-KRG, 2016), the extraction volumes have been determined for all aquifers. Further, the time-averaged extraction of groundwater, Q is given by Equation (3.29) below:

$$Q = \frac{\sum_{i=1}^{N} Q_i}{N} \qquad \text{……….. (3.29)}$$

Since lakes, wetlands and seas are not existing in this semi-arid studied area, and in-counter to the most common case studies that the recharges from rivers and streams are contributing and replenishing the groundwater. This case study is characterised by groundwater under-drains toward both the Greater Zab and Lesser Zab rivers (**Error! Reference source not found.**), and t hat has not been considered because of unavailable quantitative data, but even so, the groundwater balance assessment have been carried out based on the other available data.

Cumulative change in groundwater storage:

Turning to the cumulative groundwater storage, (Loáiciga, 2008) has stated that the cumulative annually change for long-time series in groundwater disclose the aquifer storage conditions during wet periods, and of nearly depleted aquifer storage during long droughts and abundant groundwater extraction. The cumulative annual variation in groundwater storage in year n is (V_n), see Equation (3.30), and (S_o) denotes the initial groundwater storage:

$$V_n = \sum_{i=1}^{n} \Delta S_i = S_n - S_o = \sum_{i=1}^{n} (R_i - D_i - E_i - Q_i) \qquad \text{……….. (3.30)}$$

$1 \leq n \leq N$

Adopting the time-averaged groundwater balance, it can be expressed in the common equation below (Loáiciga, 2017). Where the storage change of groundwater in the year (i) is set by Equation (3.31) and (Figure 4.22).

$$\Delta S_i = S_i - S_{i-1} \qquad \text{……….. (3.31)}$$

Storage and flux componnts herein represent the annual values of study area basinand represented in million cubic meters (MCM). Both the (S_{i-1}) and (S_i) are signify the initial and last groundwater storage of (i) years, respectively.

Where: i =1, 2,... N. The N denotes the time span years of the typical period used for assessment

Mass curve analysis:

The safe yield has been estimated by a mass curve approach using the graphic method, it relies on the whole recorded datasets. The longer the dataset, the more reliable the estimates of safe yield and storage capacity, see (Figure 4.23). The approach relies on the net recharge, which is the product of subtracting both the annual discharge and the potential evapotranspiration from annual recharge. Therefore, the cumulative net recharge is the following:

$$CR_n = \sum_{i=1}^{35} (R_i - D_i - PET_i) \qquad \text{……….. (3.32)}$$

i = 1, 2, 3, ……., N

Where, CR_n is cumulative net recharge.

The plotted vertical line distance, which intersecting tangents at high change points along the mass curve , and should be before periods of low recharge represents the estimated aquifer storage capacity. The least slope tangent line, which projects forward and intersects the mass curve is defined as the safe yield, and the slope of this tangential line is represented the annual groundwater volume that can be extracted. A tangent line that does not intersect the curve when projected forward with respect to time signifies extraction rates, which far exceed aquifer replenishment and is, accordingly, unsustainable for long-term.

3.12.4. Rainwater harvesting system data analysis

Rainwater harvesting system data have consisted of ten categories. The dataset have been managed by using Microsoft Excel spreadsheets (Microsoft Corporation, 2016), to categorise it into sub-sets and further to make analysis associated with the application of mathematical functions. Weighting process has been undertaken through: (a) data arrangement under each indicator column, (b) Along each column of dataset, the minimum value has been subtracted from the maximum value then the result divided by four, the reason behind that is to make the weighting judgment more precise by differentiating the data into intervals, (c) Every subset of data for every single indicator has been selected and given a proportional (relative) weight values, either 25% = 0.25, 50% = 0.5, 75% = 0.75, or 100% = 1.00, there has been sorted out into four intervals, (d) Later, the proportional (relative) weights have been ordered as 25%, 50%, 75%, and 100%.. Functions that have been used for this purpose were (INDEX) and (SUMPRODUCT); (e) The formula that has been used to pick out the corresponding values for every interval is illustrated in Equation (3.33), there the least subset has been given proportional weight of % 25 as it has little impact compared with the data within its set, i.e., the data which have the less values the least percentage 0.25 were given. On the other hand, the data, which have the more values the most percentage 1.00 were given.

There were exceptions, two indicators that are; construction cost and ponds area, their percentages have been taken inversely, these exceptions attribute to; whenever the cost increases the economic cost-effectiveness decrease, as for the ponds area; whenever the basin inundation area increased, legal issues will excite and raises property ownership issues, in addition to the reduction in size of agricultural lands. Table 3.1 shows an example of irrigated area indicator that consists of data from 0 to 4000 Donums[6], there the data have been divided

[6] Donum was the Ottoman unit to measure area and is equal to 2500 square metres. The unit is still in use in many areas previously ruled by the Ottomans empire.

into 4 intervals, from 0 to 1000, 1000 to 2000, 2000 to 3000, 3000 to 4000, each interval against the corresponded proportional weight.

Table 3.1 The lower and upper limits of irrigated area data ranges verse proportional weights.

Ranges		**Proportional weights**
Minimum	**Maximum**	
0	1000	0.25
1001	2000	0.5
2001	3000	0.75
3001	4000	1

SPW = INDEX (range from 0.25 to 1.00,SUMPRODUCT(--(all selected data under irrigated area column<=maximum ranges from 1000 to 4000),--(selected data under irrigated area column>= minimum ranges from 0 to 1000), ROW (number of rows to be analysed))) **……………………………………... (3.33)**

Where

SPW; is Selected proportional weights

This process has been repeated for all indicators, and hence, all were resulted proportional weights for every nominated pond inserted into corresponding table cells as shown in (Table 3.1). Thereafter, (Equation 3.33) has been used to find out the weighted score for every detention pond, i.e. each scaled weight is then multiplied by the appropriate proportional weight, giving a weighted score, and i.e. all results are out of 37. Giving scaled weights for every indicator can be differing from points of view and the aims of the study; this is true even the set of indicators is the same. Therefore, the scaling is chosen based on the essentiality and the importance of each indicator for our purpose.

Table 3.2 presents the ideal weighted score, which is equal to 37, this based on the estimated scaled weights multiplied by one as very high impact value. The table also shows the estimated weight values for all indicators. It can be seen clearly through the table that; livestock's watering, harvested water volume, irrigated area, and beneficiaries & socio-economics, are given the highest rank of the score weights, the highest weight of "5" has been considered because two of the indicators "livestock's watering, irrigated area" were the main purpose to construct the ponds. However, in the perspective of water shortages in semi-arid regions, the harvested rainwater volume plays the pivot role to grow livestock's numbers and widen the irrigated area. As a result, this causes opposite migration from urban to suburbs due to ensuring water availability, this will increase suburbs' settlements. The villagers and farmers have the interest in ranching, livestock's and agricultural investments, which will consequently improve the socio-economic situation as whole.

It is worth mentioning, that the sustainable management of water will implicitly affect the socio-economy and social situations. This especially is a fact in those areas that have critically suffered from political issues and conflicts. For instance, during the period of 1970s, 1980s and later, military actions and battles happened between the ruling power and rebels in Iraqi Kurdistan region, more than 4000 villages were destroyed. The region has experienced vast migration campaigns that displaced villagers to coercive settlement complexes in cities and urban areas (Bruinessen, 2016). The planners should take in consideration the key drivers to resettle those people into their origin places by following a sustainable manner of life. The importance of the mentioned indicators impose that they have to be prioritised first.

The potentiality of groundwater recharge in such area cannot be marginalised, it is considered as an assurance of water provision for the next generations;; that has been facing depression since last decade (Aeschbach-Hertig & Gleeson, 2012; Ebrahimi et al., 2016; Everard, 2015). Therefore, it led to consider that the groundwater issue has to be given a scaled weight of “4”.

As for the construction cost and flood risk management affairs, those two indicators can be ordered in scaled weight “3” as neutral, these two indicators have not been considered as the major objectives for the use of rainwater harvesting systems in suburbs. Despite there is still limited proofs on the effectiveness of these systems and a need to quantify their admitted benefits, i.e. in terms of flood protection and water quality among others, but also we cannot be given lowest rates of scale weights. This has been seeing in terms of the essentially of financial supports, cost-benefit considerations, in addition for tackling disasters that following flood events in semi-arid regions.

A scaled weight “3” was given to the construction cost and flood risk management indicators, as these two indicators have not been considered among the major objectives for the application of RWHS in the studied area. Despite there are still limited proofs on the effectiveness of these systems and a need to quantify their admitted benefits, i.e. in terms of flood protection and water quality among others (Perales-Momparler et al., 2016), but also we cannot be given lowest rates of scaled weights. This has been seeing in terms of the essentially of financial supports, cost-benefit considerations, in addition for tackling disasters that following flood events in semi-arid regions.

Ponds provide aesthetic worth to areas that construct in. Origin birds, migratory birds, attract hovering around ponds as well as wild animals. Studies (Barron, 2009; Bogaski, 2012) show aesthetic beauty, recreational values and biodiversity conservation are almost equal, and come to following the utilization for irrigation purposes and economy costs, therefore have given scaled weights “2” and “1”.

Economic benefits from the ponds show that benefit cost ratio in almost crops are nearly double that assert the high value in financial returns the alternate land use by cultivating grasses that have a great desire in dairy farms (Shrivastava et al., 2015).

Table 3.2 The indicators and weight sum calculation.

#	Indicators	Scale weight	Proportional (Relative) weights				Indicator Score
			low impact	**medium impact**	**high impact**	**very high impact**	
			0.25	**0.50**	**0.75**	**1.00**	
1	Construction cost	3	0	0	0	1	3
2	Pond area	3	0	0	0	1	3
3	Livestock’s watering	5	0	0	0	1	5
4	Harvested water volume	5	0	0	0	1	5
5	Irrigated area	5	0	0	0	1	5
6	Groundwater recharge	4	0	0	0	1	4
7	Flood management	4	0	0	0	1	4
8	Beneficiaries & socio-economic issue	5	0	0	0	1	5
9	Recreation	1	0	0	0	1	1
10	Biodiversity	2	0	0	0	1	2
Weighted Scores for each RWH basin							37

Likewise the climate and groundwater data analyses, ArcGIS v.10.5 was also been utilised to generate spatial distribution sets of maps, which show the variables that govern decision-making process of the RWHP spatially distributed and in differential form. The spatial analysis tool for the ordinary kriging method (ESRI, 2017; Goovaerts, 2000; Jamaludin & Suhaimi, 2013) was used for the development of classified symbology maps too, as will be presented later in subsection 4.5.1, chapter 4.

3.12.5. Statutory document review analysis

NVivo qualitative data analysis software produced by QSR International Pty Ltd. can be used for the documentation reviews (Richards, 2014). It is a software program employed for qualitative and mixed-methods research. It is used for the analyses of unstructured texts specifically. By which the qualitative data content is organised and further to analyse.

In contrast with the experimental lab tests, that are being done on quantitative data as a positivism Epistemological stance, which is called "in vitro tests", the qualitative data analyses are being conducted on the basis of "in vivo tests" as an interpretivism Epistemological stance, which there would be the interventions for the humans' perceptions. For this reason, the tool named as NVivo. It allows the reviewed documents to critically inter-linked and categorised in thematic classifications. It is a tool to manage data and find patterns within the data. However, it will not proceed with the analytical work that has to be undertaken by the researcher.

To analyse literature and transcripts, NVivo Version 12 (QSR International, 2018) has been used that made available at the University of Salford. this software can help to provide a technique, by which define codes (the attributes and relationships to be specified) and arrange data.

NVivo uses “sources” and “nodes” and the concept of "coding”. Sources are the research materials such as literature and any documents which have been relied on, these in both formats: the softcopies "as internal sources" or hardcopies "as external sources". They can include documents, PDFs, audio recordings, videos, etc. The sources used in this research were pieces of literature and legal documents relating to water resources.

Coding is the process of classifying source materials by topics and coding them in “nodes”. “Nodes” are known as ‘containers’ where codes can be stored along with the selected parts of the materials relating to a particular feature of data. Next, the data included in each node can be used to search for patterns. Once the data has been analysed, the framework matrices can be created, queries or frequency of words used in the sources. It can also create graphs, models, reports, and charts.

The first step followed was the importation of the translated selections of the legal articles and items to NVivo as internal sources. Next, nodes and sub-nodes (as tree nodes) were created. These nodes organised according to the attributes of legislations and their relationships or additional features of the Laws content. The nodes were created are to represent the attributes of legal clauses' focus points of the in-power laws. The significant parts of the clauses of the

Laws where those attributes arose were stored in the related nodes. Figure 3.16 shows an example of the nodes and coding used in the analysis.

Statutory

Name	Files	References
Reviews	0	0
Stances of the constitutions	3	5
Legal Framework	0	0
International Water Conventions and Treaties	1	1
Convention of the Use of International Watercoursesthe Law of the Use of International Wa	1	3
Ratification of The Convention to Establish the (ACSAD)	1	1
International Water Conventions and Treaties	1	1
Strategic plans	0	0
The Ministry of Water Resources Law	1	1
Regional Development Strategy for Kurdistan Region	1	1
Administrative legislations	0	0
Law of Irrigation Ministry Companies and Bodies	1	1
Law of Studies and Design Centres for Irrigation, Water and Soil Research Projects	1	1
Penal Law	1	1
Domestic concern water legislations	0	0
Public Health Law	2	3
Regulation on the maintenance of rivers and public water from pollution	2	2
Law of the General Authority for Water and Sewerage	1	1
Groundwater legislations	0	0
Instructions for groundwater well drilling	2	15
Amended Instructions of groundwater well drilling	1	2
Surface water legislations	0	0
Conserving Water Resources Regulation	2	3
Ministry of Water Resources Law	3	5
Irrigation Law	1	1
Law of Maintenance of Irrigation and Drainage Systems	1	2
Law of Beaches Utilization	1	1
Agricultural legislations	0	0
Regulation of National Determinants of Wastewater Treatment in Agricultural Irrigation	2	2
Natural Pastures Law	1	1
Law of Protection and Development of Agricultural Production	1	1
Iraqi Civil Law	1	1
Forests and Woodlots Law	2	2
Environmental legislations	0	0
Environmental Protection and Improvement Law	1	1
Kurdistan Region Environment Protection and Improvement	1	2
Inferences	0	0
Regulatory Laws	1	1
Islamic Law Related to Water Rights	1	1
Governance Power in Charge of the Management of Water Resources	4	4

Figure 3.16 Example of nodes tree and coding in NVivo 12

For each Law, a matrix was formulated in NVivo. It was composed to relate code references to each document and Article, allowing to capture the important issue arising from the references and the number of times mentioned in the legislation. The matrix composed by NVivo12 were utilised as a concept map, see Figure 5.1, which is considered as a part for the development of the sustainable water management framework.

Chapter 4: Results and Discussions

4.1. Introduction

This chapter explains the overall outcomes of the investigation and tests. Section 4.2 goes through the procedures of checking the responses of the people who attended the seminars, filled in the questionnaire and took part in face-to-face focus group discussions, then the analyses and discussions of the results follows. In section 4.3, there are illustrations in the form of figures and tables on recorded climate variables of the case study area for the scoped period from 1980 to 2014; in addition, there will be discussions on the change of different variables. While in section 4.4, there is a discussion on groundwater issues concerning the depletion and dropdown of groundwater levels, following that, section 4.5 discusses the outcomes that have been obtained on SuDS technique, which has known RWHP. Next, a review and analysis pertained to water resources legislations have been undertaken in section 4.6. Lastly, section 4.7 concludes the outcomes and their relations on implementing SuDS and suggests the technical supportive framework as the core aim of the research.

4.2. Results of strategic framework for sustainable drainage management survey

Table 4.1 shows the Pearson’s correlation coefficients between the themes. The values of the correlation coefficient fall between 0.728 and 0.967. The lowest correlation coefficient of 0.728 was observed between Theme 1 and Theme 4 shown in Figure 3.3, while the highest value of correlation coefficient 0.964 was witnessed between Theme 3 and Theme 6.

Questionnaire results reveal the following challenges to decision-making; conflicts (45.5%) > health (23.1%) > economic growth (19.8%) > social poverty (11.6%). No significant differences were observed (p-value of 0.083) between the influences of these challenges in the decision-making process, see (Figure 4.1).

Dynamic involvement of the local community in planning, decision-making and monitoring is essential. The beneficiaries (local authorities, environment agencies and local communities) should enjoy sufficient flexibility to choose the service level that responds well to their needs and capacities. Ownership or, at least, co-ownership of sustainable drainage infrastructure by the local community is crucial for long-term management in a sustainable manner. Moreover, effective participation of the local community at all age stages of a sustainable drainage project will positively contribute to a sense of ownership, helping to ensure that the services provided to the community are based on their needs, priorities and affordability.

The financial and physical influences were of similar importance, accounting for approximately 85% of the total influence on business wellness and productivity. The collective risks related to the regulation and business reputation features accounted for around 15%.

The private sector should be actively supported in initiating capacities for investment, building and coherent service delivery. Creating a public-private partnership would be effective, particularly during the initial stage, which supports the rehabilitation of the existing infrastructure, improves efficiency and service quality of utilities as well as setting-up new sustainable drainage projects.

Moreover, economic water scarcity is an outstanding issue that has to be avoided. Accordingly, there is a need for regulatory and enhancement measures to secure the proper engagement of the private sector and provide an appropriate atmosphere for safe investment. Regulations of water supply and sanitation services are dispersed between several ministries and agencies bringing challenges and difficulties associated with complex coordination mechanisms and consistency. In this regard, effort is required to introduce incentives to encourage solidarity among the various regulatory bodies with diverse responsibilities (e.g., public health management, drinking water quality and licensing of water utilities) and to advance regulatory capacity at various levels. Moreover, outdated or restrictive regulations need to be identified and updated.

Results drawn from the questionnaire (questions 3 and 6) and outcomes from discussions during workshops (academics and decision-makers) show that the construction of water and sanitation facilities contribute to an increase in work force and reduces the unemployment proportion. This is not limited to the implementation period, but further to the long-term management, operation and maintenance needs.

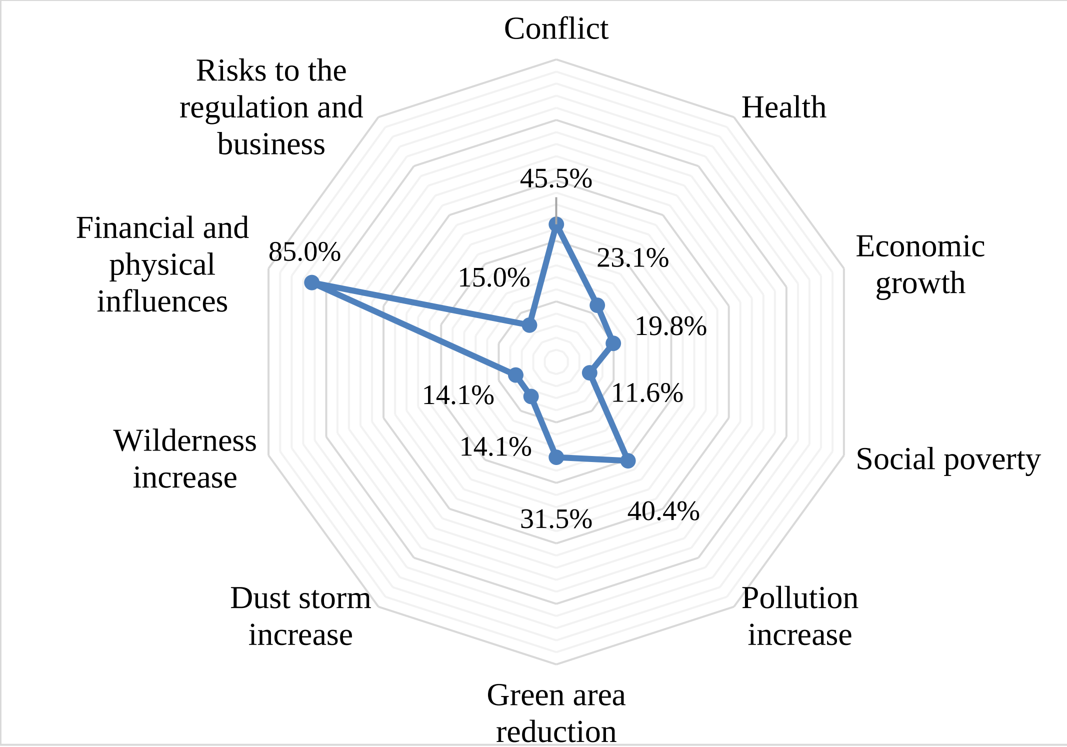


Figure 4.1 A radar decagram chart of the concerned influential factors

Table 4.1 Correlation coefficients between themes (correlations are significant at the 0.01 level)

Themes	Theme 1	Theme 2	Theme 3	Theme 4	Theme 5	Theme 6
Theme 1	1.000	0.953	0.835	0.728	0.914	0.894
Theme 2	-	1.000	0.895	0.832	0.964	0.947
Theme 3	-	-	1.000	0.890	0.920	0.967
Theme 4	-	-	-	1.000	0.908	0.882
Theme 5	-	-	-	-	1.000	0.963
Theme 6	-	-	-	-	-	1.000
Correlation is significant at the 0.01 level, P-Value ≤ 0.01 (HS), (0.05 ≥ P-Value > 0.01) (S)						

Findings also indicate that climate change will pose an enormous challenge to the current combined conventional drainage system in terms of capacity while coping with increasing runoff. Urban drainage facilities should be developed in cooperation with water resources management stakeholders and utilities, using an integrative approach. Water use should be sustainable and abide by environmental guidelines. Wastewater disposal should be planned and managed with a view to minimising environmental impact and ensuring water resources protection.

Concerning the tested environment-related issues pollution increase, green area reduction, dust storm increase and wilderness increase, the highest mark (40.4%) was associated with the increase in pollution followed by shrinkage in green areas (31.5%), while the increase in dust storm and wilderness were found to be about 14.1%. The results indicate that perceptions regarding environmental phenomena are influenced by the scarcity of water and its mismanagement. An increase of pollution is attributed to the advancement of industry and agriculture, which has led to an increase in population and the demand by most people for a higher standard of living, all triggering an increase in water consumption. At the same time, wastewater discharges also worsen the situation.

The indifference for the sustainable management of water, rainwater harvesting, the use of SuDS techniques, and source control of storm water and groundwater conservation has led to water shortages. Consequently, decreases in water supply for irrigation in agriculture have been observed.

4.3. Climate variability results

The global warming impact has become a theme of recent times. The climate has been changing overall in the world, causing changes in the climate pattern of most regions in the world. The proposed study area is considered as a part of semi-arid region now. For assessing the climate pattern and the alterations along the time series, it is necessary to examine the historical data records to investigate the weather situation in the previous period and explore the trend of records in such climate variable indices. These are required to assess the need for sustainable measures and systems, as a part of conserving the environment and human life.

The immediate objective of this section is to improve awareness of climate change for policymakers and communities and of the promising SuDS technologies that are relevant for adapting to climate change. Certainly, this awareness cannot be taken for granted; although global climatological studies predict drier and hotter climate for the region, with more frequent climatic extreme events (drought and floods), an understanding of how these macro-level trends can be interpreted at the local level is rather limited. Therefore, the specific challenges posed by climate change for the case study area, in particular for their rural communities need to be understood. Better awareness's of the expected climate change effects-decrease in rainfall, increase in temperature and evapotranspiration-are essential for planning suitable adaptation measures.

4.3.1. Precipitation and temperature assessment

The climate of Erbil province is generally characterised by a Mediterranean climate: warm and dry summers, and cold and wet winters. Precipitation usually takes place from October to May. A significant proportion (about 88%) of the annual precipitation falls between early November and late April. The dry season typically stretches from June to September. Temperature rate rises, and precipitation decreases are characteristic over the period from 1980 to 2014. Two dry periods were observed: 1999-2001 and 2007-2008. The year 2008 was found to be the driest year in terms of precipitation observed at all meteorological stations (MS).

Results revealed that the aggregated precipitation of the wet months (October–May) represents about 99% of the total annual precipitation. Accumulated precipitation of the non-rainy months (June–September) accounts for nearly 1% of the total. The aggregated precipitation of the months November–April represents approximately 88% of the total annual precipitation. The long-term minimum annual precipitation was between 31.5mm and 370.4mm. The corresponding temperature ranged from 7.4°C to 20.4°C. The long-term annual maximum precipitation ranged from 392.2mm to 1625.3mm. The temperatures were between12.1°C and 24.0°C. However, the long-term mean annual precipitations were from 201.5mm to 980.9mm. The corresponding temperatures were between 9.7°C and 22.3°C.

Figure 4.2 shows the spatial distribution of the long-term minimum annual precipitation (LTMinAP) across the study area. The long-term minimum annual precipitation varies from almost 390 mm at the most upper part of Erbil province to 40 mm at the most lower part of the province. The long-term maximum annual precipitation (LTMaxAP) ranges between nearly 1600 mm at the most upper part of Erbil province and 400 mm at the lowest part of the province (Figure 4.3). The long-term mean annual precipitation (LTMAP) extends from about 200 mm at the lowest part of the province to as much as 1050 mm at the most upper part of the province (Figure 4.4).

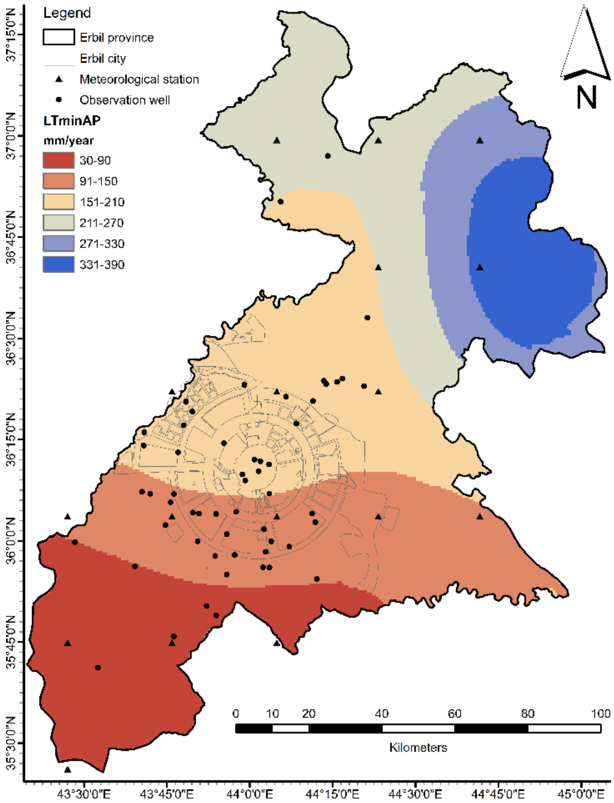


Figure 4.2 Spatial distribution of the (LTminAP)

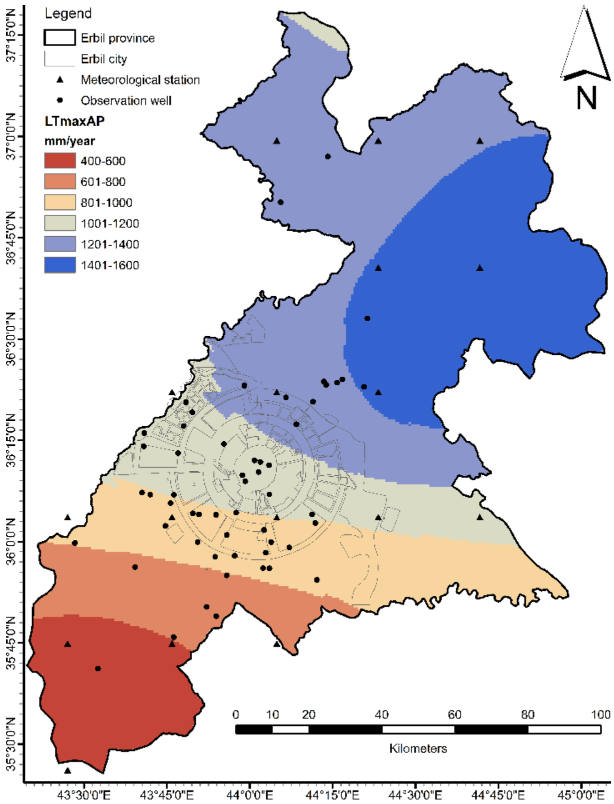


Figure 4.3 Spatial distribution of the (LTmaxAP)

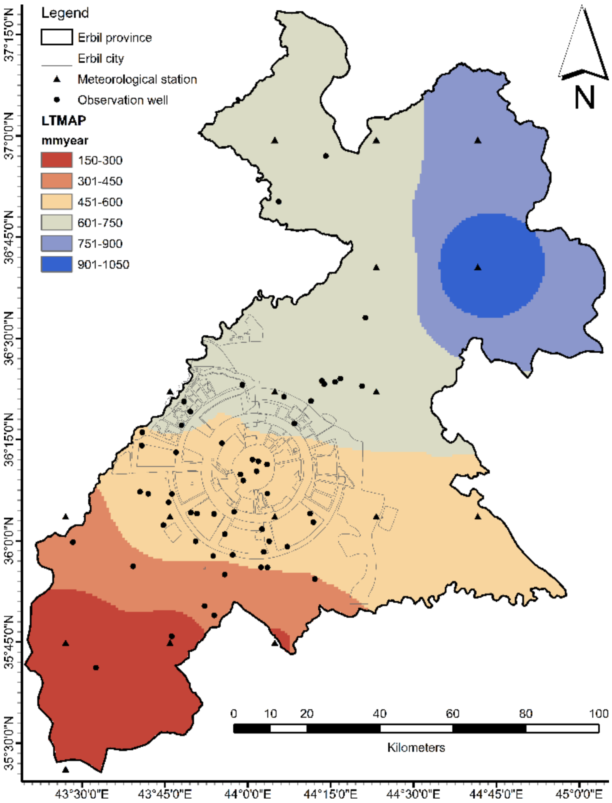


Figure 4.4 Spatial distribution of the (LTMAP)

The range of the long-term minimum (LTMinAT) and maximum annual temperatures (LTMaxAT) are almost between 7.5°C and 20.0°C (Figure 4.5) and between 12.0°C and 24.0°C (Figure 4.6), respectively. The long-term mean annual temperature (LTMAT) ranged nearly between 10.5°C and 22.0°C (Figure 4.7).

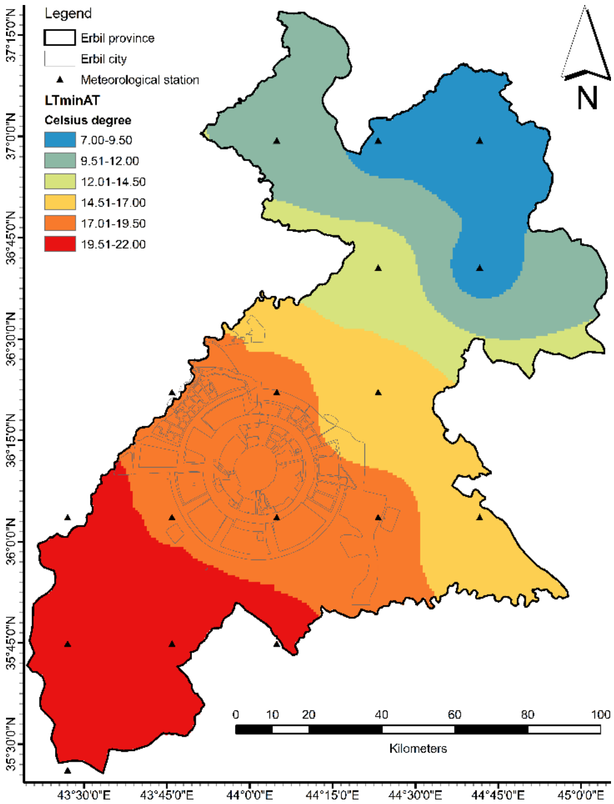


Figure 4.5 Spatial distribution of the (LTminAT)

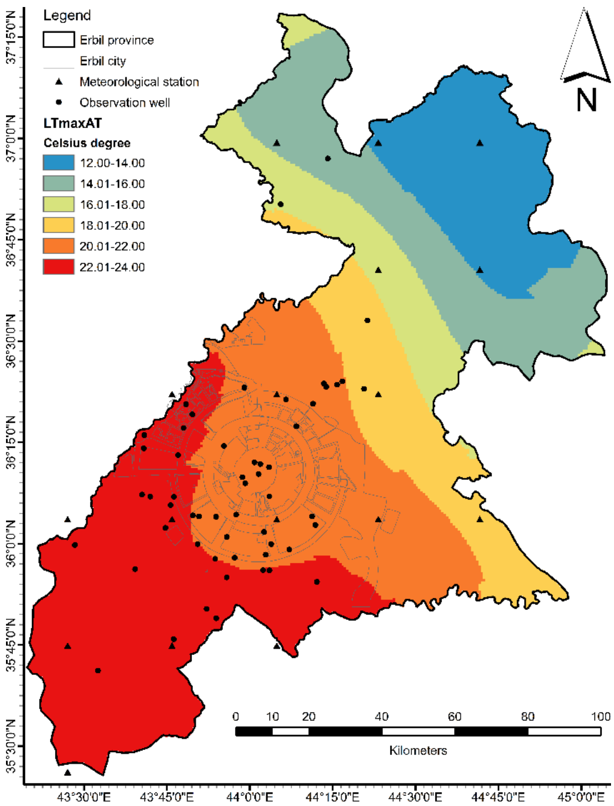


Figure 4.6 Spatial distribution of the (LTmaxAT)

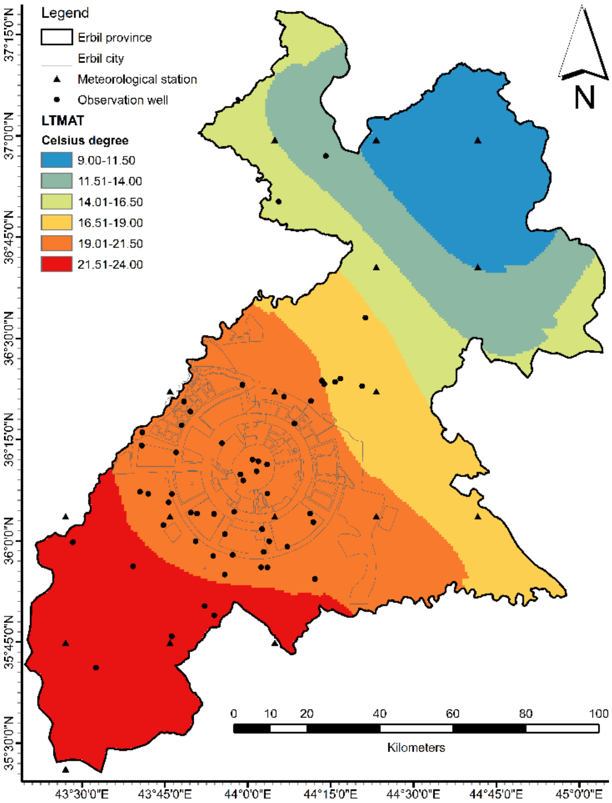


Figure 4.7 Spatial distribution of the (LTMAT)

However, Figure 4.8 depicts the variations in annual precipitation and mean annual temperature between 1980 and 2014 at the seventeen (MS)s. Relatively wet periods were observed from 1992 to 1998 and from 2011 to 2014. Significant reductions in precipitation were noticed between 1999 and 2001, and between 2007 and 2008. The minimum annual temperature was observed for 1992 at all stations, while the maximum annual temperature was recorded in 2010 at all stations except for station 2, where the maximum annual temperature was noted in 2014, and at station 4 in 2013. However, higher temperature rates were recorded between 2000 and 2010. An overall precipitation-downward trend and temperature upward tendency were perceived at all stations in Erbil province. This suggests that Erbil province tends to be drier and warmer and is vulnerable to drought.

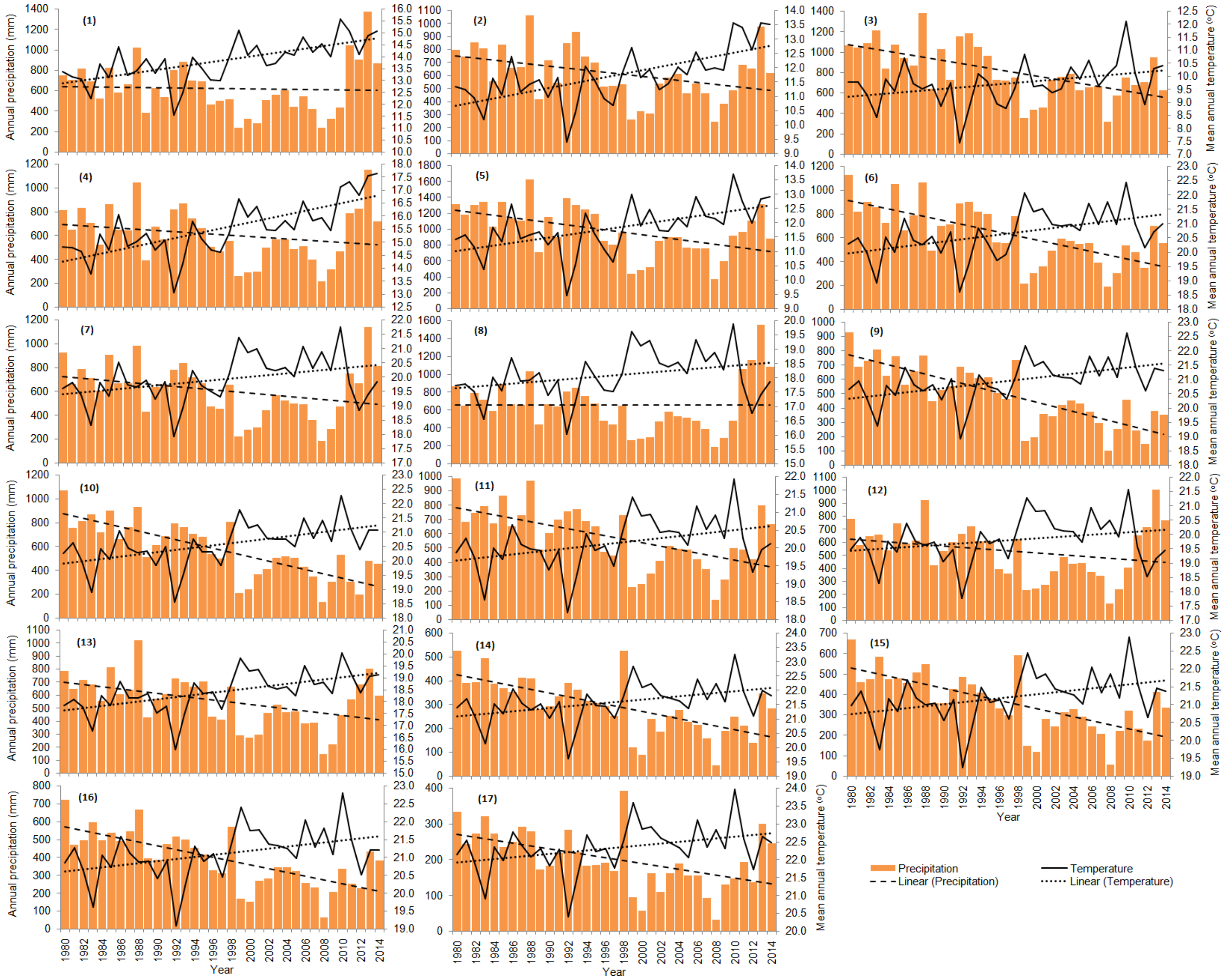


Figure 4.8 Boxplot of LTMAP and LTMAT at 17 meteorological stations (MS)s

4.3.2. Potential evapotranspiration assessment

The calculated long-term minimum, maximum, and mean annual precipitation, temperature, and potential evapotranspiration are presented in (Appendix D.1). The long-term minimum annual potential evapotranspiration rates were found to be between 1098mm and 1443mm with a mean of 1295mm and a standard deviation of 72.0mm. Whereas, the corresponding maximum and mean values ranged from 1986mm to 2347mm with a mean of 2145mm and a standard deviation of 88.0mm, and between 1614mm and 1995mm with a mean of 1795mm and a standard deviation of 98.0mm, respectively.

Figure 4.9 portrays the long-term mean monthly precipitation (P), long-term mean monthly potential evapotranspiration (PET), and the long-term mean monthly deficit and surplus for all the (MS)s. The northern and the mid parts (mountainous and plateaus lands) of the study area where (MS1 to MS13) are located associated with a high amount of precipitation from November up to the mid of March, whereas the southern part (plain area) of the study area where covered by (MS14 to MS17) is linked to high-temperature and less precipitation coupled with frequent drought episodes, where more water needed for multiple purposes uses.

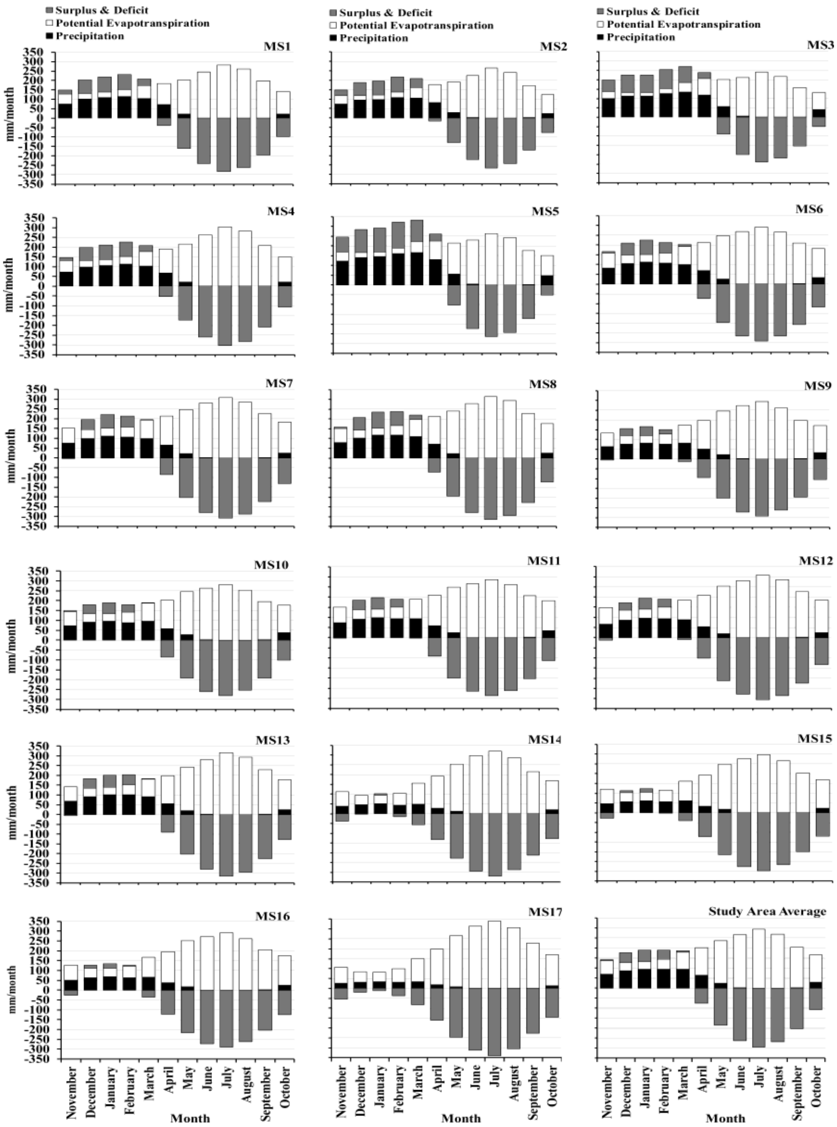


Figure 4.9 Boxplot of LTMMP and LTMMPET for the 17 (MS)s.

Table 4.2 and Figure 4.10 show the average monthly areal precipitation (P) values and (PET) for all stations across the area. The value of (P) ranged between 0.06mm that observed in July and 94.7mm noticed in February with an average of 46.60 mm and standard deviation (S.Dev) of 41.02mm. Concerning the PET, the corresponding values are 36.18 mm observed in January, 293.97 mm noted in July with an average of 149.70mm and S.Dev. of 95.97mm. The months November to March are associated with surplus whereas deficit is linked to all other months. Figure 4.11 illustrates the long-term mean monthly potential evapotranspiration, it depicts that the months of June, July, and August have been recognized as that vast amounts of evapotranspiration lose in their periods, in reverse with months of December, January, and February. Whereas, Figure 4.12 demonstrates the long-term mean annual potential evapotranspiration and mean annual precipitation of all stations along with depicting the meteorological stations in different areas. As it is clear that the mountainous areas which covered by MS1-MS5 receive more precipitation joined with less evapotranspiration, in contrast with plain areas, which found that had less precipitation and lost an abundant amount of evapotranspiration.

Table 4.2 LTMMP, LTMMPET and water status for the period (1980-2014)

Month	P (mm)	PET (mm)	Difference	Status
November	70.11	67.07	-3.04	Surplus
December	87.74	39.86	-47.88	Surplus
January	94.24	36.18	-58.06	Surplus
February	94.71	48.32	-46.39	Surplus
March	93.15	86.75	-6.40	Surplus
April	63.14	137.98	74.84	Deficit
May	25.29	211.18	185.89	Deficit
June	1.37	264.95	263.58	Deficit
July	0.06	293.97	293.91	Deficit
August	0.10	268.85	268.75	Deficit
September	1.16	203.76	202.60	Deficit
October	28.11	137.42	109.31	Deficit
Mean	46.60	149.69	103.09	Deficit
S. Dev.	41.02	95.97	135.37	
Min	0.06	36.18	-58.06	
Max	94.71	293.97	293.91	

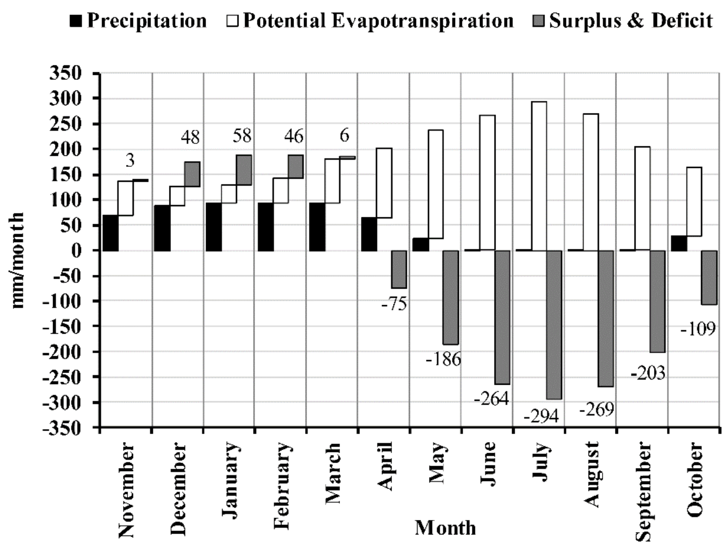


Figure 4.10 The LTMMP and LTMMPET and water status

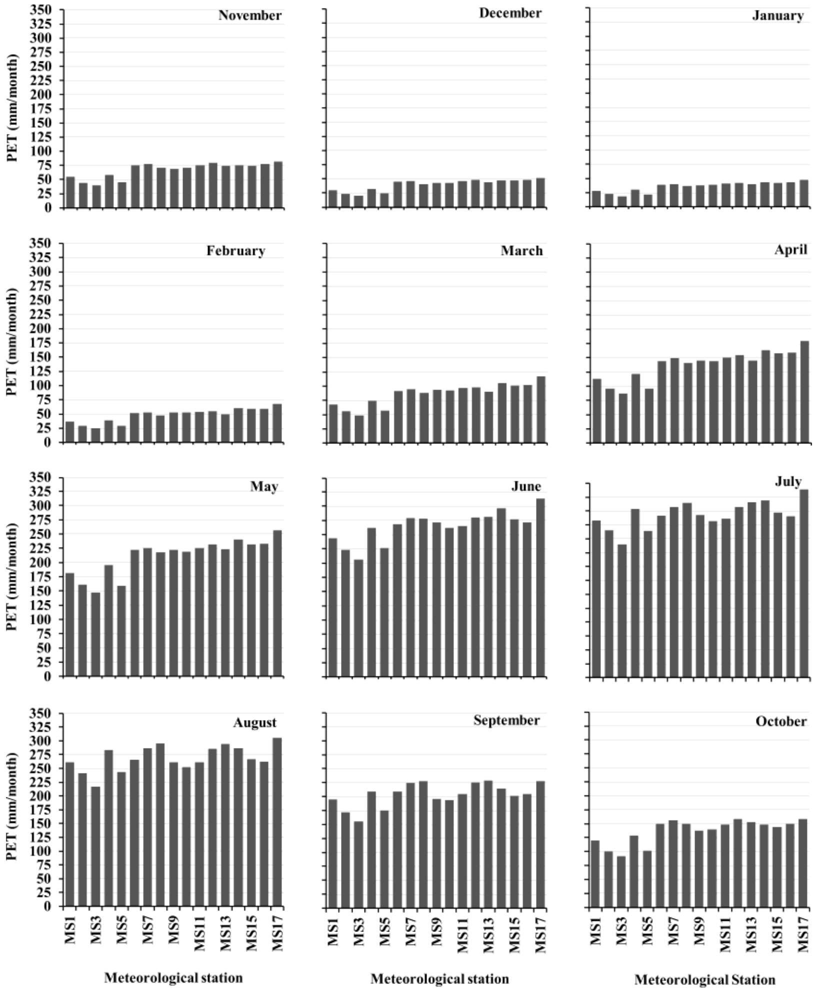


Figure 4.11 The (LTMMPET) of 17 (MS)s

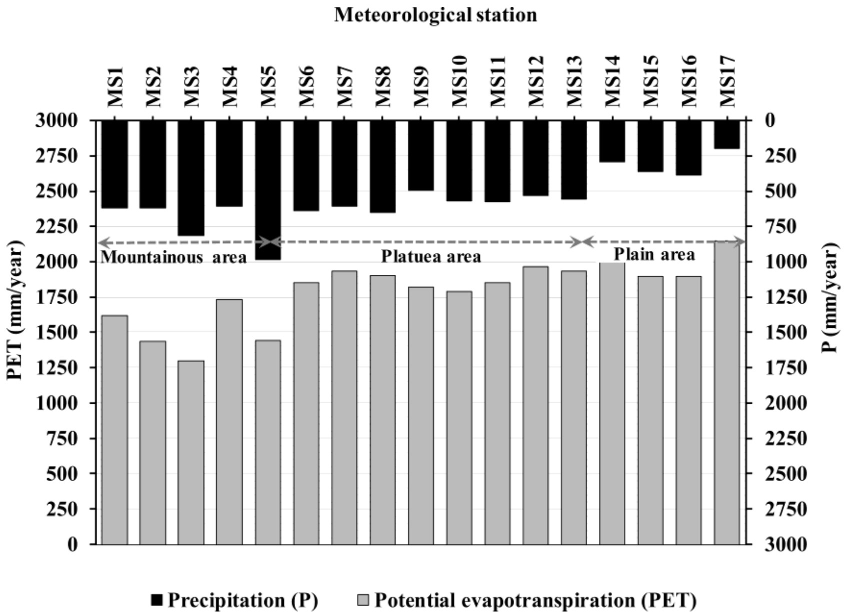


Figure 4.12 (LTMAPET) and (LTMAP) of 17 (MS)s

Figure 4.13 suggested that considerably high PET values are associated with three consecutive years (1999, 2000, and 2001) just under 2000mm/year, whereas notably low PET values are linked to the years 1983 and 2013that is a bit over 1600mm/year. A significant increase is detected of PET between 1992 of about 1663mm and 1999 of approximately 1995mm. The years between 1999 and 2005 shows a notable decline in PET values from 1995mm to 1818mm. Remarkable drop is observed between 2010 and 2013 as the PET value dropped from about 1930mm in 2010 to nearly 1600mm. High PET values between 1925mm and almost 1950mm are also noticed in the years 2006, 2008, and 2010. As all, the trend line gives an indication that the studied area had been passing through steps up increments in evapotranspiration by almost 2.5mm/year, which has adverse impacts on water reserves in soil cover and sub-soil, besides, even the excessive water demands by crops.

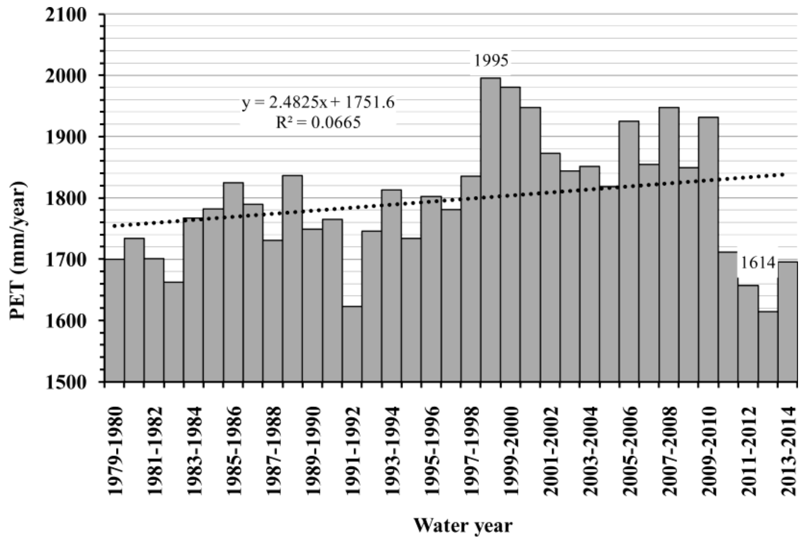


Figure 4.13 The (LTMAPET) over the study area with trend line (1980-2014)

Figure 4.14 shows the monthly variation of potential evapotranspiration (PET) rates. For the July records, the highest value of evapotranspiration was recorded for all 17 (MS)s across the case study area, while the minimum value in the northern mountainous part attributes to December, whereas, in the mid plateau and south steppe parts, January had the lowest record. However, the studied area had the lowest annual record of 2000 mm evapotranspiration. Just after the period 1998–1999; this area had experienced a severe drought, hitting a maximum record of 2347 mm evapotranspiration along the study period, see (

Figure 4.15).

Figure 4.16, Figure 4.17, and Figure 4.18 portray the spatially distribution of PET rates along the scoped time period for the studied area of minimum annual PET, maximum annual PET, and mean annual PET, respectively.

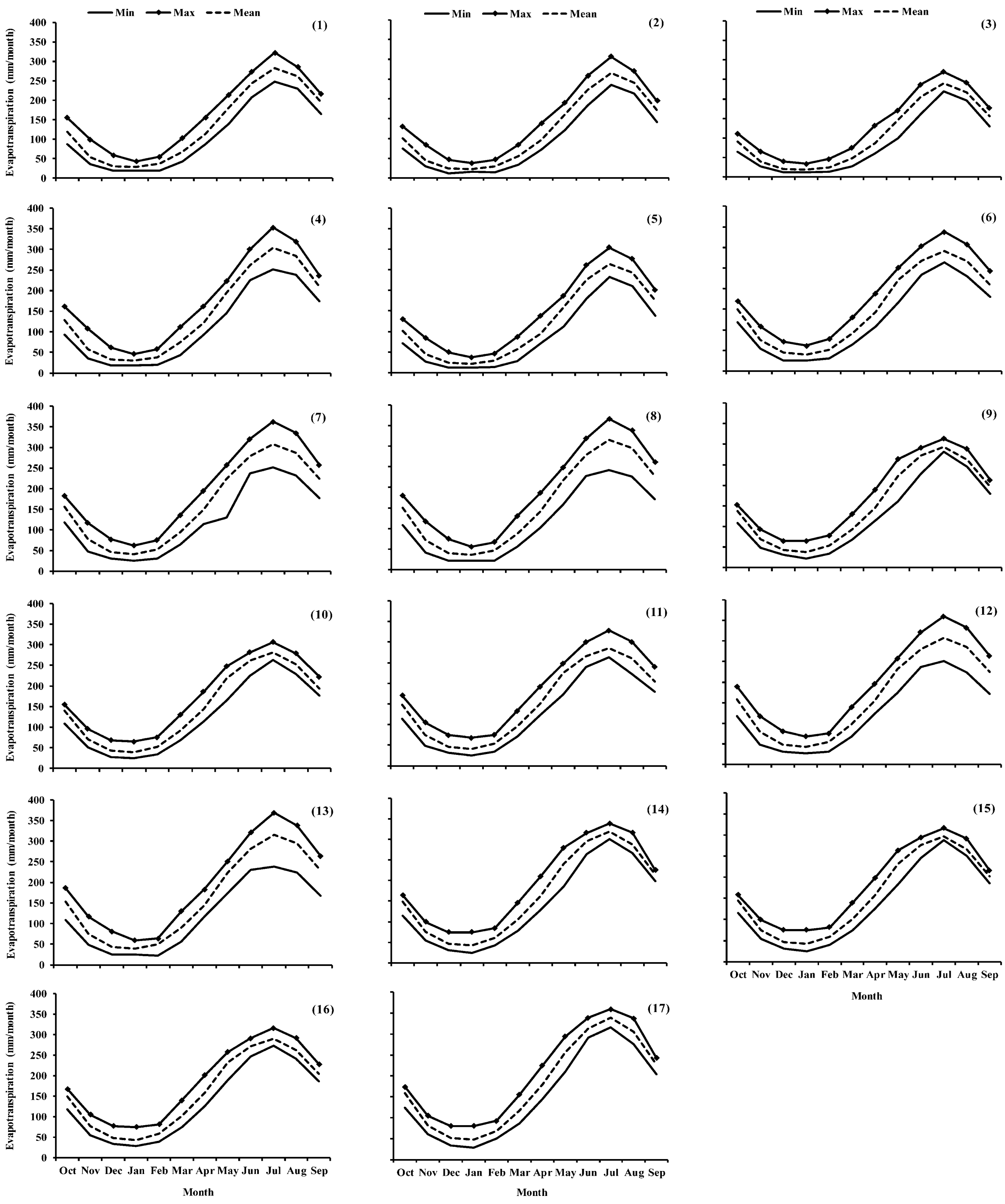


Figure 4.14 Boxplot of monthly variation of potential evapotranspiration (PET)

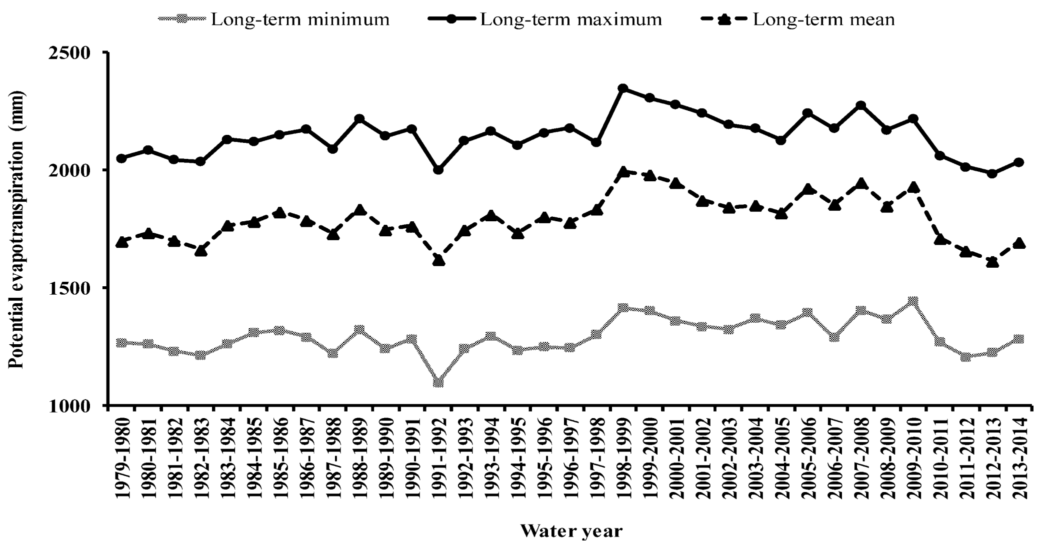


Figure 4.15 Long-term potential evapotranspiration rates for water

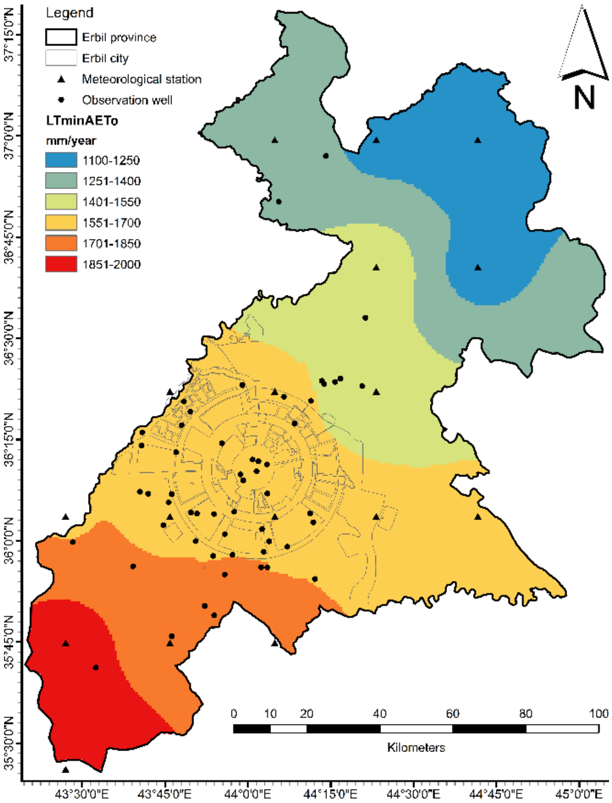


Figure 4.16 Spatial distribution of (LTminAPET)

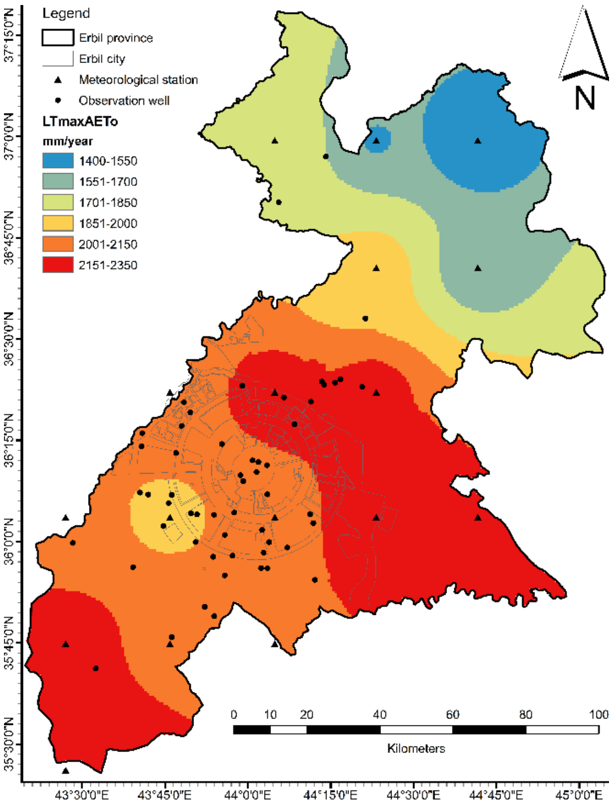


Figure 4.17 Spatial distribution of (LTmaxAPET)

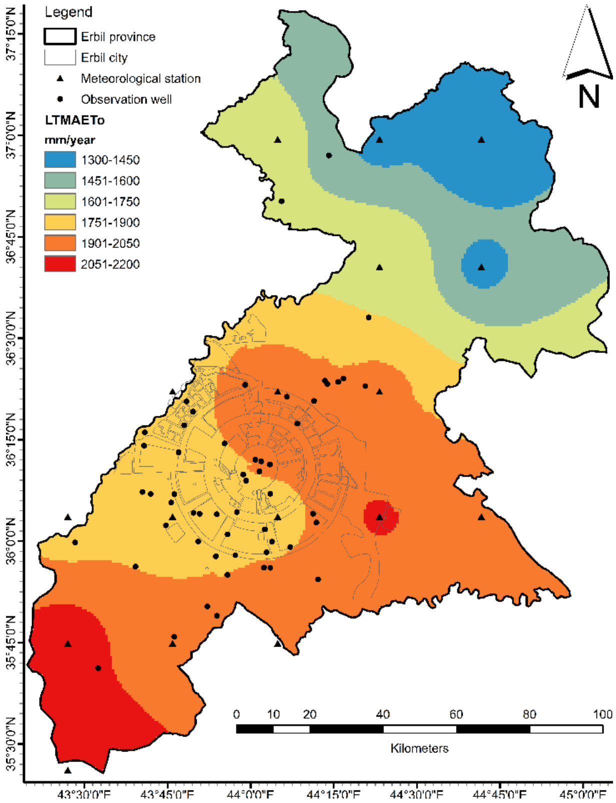


Figure 4.18 Spatial distribution of (LTMAPET).

4.3.3. Drought index assessment

For assessing the climate class and water availability in the studied area, the Aridity Index (AI) is perceived to be needed and has been adopted. It is defined as a bioclimatic index, as it considers both physical phenomena (precipitation and evapotranspiration) and biological processes (plant transpiration). Moreover, the index represents one of the most relevant indicators for studying desertification processes (Colantoni et al., 2015; Hussien & Fayyadh, 2013). The Aridity Indices (AI) have been determined based on the gathered data, as it is a well-known method for quantifying the differences between rainfall contributions and water demand which, through the formula adopted by FAO[7], UNEP[8], and UNCCD[9], represents a simple but powerful tool for scientific study, territorial observation and classification. The Aridity Index is a result of dividing the total annual precipitation (P) by the annual potential evapotranspiration (PET), Equation (4.1):

$$\mathrm{AI} = \frac{\mathrm{P}}{\mathrm{PET}} \qquad \text{……….. (4.1)}$$

[7]Food and Agriculture Organization (http://www.fao.org/).
[8]United Nations Environment Programme (http://www.unep.org/).
[9]United Nations Convention to Combat Desertification (http://www.unccd.int/main.php).

There are different classes of aridity, according to the classification of the Union Nation Environmental Program (Middleton & Thomas, 1992; UNEP, 1991), the (AI) values below 0.5 define the arid or semi-arid areas, whilst the values over 0.65 represent the humid and hyper-humid zones, as shown in the following Table 4.3:

Table 4.3 Climate zone classification (Thomas & Middleton, 1997; UNEP, 1991)

Zone	Precipitation / Evapotranspiration(P/PET)
Hyper-arid	< 0.05
Arid	0.05 – 0.20
Semi-arid	0.20 – 0.50
Dry sub-humid	0.51 – 0.65
Moist sub-humid and humid	> 0.65

In (Appendix D.4), the data of 35 hydrological years have been tabulated, the mean annual precipitation and the potential evapotranspiration, further, the annual, the decadal, and the long-term aridity indices and classifications corresponding to each one. The annual index analyses show that the area has mostly been being classed as semi-arid, except the years 1988 and 2013 were wet, both three consecutive years of (1999-2001) and (2007-2009) were subjected to intense drought periods, that is, the area was tending to change to be an arid zone, whereas based on the decadal index analysis, the years of the 2000s' were classed as arid period. The long-term (AI) was being (0.311), which limited the recharge of groundwater in the area, which caused moisture loss and contributed to drought condition, as a consequence, it reflected drought crisis that affecting negatively on the recharge of groundwater.

Table 4.4 shows the drought severity analysis according to the Standardised Precipitation Index (SPI) values for the period 1980 to 2014 (35 years). Results of the 12-month SPI show that moderate to severe dry was linked to 20% of the total period (35 years). 18 % of the total period was associated with moderate to very wet condition. The nearly normal condition was linked to 62% of the entire period. The corresponding percentages for the 6-month SPI are 13%, 9%, and 78%, respectively. With respect to the 3-month SPI, the moderately dry condition was associated with 6%, the moderately wet was linked to 9% and the nearly normal condition to 85% of the whole period. Results presented in this table are impressively close to the outcomes of the analysis carried out by UNESCO in 2014 (Lück et al., 2014).

Table 4.4 Distribution of drought severity (%)

Severity	Percentage of drought severity (%) over 35 years		
	3-month SPI	**6-month SPI**	**12-month SPI**
Near Normal (NN)	85	78	62
Moderately dry (MD)	6	9	10
Moderately wet (MW)	9	6	12
Very wet (VW)	/	3	6
Severely dry (SD)	/	4	10
Total	**100**	**100**	**100**

Figure 4.19 and (Appendices D.5 & D.6) are demonstrating the climate conditions along the period that has been studied, it displays that the years' condition was largely normally distributed and there were 8, 21 and 6 years assigned as wet, normal, and dry, respectively.

It is worth mentioning that the lowest annual precipitation of 163mm was recorded in 2008, accounting for about 29% of the long-term average annual precipitation. The years 1999, 2000 and 2009 were associated with considerably lower precipitation than what can be considered as average: 36%, 42% and 53%, respectively.

Correspondingly, the weather condition for each year has also been calculated based on the amount of rainfall as the upper and lower thresholds approach (Furat A. M. Al-Faraj & Al-Dabbagh, 2015; Furat A.M. Al-Faraj & Scholz, 2014), which are: (Mean value + 0.75 of standard deviation) and (Mean value - 0.75 of standard deviation). In general, results indicate that the normal condition was associated with 60% of the water years, and 23% were wet years, while the remaining 17% were dry years.

In either case, it seems that the upper and lower thresholds approach of climate condition distributions is most likely similar to the 12-months SPI.

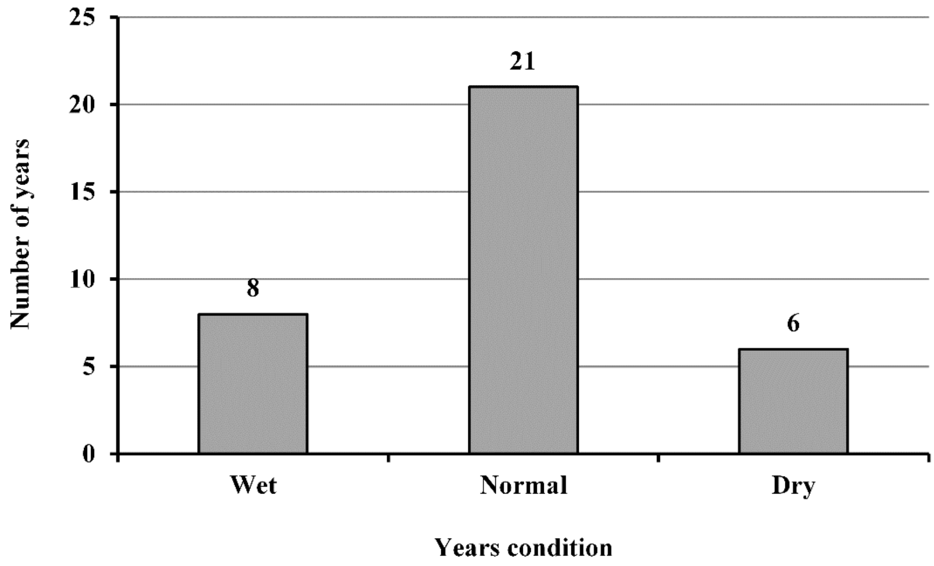


Figure 4.19 Climate condition distribution over the last 35 years

4.4. Results obtained from the groundwater study

4.4.1. Surveyed data on groundwater issues

The qualitative survey reveals that the heavy withdrawals of groundwater for agriculture and drinking water production have caused a notable decline in groundwater levels associated with negative economic and environmental consequences. Short-term or seasonal rainfall and higher temperatures in summer together with a lack of surface water resources has forced individual farmers and households to mainly rely on groundwater resources with extensive drilling programmes, which resulted in a considerable drop in groundwater levels. This corresponds to the results shown in (Appendix D.7 and D.11). Information and data drawn from discussions with the MoAWR-KRG staff and local communities indicated that more drilling activities have increased the cost of pumping as farmers deepen their wells by re-drilling alternative contiguous wells to reach falling water tables. The estimated cost of drilling is 40- 50$/m depth (casing included) for intergranular formations (unconsolidated deposits) of up to 450 m in depth, 55 60$/m (casing included) for intergranular fissured formations (consolidated deposits) of up to 280 m in depth, and 70-80$/m (casing excluded-open hole) for Karstified formations of up to 180 m in depth (see Figure 3.8 b) for corresponding formations. The cost depends mainly on soil type, type of drilling equipment such as rotary or hammer, the type of well casing and the drilling depth. In addition, both the increased cost of pumping and drying up of a notable number of wells has adversely impacted on the socio-economic condition, particularly of the small-holder farms. Official correspondences pointed out that the temporal economic growth in Iraq after 2003 has notably increased the number of smallholdings in the countryside and outskirts of towns. People in Erbil and other provinces tend to spend at least the weekend in the countryside, which caused urban sprawl in terms of housing developments, increased farming practices and illegal drilling of private wells. Unstable political and security conditions coupled with insufficient financial provisions and the inability of enforcement of civil actions to appropriately implement laws has exacerbated the random development and increased the non-rational abstraction of groundwater.

Information compiled through a series of meetings with the MoAWR-KRG staff and from the interviews of smallholding owners in 2018 mentioned that the region has been facing frequent dry spells because of climate change (see, Figure 4.8) reduced precipitation and increased temperature), which elevated the reliability on groundwater to meet the increased water demands. Inconsistency in managing groundwater aquifers, lack of integrated management of groundwater resources, and absence of groundwater withdrawal monitoring system has exacerbated the non-rationality of using groundwater.

4.4.2. Groundwater balance result

Appendix D.9 includes data on resulting-in the overall aquifer status along thirty-five years of the study area for the scope targeted period from 1980 to 2014, these were the base for the calculations of net recharges. However, the negative values of recharge rate and volumes do not have physical meanings, that is why negative results in the table were set to zero for all calculations. Only the (Rough mountainous land, alpine phase), and (Rough mountainous land) with their corresponded aquifers were safe along the studied period. Whereas the other aquifers were not safe in most of the years for water drafting and provision. The area experienced a number of drought episodes. Also, the permissible well numbers that had to be operated has been calculated, that is based on the ratio of recharge rate to the productivity of each aquifer.

It can be noticed as an average of the long-term, that out of 15089 km^2 area, only 1425 km^2 was safe to draft groundwater, which is located in the mountainous areas on karst aquifers and also allows only 1203 wells to be operated, and not exceed a volume of just 76 MCM per annum. This indicates that as per that climate conditions of the targeted period, there was a restricted volume of groundwater reserves that should utilise as per robust water resources planning.

Figure 4.20 portrays the relation between long-term effective precipitation (LTPeff) verse the time series of the studied area. The correlation coefficient of (r = -0.45) shows a dispersed regression over time. That is a clear and simple line graph showing dramatically fluctuated downward and deescalating trend of effective precipitation, further, there were significant sharp drops in the hydrologic years (1989, 1998, and 2008). It is notable that there was an almost four-fold difference between the wettest and the driest years 1988 and 1999 respectively. In recent years, its experienced recovery due to climate variability. The overall trend indicates that climate change had an influential impact on. It is worth mentioning; in cases that the decrease in received effective precipitation joined with excessive groundwater abstractions due to pressing needs, indeed that exacerbates the situation more.

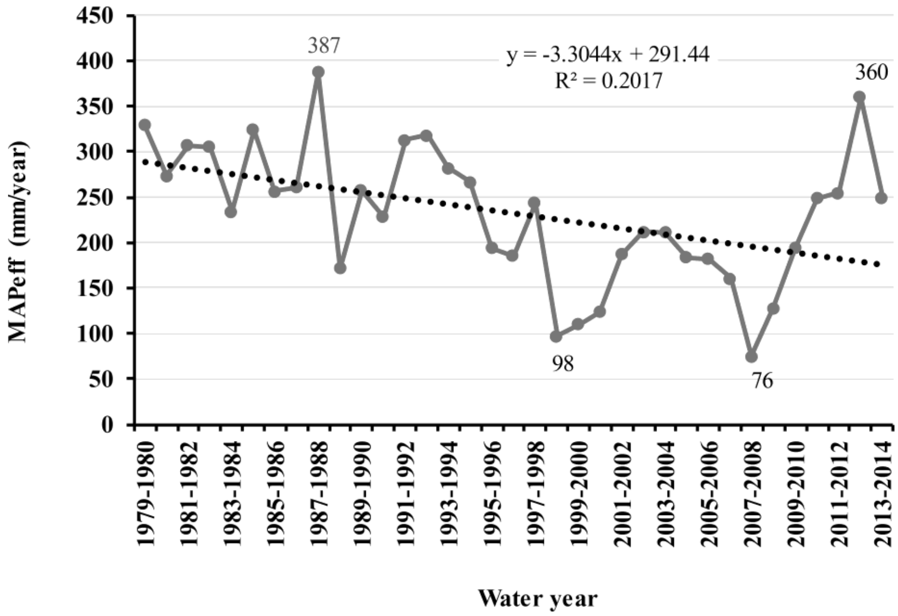


Figure 4.20 Long-term annual effective precipitation and trendline

Appendix D.10 is a sample calculation for the hydrologic year 2013-2014, the mean monthly precipitation (MMP), evapotranspiration (MMPET), and seasonal effective precipitation (P_{eff}) were the base data on resulting-in recharge volume, recharge rate, and aquifers' status. The results of recharge volume for each hydrologic year were compiled in different tables to draw (Figure 4.21, Figure 4.22, Figure 4.23). The Karst fissured aquifers that corresponded to the (Rough mountainous land, alpine phase), (Rough mountainous land), and (Rough broken and stony land) were safe. Whereas the other aquifers were not safe in most of the years for water drafting and provision.

It can be noticed as an average of the long-term, that out of 15089 km^2 area, only 5618 km^2 was safe to utilise for groundwater drafting, which is located in the mountainous areas on Karst aquifers. Additionally, only 6283 wells were permissible to extract water in (2013-2014), but the long-term average was 5890 wells that to be operated, and not exceed drafting volume of just 256MCM per annum as an average of the long-term. There are two result indications: First, the more time-scale basis shorter (monthly instead of annual), the more the reliable results are, and the second, solid and sustainable groundwater management is needed to conserve the storage volume per year.

Figure 4.21 depicts the fluxes: recharge, extraction, storage volumes, and the trend line over the time series from 1980 through 2014 in Erbil's aquifers. (Noting that available extraction data were from 2004 to 2016). It is seen that there was significant inconsistency in recharge quantities (the grey line) along the studies period, noting that the area has been passed through a number of dry spells in 1999 and 2008, that the replenishment was almost non-existent. The coefficient of correlation (r = -0.242) is representing the dotted line of downward regression trend because of fluctuation in values.

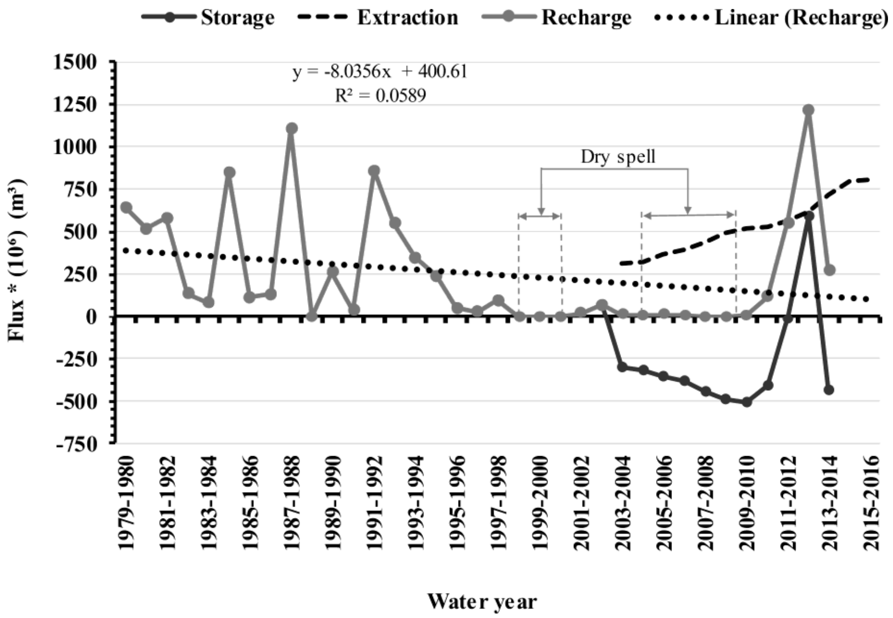


Figure 4.21 Line graphs of the annual fluxes along the study period

The dashed line graph represents groundwater extraction; it indicates a steady upward trend with time and along with the reported data of extraction. The groundwater extraction hit a maximum of 805 MCM; it shows a dramatic and remarkable difference with recharge volume that was being percolated of about 259 MCM as the average for long-term. Simply stating, it has been notoriously indicated that the over-abstraction of groundwater is referring to the lack of water availability, weak groundwater management, weakness in the power of the law, legislations do not match the real situation, and flawed legislation. Additionally, climate alterations caused extreme potential evapotranspiration.

As for the storage volume that is drawn in (black line), it displays the preceded storage that was being depleted as far 511 MCM in the hydrologic year 2009-2010, which signalises a risky notice for the water future resources in this semi-arid area.

The most notable perception is that; along the period of recorded extraction data, the extraction line graph far exceeds the recharge line graph; truly, it brings imperative attentions to decision-makers. It is seen that the estimated annual recharge can be set as a base for groundwater management either by restricting the amount of extraction or by limiting the licensed time to operate wells. Besides, there are two considerable factors have to be bear in mind which are setting a factorised margin to managed yields for future security and considering the predicted future climate alterations severity. Therefore, proper and frequent revisions are needed to be put-in-place for groundwater legislations and a flexible and dynamic groundwater management framework is needed.

Figure 4.22 describes the cumulative change in storage of groundwater in the study area per annum throughout the period 1980 to 2014, which was determined by applying (Equation 3.30). The lower-bound assessment of the capacity of Erbil aquifer's storage can be simply found from (Figure 4.22), which been calculated by applying (Equation 4.2) (Loáiciga, 2008). The variance between the minimum and the maximum of cumulative change in storage is equal to the lower bound of the aquifer storage. Therefore, the quantified lower-bound of the aquifer storage capacity is C = 973 – (−1105) = 2078 MCM as labelled in the figure below.

$$C = S_{max} - S_{min} = V_{max} - V_{min} = \sum_{i=1}^{n_{max}} \Delta S_i - \sum_{i=1}^{n_{min}} \Delta S_i \qquad \text{………. (4.2)}$$

Where: C is the capacity of aquifers; V is groundwater storage volume; n is the time series length that inset at least one typical period and should be extended enough to present both aquifer storage statuses: the full as denoted by (S_{max}) and the depleted as denoted by (S_{min}).

Based on the groundwater drafting patterns, and variability of regional climate, decade's time span series might be decided as a requirement of result certainty. The longer time span period, the more result certainty is.

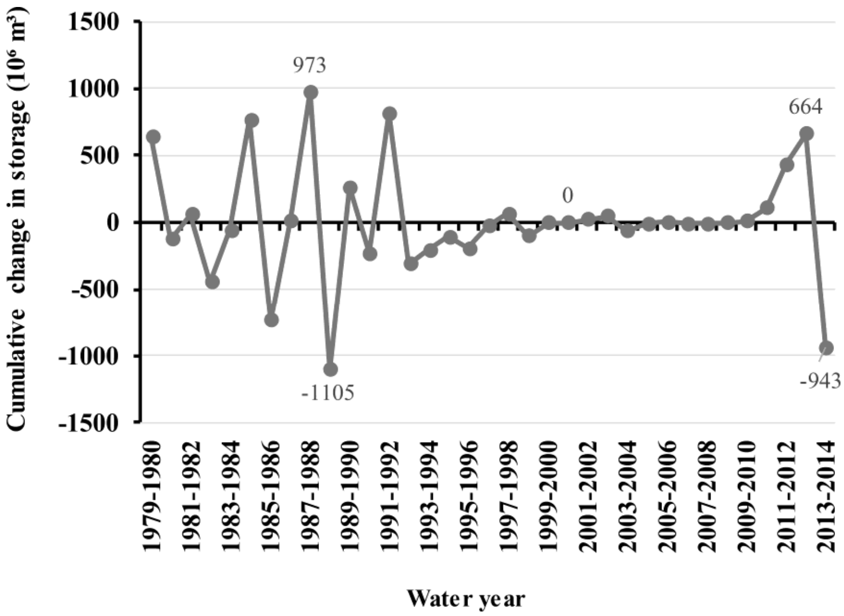


Figure 4.22 Cumulative change in groundwater storage for the Erbil aquifers

There has been dealt with the estimation of groundwater recharge for the different types of aquifers in Erbil basin. In order to assess the safe yield of these aquifers, the net recharge volumes have been adopted on. Figure 4.23 shows the analysis of the mass curve for the aquifers corresponding to the studied period.

It can be seen the time-spanned period had been subjecting to three dry episodes that affected negatively on groundwater reserves. The longer draught spell extended for several years, that is 1999 to 2008 that was corresponding to the great amounts of groundwater abstractions due to excessive demands, and the increased number of illegal water wells, which made the situation exacerbated more. Furthermore, the tangential line slope represents the safe yield that in this case counts to 125 MCM per year and corresponds to the lower-bound of aquifer storage estimation of 2078 MCM.

Attentions can be drawn for the decision-makers and water resources planners; they should consider the groundwater reserves as the last preference for water provisions in semi-arid areas. The safe yield figures can be the crucial standard that cannot be surpassed, this will be based on both the climate alterations that pass through the region, and that will be passing in the future, in addition to, the geomorphology of the studied area. It is worth to mention, the power of Law is seen as a significant factor that restricting non-rational groundwater utilisation, that is, solid sustainable groundwater management is needed as a base for future planning.

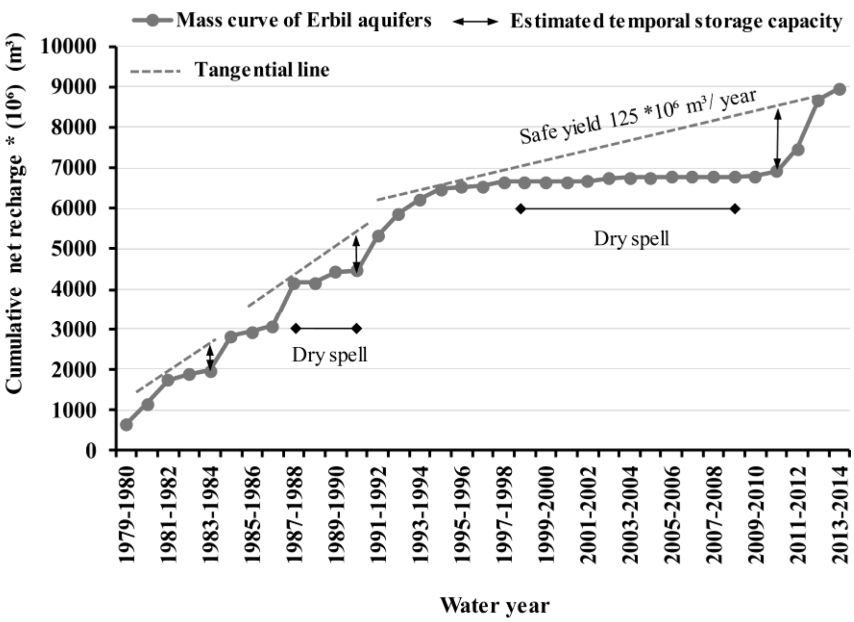


Figure 4.23 Mass curve of net recharge for the study area aquifers

4.4.3. Groundwater levels depression results

Results in (Appendix D.12) show that the fall in groundwater level was between 11% and 88% in the urbanised area with respect to the reference water level observed in 2004. The average fall was about 52% and the standard deviation was nearly 20%. This suggests that the level of groundwater has been significantly decreased indicating the combined impact of the non-rational utilization of groundwater, impact of drought periods (1999-2001 and 2007-2008), and the lack of groundwater recharge. Findings also highlights the future potential risk of the combined effect on irrigated agriculture area and public and livestock water supply. Moreover, the notable drop observed in groundwater level between 2004 and 2015 has underlined that the ground water level at some sites has reached a critical level indicating that the utilization of groundwater has to be carefully treated and sustainably managed, the present utilization of groundwater in the study area is unsustainable and a special attention should be paid to the sustainable use of groundwater and the necessity of healthy management of groundwater.

Furthermore, a spatial distribution map has also been prepared; see (Figure 4.24 and Appendix D.13). This is prepared based on the regression slope (b-value) trends for twenty selected wells. The regression values give an overall indication that the groundwater level in all the twenty observation wells that have been chosen in urbanised and outskirt areas have been dropping, the values of declination range from 0.05 to almost 6, and by focusing onto this map, it can be perceived the that urban areas were most affected than suburbs.

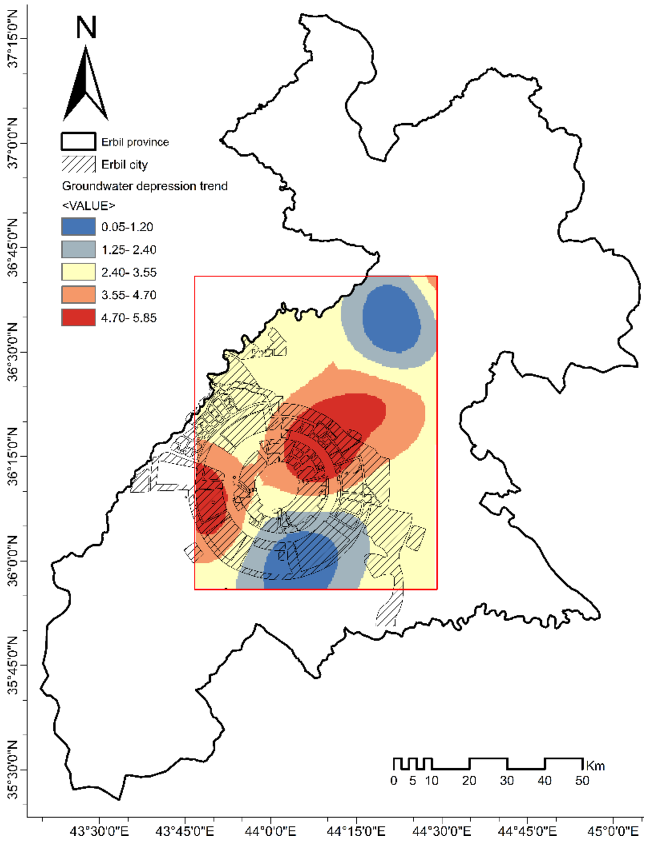


Figure 4.24 The depression trend in the selected twenty observation wells

(Famiglietti, 2014; Voss et al., 2013) has shown that the Northern Middle East aquifers that located in (semi-arid region) including those in Iraq were losing almost 17mm between 2003 and 2009. This is equivalent to 13 Km^3/year by relying on satellite data analysis (GRACE). However, there are considerable differences between different regions ranging from several centimetres to a few decimetres. The water level in Erbil's basin has fallen several meters in most of the observation wells within a period of 12 years.

Turning to the whole study area, and by looking at (Appendix D.8), it manifests that nearly 53% of the total number of drilled wells in the province are legal, and almost 35% were illegally drilled by smallholder farms and/or households. This mainly suggests; (a) that there is an absence or weakness of law enforcement concerning drilling of wells and groundwater development regulations; (b) notable exhaustion of groundwater resources (the local communities are considerably overexploiting the groundwater to mainly meet the irrigation and drinking water supply needs); (c) the current existing wells provide 50% of water for irrigated agriculture, 46% for drinking water supply and the remaining 4% are used for industrial and livestock watering. Furthermore, a considerable number of wells were drilled for almost 200 meters and more, which indicates the unavailability of groundwater at shallow levels. The number of wells increased by 53% within a five-year period. Only 45% of the difference is legally drilled, which can be attributed to a number of reasons that are social prosperity, economic revival and development on one hand, and administrative sagging, poor law enforcement and weakness in instructions and regulations on the other hand. Also, the table shows that almost 60% of recently drilled wells were at 150 to 200m depth.

The aquifer's permeability, it is variable both directions; horizontally and vertically. The average yield of the existing wells is 9.1 L/s according to the well's dataset. Therefore, geological formations, total rainfall during the rainy season, and excessive groundwater abstractions are the main factors explaining the observed groundwater trends in the study area. Groundwater levels are in a state of decline as proved by the negative trend line equations.

Results indicate that nearly 91% of the examined observation wells are associated with declining trends in groundwater levels. About 26% of those of declining trends are associated with low declining trends of slopes less than 0.265 (1st percentile), 50% are linked with strong declining trends of slopes larger than 0.68 (3rd percentile), and the remaining 24% are considered to have moderately declining trends ($0.265 \leq$ slope ≤ 0.68). The corresponding drop (m/year) ranges for low, moderate and strong declining trends are < 0.58 m/year, 0.58 m/year ≤ drop ≤ 1.73 m/year, and >1.73 m/year, respectively. This is due to large-scale abstraction of groundwater together with insufficient rainfall for recharge and the absence of a sustainable groundwater replenishment system, which resulted in a substantial loss of storage and reduction in the availability of groundwater as a reliable source for irrigated agriculture and domestic water use.

The remaining 9% of the total wells are associated with stable or slightly rising trends of slopes ranging from 0.005 to 0.32 with a mean of 0.11. This is attributed to the fact that most of those observation wells are situated in Karstified formations, where the corresponding aquifers are subjected to a rapid recharge process. This agrees with (O. Mustafa et al., 2015), concluding that based on a meteoric water line, the recharged precipitation is of Mediterranean origin and infiltrates rapidly. (Appendix D.11) shows the trends (downward and upward) for groundwater levels of 54 observation wells over a period of 12 years. Whereas (Appendix D.7) presents the results of the M-K analysis; nearly 91% of observation wells experienced a significant declining trend in groundwater levels at a 5% level of significance. About 6% of the examined wells were associated with significant upward trends in groundwater levels and the remaining 3% were linked to insignificant upward trends in levels.

A conceptual diagram has been developed demonstrating the main drivers that cause a serious degradation in groundwater levels in arid and semi-arid areas, see (Figure 4.25). Overexploitation of groundwater, population growth associated with a notable increase in water demands, and climate change and variability contribute significantly to groundwater decline. Illegal abstraction of groundwater, weakness in application of existing regulations and legislation and delay in updating the current regulations and legislation are the main features of the non-rational utilization of groundwater. Reduction in annual precipitation, increase in temperature and evapotranspiration rates and successive droughts have increased the dependency on groundwater, particularly in areas where there is a shortage in surface water. The fall in the annual amount of precipitation decreases groundwater aquifer replenishment (recharge of groundwater), resulting in decreasing groundwater levels as the withdrawal rate exceeds recharge. Major uncertainty still surrounds the detailed effects of climate change on groundwater replenishment. This may attribute to the limited research on the impacts of climate change on groundwater. The direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Less precipitation in winters and warmer summers lead to notable deficits in groundwater recharge. However, aquifers are recharged more effectively by prolonged steady rain, which continues into the spring, rather than short periods of intense rainfall (UK Groundwater Forum, 2011).

The effects of climate change on groundwater across Erbil province may include: (a) a long-term decline in groundwater storage, and (b) increased frequency and severity of groundwater droughts. These effects critically have impacts on the socio-economic conditions of the local communities, on groundwater-related impacts on water supplies, on livestock's watering and on ecosystems that depend on groundwater like as; wetlands, ecosystems in streams fed by groundwater, hanging valleys and swamps, limestone cave systems, and springs.

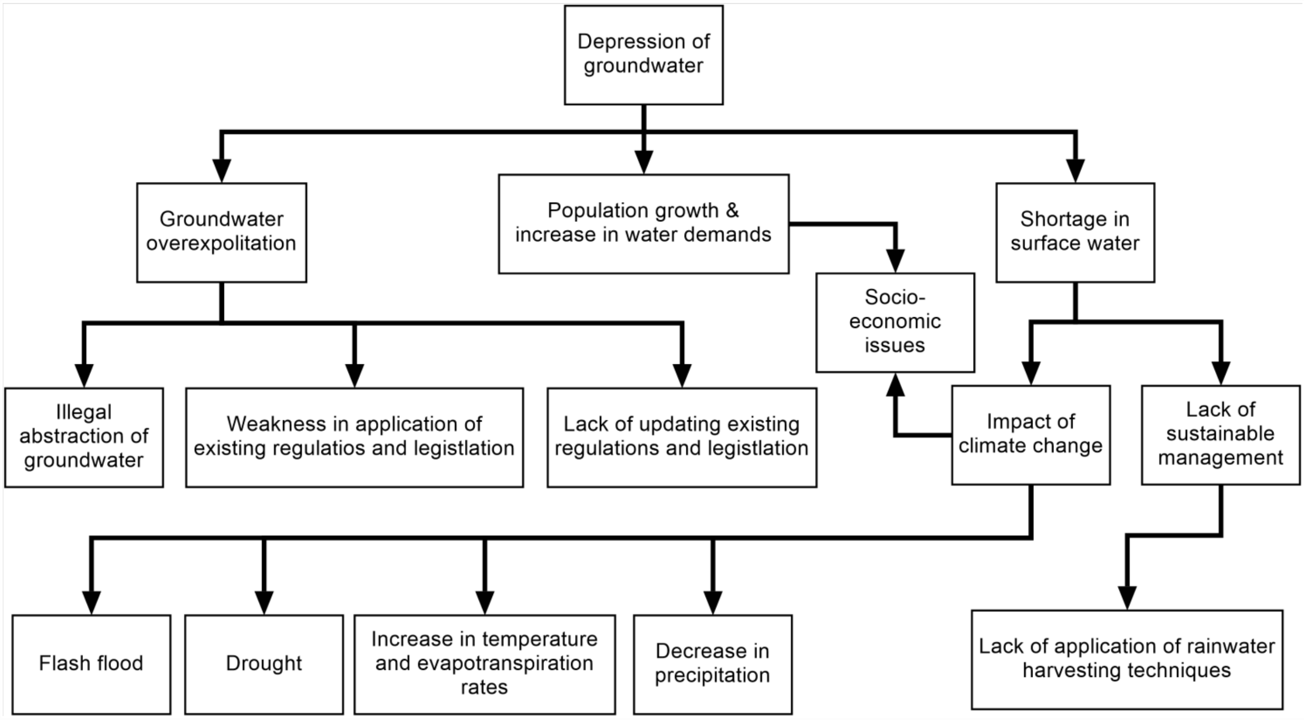


Figure 4.25 Conceptual diagram of drivers affecting groundwater availability and depletion

An additional framework has been developed which demonstrating the interrelated components that leads to sustained groundwater management, see (Figure 4.26). It can be seen that the causes of groundwater depletion lie on two main reasons which are; the decrease in precipitation and surface water on the one hand, and the administrative imperfection on the other that developing countries suffer.

As for the first induction, it can be presented in further details, which is firstly due to the climate alterations impact, and secondly because of unsustainable water management, the latter being closely related to the problems of the ecosystem.

For more inferences, and concerning to the administrative flaws, it can be interpreted it is due to the absence of certain legislation, the actions and process by which laws and regulations can be executed, and also, the economic and poverty issues and linked to their consequences.

Regarding problems in the legislation, it can be seen that there is a progression series of problems that push on each other, If both authorities; the legislative and administrative bodies do not find quick solutions, the situation will be exacerbated more, these are indirectly linked to poverty and other economic affairs as well.

Referring to the problems caused by climate change and lack of sustainability, there is a need to employ schemes and techniques such as operating and developing rainwater harvesting techniques based on sound legal and technical regulations on one hand, and adopting practices to reduce the effects of climate change on the other hand, which in return it will be driving to tackle the economic and poverty issues too.

It is recognised that both economic and eco-system issues are linked with each other, decision-makers, policymakers, and managers can focus prudently on concerning sensitive pivot issues represented as themes in the framework, which have significant roles in organizing sustainable groundwater management.

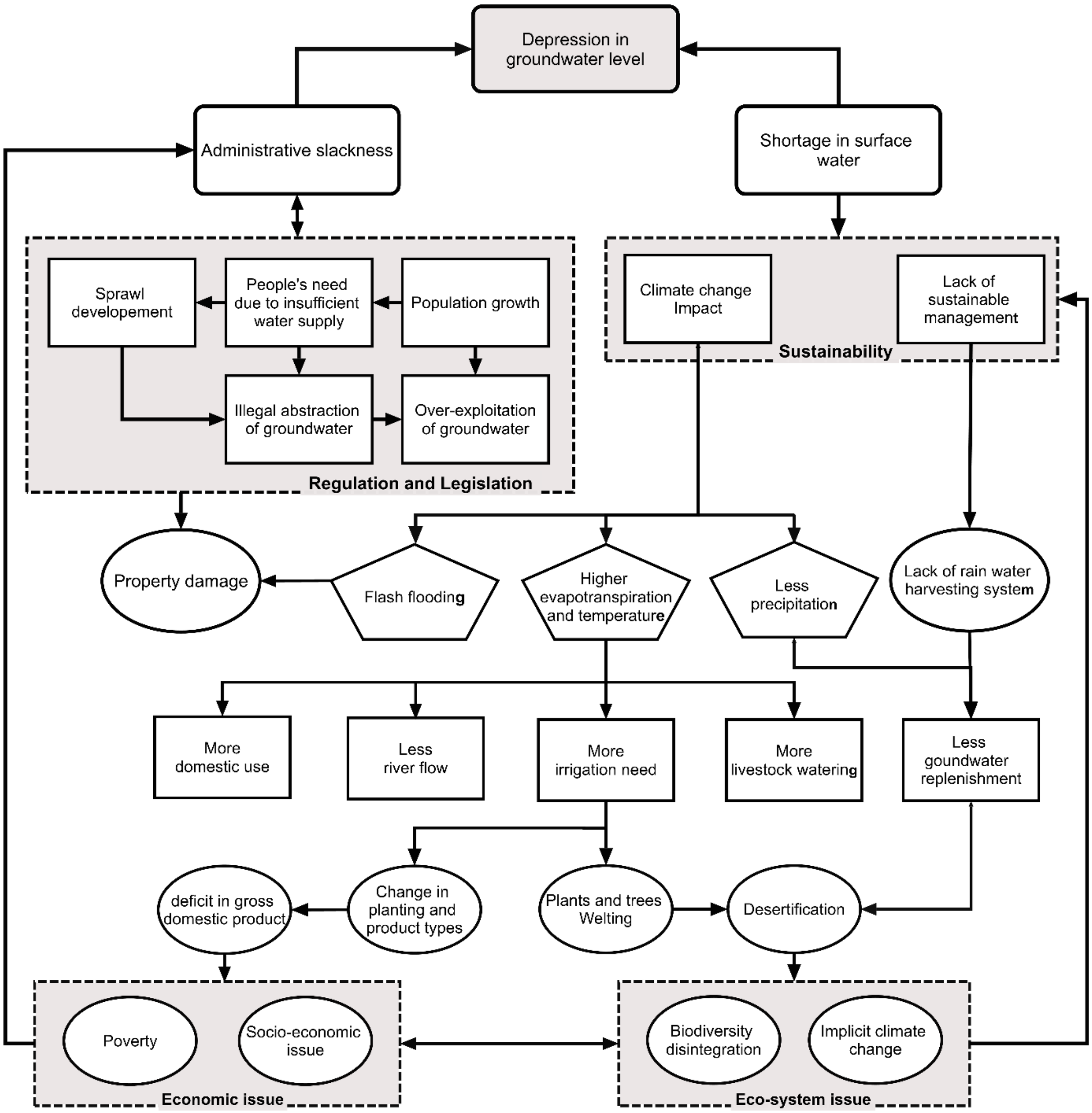


Figure 4.26 Conceptual diagram of interrelated aspects framework for sustainable groundwater management

4.5. Results obtained from the rainwater harvesting ponds

4.5.1. RWHP assessment

The exploration into the results throughout this research is to find out the suitability and the feasibility of rainwater harvesting system in the case study area as considered as part of semi-arid region; this technique is one of sustainable drainage systems (SuDS) that have been being used in different areas around the world.

Findings show that economically this system in this area was effectively and benefit cost. In other words, 48 out of 55 ponds have cost in a higher range of relative weight, i.e. less cost, which is a good indicator that can be inferred from the results, as this system of SuDS would be feasible for application in such a region, see Table 4.5. It is worth mentioning, that this result not necessarily be generalised, there are many factors are involving; for instance, the economic situation of the country, pond site selection, availability of raw materials, high quality of construction techniques, and many other interrelated factors.

Two other indicators; the pond basin area and flood risk reduction, were counted 48 and 55 ponds out of 55, both are within the higher ranges of relative weights respectively, which is also considered as a significant evidence for relative use of SuDS techniques for this region. The selection of detention pond site is a substantial issue, whatever the basin area is smaller, and the expropriation of lands will be fewer, which avoids the property disputes, administrative and legal matters with proprietors of land.

Through closer look at Figure 4.27, it can be noticed that most detention ponds, which located in the north part of the city, are characterised by high land topographic area, in contrast with southwest part, as the ponds there are taking more spaces.

Table 4.5 The frequency distribution of all proportional weights vs indicators

Indicators	**Frequency of proportional weights**			
	0.25	**0.5**	**0.75**	**1**
Construction cost	1	6	27	21
Ponds area	2	5	15	33
Livestock’s' watering	37	14	3	1
Harvested water volume	34	17	2	2
Irrigated area	52	2	0	1
Groundwater recharge	52	0	1	2
Flooding risks management	0	0	0	55
Beneficiaries & socio-economic	51	2	1	1
Recreation	14	13	13	15
Biodiversity	18	17	12	8

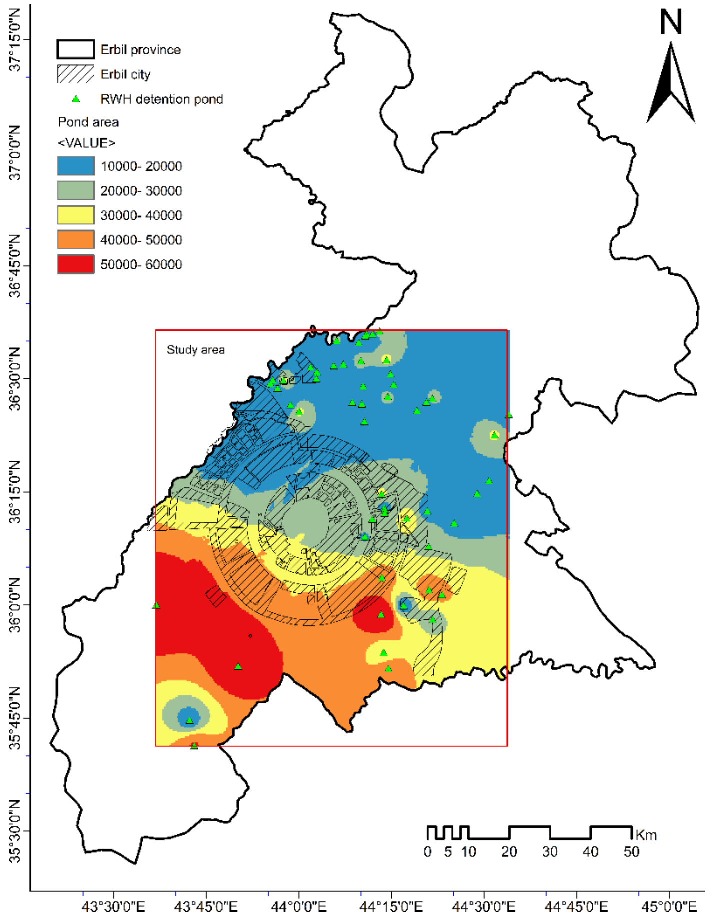


Figure 4.27 The spatial distribution of ponds with respect to basin area

Turning to the other four indicators; harvested water volume; irrigated areas; livestock's watering; and number of beneficiaries, it can be noticed that most ponds were got less weights, here, it can be noticed; that there are many other factors lie behind this; (a) The survey or the assumption of the designers on feasibility study might be inaccurate. (b) A number of ponds have situated in non-arable areas. (c) The number of villagers and farmers were not counted as it is. (d) Or can be attributed to the political situation that most of villagers had migrated to urban areas in the past decades due to political conflicts, and still most of them are living there, this will reduce the number of beneficiaries and livestock's watering, see Figure 4.27, Figure 4.28, Figure 4.29.

Figure 4.28 shows that a number of ponds, which are within the southeast zone are retaining most amount of rainwater.

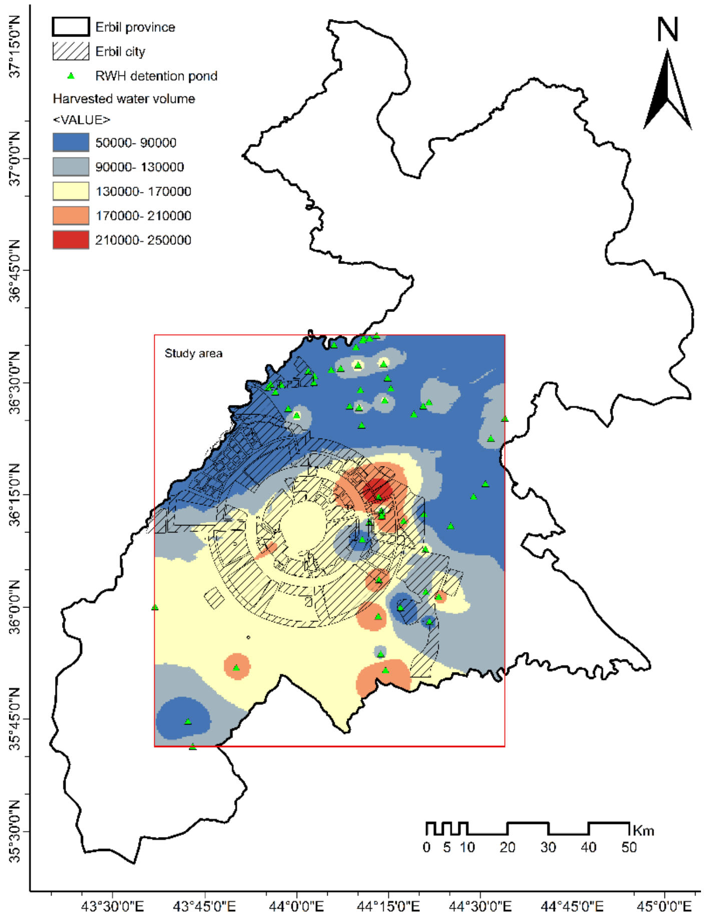


Figure 4.28 The spatial distribution of ponds with respect to harvested water volume

An indication has been noted that the ponds which are located within the steppe areas are most likely supporting water shortages in dry-spell seasons for the areas known as rain-fed lands. Therefore, those ponds are considered the most feasible than others pertaining to the use for agricultural exploitation. Obviously, villagers are gathering around areas in which water are available, a larger number of farmers and villagers are living in the plateau, this indicates that in addition to the availability of rains, the topography has the role for gathering people and get benefit from this technique, see Figure 4.29.

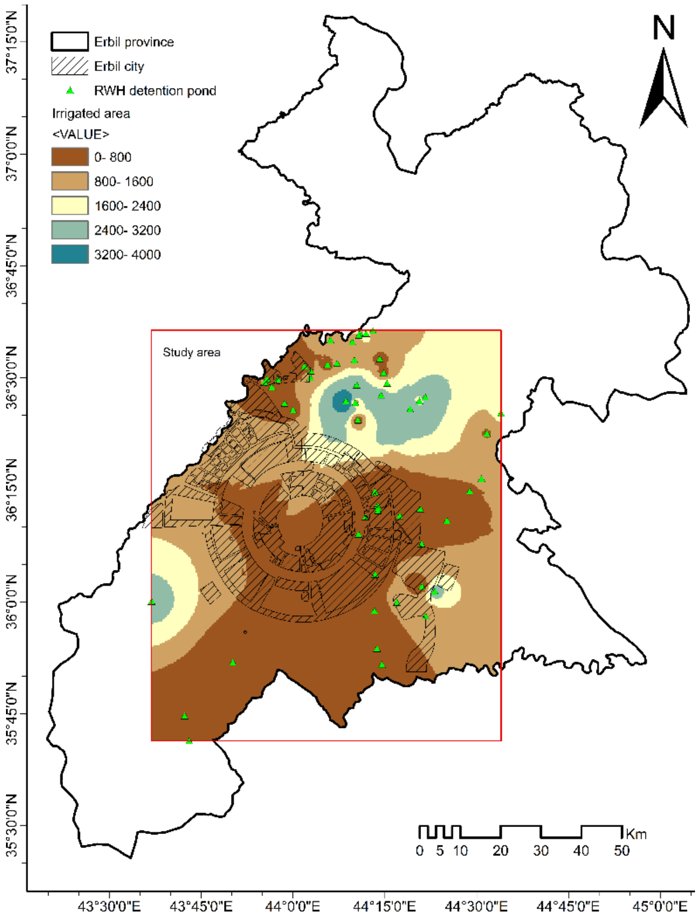


Figure 4.29 The spatial distribution of ponds with respect to irrigation area

These ponds have been supporting livestock's watering; big portions of livestock flocks are secured watering after the run of these ponds. It is worth mentioning, based on the availability of rainfall and suitable topography; the RWHS performances are different due to varying degrees in terms of irrigation, watering livestock's, ground water recharge, socio-economic development, and biodiversity, see Figure 4.30 and Figure 4.31.

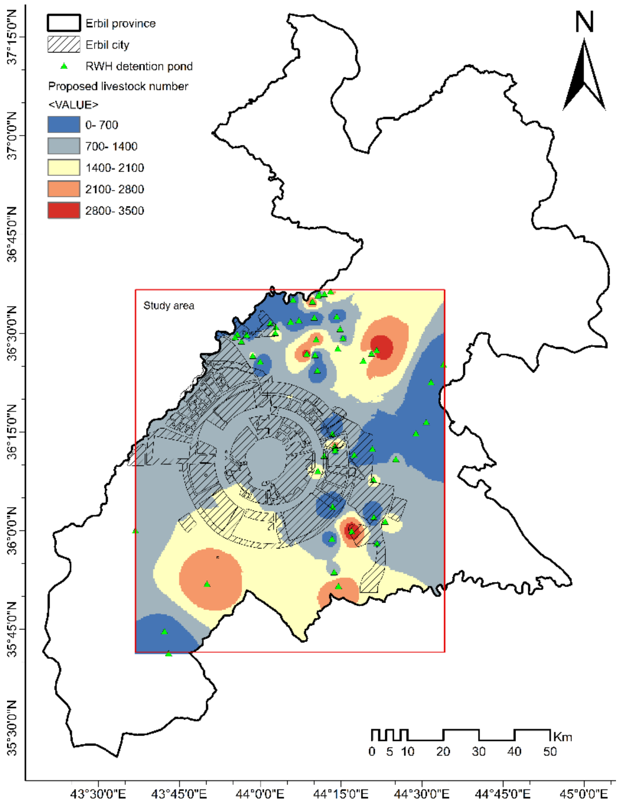


Figure 4.30 The spatial distribution of ponds with respect to livestock numbers

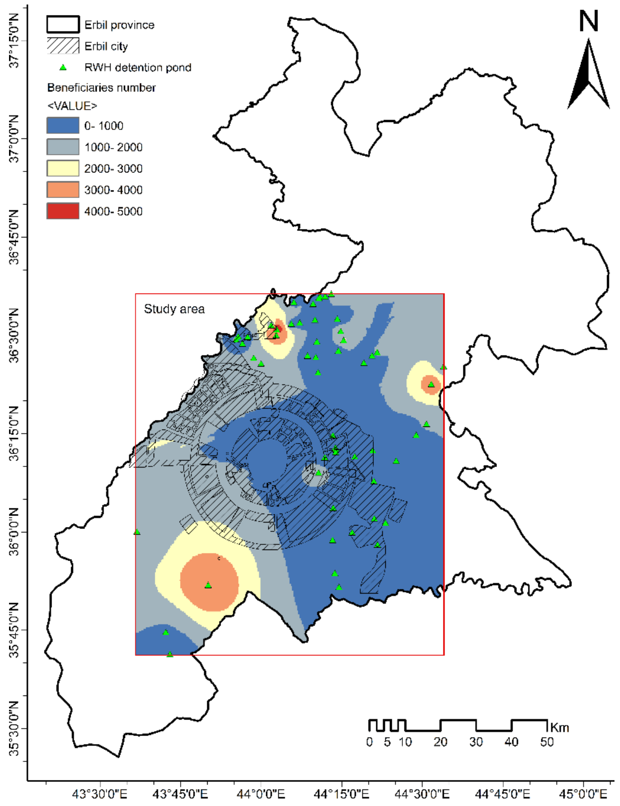


Figure 4.31 The spatial distribution of ponds with respect to the number of beneficiaries

The thread controversial theme is groundwater recharge. That might be got benefit from this system. It can be noticed clearly through (Table 4.5 and Appendix D.3) there are only 3 ponds out of 55 (approximately 5.5%) has thoroughly been contributing for recharging groundwater. This suggests that further site investigations and hydro-geological studies are needed to properly improve groundwater recharge. here, we need something of meditation; despite recharging groundwater is the concerning issue that has become as a global scale issue, especially in arid and semi-arid regions, it can be expected that the pre-investigations on-site selections and hydrogeological studies were not focused on the issues of groundwater recharge, or might there were other issues had been interested in. Despite that, there are ways for more studying, such as cross-checking the results or investigating through the process of modelling that leads to different results. Further, it should to be noted that clayey soil areas are not helpful for groundwater replenishments.

Regarding to recreation and biodiversity, as weights; it looks likely as same level for all ponds, these two indicators were also governed by many other factors, to clarify more; the data were collected by official departments might be gathered at early period of ponds construction, or the observations were not taken in suitable seasons and so on.

Table 4.6 shows the overall weighted scores that have been calculated for each pond by using the Equation 3.1 into Table 4.5. It is obvious that 25.3 is the maximum score out of 37, and the minimum is 15.3, the difference is equal to 10. Intervals have been assumed to be 4 ranges. This can be justified; as that makes the interpretation and even comprehension of all weighted indicators over the all ponds, that is much easier than classifying it into 2 or 3 ranges. In case if the ranges are divided into more than 4 intervals that would not make more sense, as the majority of scores are laid in the first half i.e. below the average.

Table 4.6 The weighted scores for RWHS ponds

#	RWHS ID.	Scores out of 37	#	RWHS ID.	Scores out of 37
1	Du Shiwan	18.8	29	Mam Khalan	17.3
2	HarajayGijka	19.5	30	Zarwaw	18.3
3	BinaslawaGijka	18.8	31	DaraShakran	16.0
4	Balaban	16.0	32	Wasu Marian Khuaru	16.0
5	Shiwapiran	20.8	33	Wasu Marian saru	17.5
6	BaniMaran	19.3	34	Kurdalalan	16.3
7	SmaqShireen	19.5	35	Hababan	16.0
8	Baqlen	17.0	36	Kudaryan	19.8
9	Mawaran	19.3	37	Zargazawi	20.0
10	Qadiana	21.0	38	Azhga	17.5
11	Zebarok	20.8	39	SarkandKhailan	16.8

12	Duwin	19.5	40	Kawerjisk	18.3
13	Sule	25.3	41	ShekhWasan	17.5
14	BarbianiNue	20.0	42	Ziarat	19.0
15	Khra	19.5	43	Beshekh	16.0
16	KhraNue	17.8	44	Kabur	16.5
17	Piraza	18.3	45	Makerdan	16.0
18	Derona	19.3	46	KalachninKhailani	16.3
19	Drameer	17.0	47	Talajar	18.0
20	ChalaGrdala	17.3	48	Babajisk	18.0
21	KaniGani	18.0	49	Ali Rash	15.3
22	Mam Choghan 1	18.0	50	Majidawa	15.8
23	Mam Cnoghan 2	18.3	51	Lawar	15.3
24	Aliawa	16.3	52	Karitan	20.3
25	Palka Rash	19.0	53	Sharabotbchuk	21.8
26	Hiran	18.5	54	Sharabotgawra	22.8
27	Bayez Beg	18.3	55	Rulka	19.5
28	Qashqa	19.0			

The frequency distribution of results have been categorised into 4 groups and illustrated in Table 4.7, almost half of ponds got scores between 17.8 and 20.3 out of 37 as (group 1 and 2), whereas, the rest of 6 ponds i.e. one-tenth were value-laden on high score weights as group 3 and 4. This attributed to what has been previously clarified besides the other influential factor that is; setting the scaled weights that pointed out the importance of each indicator, which governs the total weighted scores.

Table 4.7 The weighted score ranges and the frequency distribution

	Groups	Ranges of scores		Frequency
Scores Ranges	1	15.3	17.8	21
	2	17.8	20.3	28
	3	20.3	22.8	5
	4	22.8	25.3	1
			Total	**55**

4.5.2. Mitigation measures, results derived from stakeholders

The transcripts were re-reviewed for many times, key points have been selected through the review that was focused on by most of the respondents, based on the highlighted significant key points, those were classified under categories as a number of themes, that can be inferred as strategies:

Strategy 1: Identifying the function of stormwater systems:

Most of residents' responses indicated that they either "do not know how the detained water goes through evaporation and ground percolation" or "do not know the socio-economic benefits are". Therefore, awareness-raising is needed.

Strategy 2: Identify related indices to education:

Terminologies instruction and their associated notions such as runoff, stormwater, watershed and sustainability, and specifically might be very strange and difficult for those who casually interested in SuDS. Picking visionary and tangible measures could be helpful to communicate effectively and to put forward abstract concepts comparatively. Rationalisation of water consumption maintains water quality is intangible concepts needs to be understood.

Strategy 3: The necessity for municipal ordinances to be issued pertaining to RWHS:

Another approach to develop the enactment of SuDS to link recommended SuDS or take opportunities to recent rule changes, for example, the municipalities' councils and the Department of Environmental Protection should implement restrictive ordinances and develop a regional model ordinance for harvesting rainwater that is appropriate to the interests of both urban and suburb communities, for instance; landowners' rights and water-sharing quotas between breeders and farmers. Additionally, the purposes of the uses of water should be set out.

Strategy 4: Capacity building for green industry professionals:

Providing guidelines for landlords, villagers, and green industry professionals on how to use the chemicals like fertilisers, herbicides, and pesticides, and their negative impacts on the surrounded environment, eco-system, and water bodies and its resources.

Strategy 5: Raise the awareness:

Residents, farmers, and villagers to be recognised the concept of rainwater harvesting ponds and their education about plantings nearby ponds can be classified into several models and dispensed to groups based on how they have utilised plantings as a form in exploiting the harvested water to sustain crop production and pave the way for bio-diversities environments. Moreover, it is essential to the municipalities to issue ordinances on the uses of any pond. For instance, not all ponds are used for farming and husbandry purposes, there would be aesthetic use ponds also, surrounding such ponds with fences and caution marks is necessary to prevent the hobbyist from swimming in non-aesthetic use ponds.

Strategy 6: The coordination between stockholders:

There are incentives to enact instructions and guidelines on the uses of the water by breeders for watering their cattle, targeting to avoid water pollution by excrements and droppings of animals while watering. These could be done by adopting a certain animal watering system around the pond to be designed in coordination with the agriculture sector. Otherwise, the polluted water could harm the cattle health, and consequently, triggers to losses of an economic resource.

Strategy 7: Public authority rights on the use of water:

The harvested water in such ponds can be utilised by the Civil Defence Corps using helicopters, it helps to deliver raw water to extinguish the unplanned and unwanted fires in rural areas in the events of the bushfire, forest fire, grass fire, hill fire, peat fire, vegetation fire, or veld fire areas that occur due to droughts conditions or in cases due to internal conflicts that occur in developing societies.

Strategy 8: Action plans:

Solid plans are needed to improve the socio-economic situation for farmers and villagers. Practical steps are needed to adopt disease prevention program due to increase of harmful insects.

4.6. Statutory reviews results

In this subchapter, water legislation based on administrative water rights and a range of planning and monitoring tools has been critically introduced and reviewed for the case study area over the last decades. It presents mechanisms to show a balance between growing demand and the need to protect and preserve water resources for current and future generations.

4.6.1. Background

For this section, a bulk number of legal documents have been reviewed that consisted of laws, regulations, and instructions associated with water issues. These documents were either approved and ratified or amended by the Iraqi Parliament, Kurdistan Parliament, or by the concerned ministries that the case study area is under their authorities. These were made available from the departments of legal affairs: Ministry of Agriculture and Water resources-KRG, Ministry of Municipality, and EPIB-KRG, in addition to the official website of the Iraqi Supreme Judicial Council (ISJC). The legal articles, items, provisions, and clauses pertain water issues have been tabulated and summarised in (Appendix E). The review of such statutory materials references has been exploited and helps to give views and insights on the water issues concerning water management framework.

In the last decades, headways in the management of water resources in the whole Iraq have greatly set back. The blames may to a certain degree lay on the conflicts and unstable political situations that passed over the region: eight years Iraqi-Iranian war during the 1980s, followed by the Gulf War in the early 1990s, and the Iraqi freedom process in 2003, in addition to the internal conflicts among the political and militaria mass groups. However, the indubitable cause was the twelve years of economic sanctions in the management of water resources that carried further burdens on the government was the definite cause of the legal reviews on water management. The 2003 Iraq invasion led by the U.S. caused severe devastation to the country's water infrastructure because of the looting and the region's adverse political turmoil. Although legislation on water resources has been in existence in Iraq since 1923, water resources in the country have persistently been a source of complication for the legislature. However, the presence of legislation on water resources since 1923 does not necessarily mean that there was an inexistence of laws protecting and regulating water resources before the establishment of the country. There were laws such as the ones derived from the Islamic Shari'a that existed before the establishment of the State of Iraq, and they helped in the regulation of various resources, including water resources. They could be from the Holy Quran, Prophetic Sunnah, or scholars' books. Besides, during Ottoman rule, there were special laws designed by the state that helped in handling such problems, with the ones for managing water resources being referred to as water laws "Al-Hujaj"[10] (Arab League, 2000).

Islamic Law was governing the use of water in Iraq before World War I. Concerning the issue of water rights, there were several articles devoted in Majallat Al-Ahkam Al-Adlia that codified the Islamic civil laws under the Ottoman Empire (Global Islamic Finance, 2009). Several laws and regulations pertaining to water have been enacted in the country after the end of World War I.

It is important to note that before 1991, every law that the Iraqi legislature passed was considered as the entire country's (lex-loci) [11] unless there were some exemptions made by a specific statute. The 1991 Gulf War and the proclamation of a no-fly zone by the U.S., the U.K., and France based on the United Nation Security Council's Resolution 688 (Security Council, 1991), which protected

[10] from the translator: it means arguments or reasoning

[11] Latin term meaning "the law of the place." It means the law of the state or the nation where the matter in litigation transpired. Lex loci bring the notion that the rights of parties to a legal proceeding are governed by the law of the place where those rights arose.

the Kurdistan region from the central government's hostilities allowed the Kurdistan Regional Government (KRG) to establish its De facto government. The 2003 U.S.-led Iraqi invasion did not change the applicable area for the Kurdistan Region's laws and regulations as they only applied to KRG's jurisdiction. In Kurdistan's jurisdiction, the parliament is the one that promulgates the laws as per the virtue accorded to them in Article 121 of the country's 2005 constitution. Article 121 of Iraqi's 2005 constitution gives the regional authorities the power of issuing regulations that govern the region's affairs. The parliament in the Kurdistan region has adopted a variety of water resource management laws that underlines the consideration of both: Federal Iraq and KRG sources of legislation on the matter.

One of the laws regulating water resources protection in Iraq is the Law of Monitoring Irrigation and Small Dams of 1923. The law does provide a clear definition of the components of the irrigation systems as related to water resources[12] (The Iraqi Parliament, 1923). The Irrigation Law no. (6) of 1962 led to the abolishment of the Law of Monitoring Irrigation, with the provisions made in the former law leading to the significant revisiting and emphasis on the latter legislation (Iraqi Sovereignty Council, 1962). However, the Irrigation Law no. (6) of 1962 was also abolished with Law no. (83) in 2018, taking its place (The Iraqi Parliament, 2018).

The "Al-Makarih" [13] Regulation is the other law that regulates water resources in the country (Iraqi Sovereignty Council, 1935). The main focus of the statute was to ensure that rivers remained free from pollution. It also focused on the development of an effective garbage transportation system and ensuring a clean street. The three elements acted as re-emphasis of Article 2 of Law no. (6) of 1929 of Public Health. However, the "Al-Makarih" Regulation is no longer effective. Law no. (45) of 1958 replaced it and in 1968, Article 21 of Regulation no. (44) led to its abolishment (IRCC, 1968). Although the "Al-Makarih" was replaced and removed, its Articles 15 through to 17 prohibited activities contaminating the public waters and rivers in Iraq, which led it to become the bedrock for the subsequent laws on water resources management in modern Iraq. However, the

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[12] According to article 2 (Iraqi Sovereignty Council, 1962), irrigation system means: (a) All channels, streams pipes and water reservoirs constructed at the government expense or being under its observation and control to distribute or store water; (b) All works, small dams, installations and creeks, which are distributed, or small parts of them being adjacent to streams, creeks, pipes, water reservoirs and all erected installations to facilitate the construction or maintenance of streams, creeks, pipes or water reservoirs; (c) Streams, connection works and flood control; and (d) Any part of a river, waterway, marsh, places where natural water concentrate or natural water leftover, which the Minister of Transport and Works consider as one of the works of irrigation. See Iraqi Supreme Judicial Council website, "قاعدة التشريعات العراقية " Iraqi Legislation Base, Ref. (Iraqi Sovereignty Council, 1962).

[13] Makarih is an Arabic term that means anything disgusting, causing bad smell and resulting in public diseases. Linguistically, it is anything the public hates or dislikes. This word is obsolete and no longer used in this sense, but is referred to as an old Iraqi slang

amendments and revisions of environmental and water regulations and laws are necessary to improve water protection and investments in an integrated manner to preserve water quality and quantity, but the legislation and statutory issues should be involved in the management of water resources, as there are many issues are seen obstacles that hold back water management processes progression, not to mention, the sustainable management criterion needs.

4.6.2. Stances of the constitutions

The constitutions of various countries do acknowledge the importance of water resource management. Owing to the diverse nature of natural resources and water resources, many constitutions that govern various countries around the globe indicate the importance of providing water resources based on ownership nature, protection, and their utilisation. For Iraq's successive constitutions, this was not the case since no constitution in the country expressed the magnitude of the subject of water throughout the twentieth century, with the present constitution being the one that highlights the matter. The constitutions developed through the twentieth century in the country sought to include water resources in the general definition of natural resources with the main reason being the abundant nature of water resources regarding the lesser population density and industrial activities as well as Iraq's prolonged inabilities and the unaltered climatic conditions experienced in the past.

The legal system followed by Iraq is a mixture of French civil law and Islamic law. Since 1921, the country has had eight adaptations of the constitution with the first constitution being developed during the auspices of British military occupation of 1925[14]. It remained valid until the 1958 revolution (Iraqi Sovereignty Council, 1958), this remained applicable until the signing of the Transitional Administrative Law and its adaptation on 8 March 2004 by the Iraqi Governing Council (IGC)[15]. The critical aspect about the current constitution adopted by the country after its

[14] Article 94 states that no monopoly or concession shall be granted for dealing with or using any of the natural resources of the land, nor for any public service, nor shall the State revenues be farmed out, except in accordance with law, provided that where the period relating to them exceeds 8 years, they must in each case be the subject of a special law (The Iraqi Kingdom, 1925)

[15] Chapter 3, Article 25 states that: "The Iraqi Transitional Government shall have exclusive competence in the following matters: (E) Managing the natural resources of Iraq, which belong to all the people of all the regions and governorates of Iraq, in consultation with the governments of the regions and the administrations of the governorates, […] for dealing with their situations in a positive way, for their needs, and for the degree of development of the different areas of the country (IGC, 2004a, 2004b), including Kurdistan Region.

approval by the (IGC) on 15 October 2005 is that it significantly includes tasks for water resources management beyond the definition of natural resources in general (Al-Istrabadi, 2005).

According to the constitution’s Article 110, the federal authorities have the task of developing water policies as per their paramount importance and the imminent danger to the country’s national security. Therefore, the constitution underlines the necessity for the federal authorities to control all the water resources in the state's jurisdiction. An extract from the article which is the item Eight states that: "the state’s authorities have exclusive powers towards water resources policy planning outside Iraq to guarantee the country’s water flow."

The Article also expresses the need for the State to protect its natural wealth. It highlights the State as the sovereign and the real owner of the natural wealth of the country in case no other authority has the capability of operating or maintaining those resources.

Apart from the country’s supreme law, which is the 2005 constitution, other relevant laws governing and protecting water resources exist as per environment and water resources protection in both Iraq and Kurdistan as discussed in the sections that follow.

4.6.3. Statutory reviews discussion (Legal framework)

4.6.3.1. Environmental Legislations

Environmental Protection and Improvement Law no. (27) of 2009:

Appendix E.1 presents a summary of this law. The legislation on the protection of the environment aims at protecting and improving the environment, which includes the protection of territorial water as well as protecting the environment from pollution. The law also aims at reducing the effects environmental pollution has on health, the environment and other natural resources.

Based on Article 4, the structure of the Environmental Protection and Improvement Council has been established, that gives the power to this council by involving members from most the ministries as stakeholders at senior levels. In addition, to establish branches in all provinces and cities across the country to initiate their activities. Moreover, both Article 24 and 25 state a new employment degree has to be appointed called the environmental superintendent that has wide authority to implement its duties on controlling the environmental aspects, that with environment police cooperation.

Article 14 is one of the essential parts of this law, considering that it defines water pollutants as well as the harmful acts towards water resources that are prohibited. The law also underlines that there may be imposed penalties on those violating the legal obligations set by the law. Other actions forbidden by the law include the discharging of domestic or industrial wastes into natural water resources as well as the discharging of agricultural liquid and service waste or other poisonous materials into those water resources. The law requires responsible entities to treat their waste in a manner that would guarantee conformity with the set standards of the regulations and international conventions ratified by the state before discharging them into the country's maritime zones, groundwater sources, and surface water sources.

Article 33 of the Law, on the other hand, specifies the amounts of the monetary fines that have to be paid. Item 1 of the Article states that:

> *"The minister or his authorized representative may give a warning to an organization, an entity, or an individual polluting the environment requiring the polluter to remove the polluting elements within a ten-day period from the day of issuing the warning. The Article also accounts for non-compliance by stating that those who fail to comply with the directive of the minister may have their activity suspended by the minister who also has the power of ordering a temporary closure of the facility for no longer than thirty days but can be extended until the entity addresses the violation."*

The fine imposed by the Article ranges between a million and ten million Iraqi Dinars. The compelling aspect about the penalty is that it is renewable every month until the perpetrators address the underlined violation. The penalty also covers illegal actions on the country's water resources. The minister or an authorised director-general has the powers to enforce this law as vested by the constitution (The Iraqi Parliament, 2009a).

Kurdistan Region Environment Protection and Improvement Law no. (8) of 2008:

In the Kurdistan region, this law is responsible for ensuring clean water provision and treatment. The main aim is the protection of nature and public health from the dangers of harmful activities and acts to the environment and human beings. The prohibitions made by Article 22 of the law include the discharge or introduction of any dangerous substances into water resources. The Article does not prohibit the discharge of waste into water resources, but it does require the individuals wishing to do so to process the waste as per the applicable standards before releasing them into water resources. Further, the Article generalises all kinds of water resources and their courses with no differentiation between private and public water resources. Article 23 highlights the need for establishing a systematic set of regional standards that ensure safe surface water, groundwater, and drinking water as well, while under Article 24, the Kurdistan Ministry of Environment can determine the allowable levels of pollution in drinking water, irrigation water, industrial and service water. The Article also provides for the review of the standard levels permitted as per the development of circumstances (The Kurdistan Parliament, 2008b), see (Appendix E.2).

4.6.3.2. Agricultural Legislations

Forests and Woodlots Law no. (30) of 2009:

The target for this legislation is the provision of protection to the natural and owned forest and tree as assets of the environment and the prohibition of logging as a way of protecting waterways and springs. This law aims at balancing between the protection of the environment and green spaces as well as the water resources. Article 9 calls individuals and other entities to desist from deforestation especially in the case where the forest leads to the protection of waterways and springs. However, the law provides for leniency in cases where there are technical necessities but for a fair compensation (The Iraqi Parliament, 2009b).

The Law of Protection and Development of Agricultural Production in the KRG, no. (4) of 2008:

The development of this law was as a means of including everything related to agriculture and highlighting their interconnection with water resources in the Kurdistan Region, Iraq. Article 1 of the law provides a clear definition of water resources and other agricultural products in the region and also bring forth the liabilities on their owners and other people that utilise the resources as per the plans and strategies of the regional authorities. Article 2, on the other hand, focuses on the treatment that would allow for the contribution of increased irrigated spaces and the provision of systems for the rational use of water (The Kurdistan Parliament, 2008a).

This article has been well-tailored, but there are notes that have to be considered for better and sustainable water management, that are: Item 2 sounds good to direct the farmers toward best agricultural practices on utilising their land for more outcomes, but this also needs to be directed on water uses as saving the quantity, and also the uses of chemical substances such as pesticides, herbicides, and fertilisers in a way that do not affect the water resources quality, however, Item 3 tries to tackle the drought episodes through building dams and lakes, but there is no a clear statement and does not imply a program that to be held by the government to build rainwater harvesting systems as ponds in the suitable areas that captures rainwater in wet seasons, then later to be used for different purposes. This need to be regulated by either a Law or Articles through an amended Law because encompasses many issues that have to be legitimated, see (Appendix E.6).

The Natural Pastures Law no. (2) of 1983:

Appendix E.11 summarises issues on protecting natural pastures in relations to water resources protection has a great importance by the Iraqi legislature. Thus, it aims to conserve water resources in natural pastures and regulation of their exploitations. Additionally, it outlines to organise an action plan for harvesting rainwater to retain water for the purposes of breeding in areas where suitable. And also, it obligates the concerning competent directorates to direct and give awareness and guidance to farmers and villagers. More importantly, upon Article 9 of this Law groundwater reserves are conserved by the restricted rules that have been set by competent directorates. Moreover, the collaboration actions among different authorities are one of the essential powers that been given to the ministry of Agriculture to protect grazelands and rangelands, and the retained waters in valleys could be one of the helpful measures to be used to overcome fire accidents (IRCC, 1983).

The Iraqi Civil Law no. (40) of 1951:

The Iraqi Civil Code of 1951, there has been a codification of the rights to use water for irrigation by landowners through Articles 1052 to 1058 under Islamic law (The Iraqi Sinate Council, 1951), see (Appendix E.23).

The Regulation of National Determinants of Wastewater Treatment in Agricultural Irrigation no. (3) of 2012:

This regulation has been legalised aiming to conserve the water resources and sustain the water quality and quantity from depletion. The wastewater re-use for agricultural purposes requires setting standards and certain criteria to be followed (Iraqi Ministers Council, 2012). (Article 3 / Item First), preventing the use of wastewater in a manner that directly or indirectly damages public health or surface and groundwater resources, or damages degrade or contaminate the soil and affect its productive capacities, the food chain and its aesthetic aspects. Whereas the acceptable methods and levels for wastewater treatment and reuses for irrigation have been Identified in Item Second. Furthermore, the standards to achieve safe limits of treated wastewater for irrigation and monitoring quality of treated wastewater used for irrigation and protect the public health from the harmful effects of wastewater pollution have been set in this Article, that is match the (Article 4 / Item 3) in the Instructions no. (2) of the Protection of the Environment from municipal waste of 2014 (EPIB, 2014). Equally important, based on this regulation, it is not permissible to use the treated water to recharge groundwater utilised for drinking purposes, it is worthy to note, this regulation has also come to force to make the most of treated water as a non-traditional source of water to achieve the sustainability principle, see (appendix E.20).

4.6.3.3. Surface water legislations

Ministry of Water Resources Law no. (50) of 2008:

The other important factor is the institutionalisation of water resources management in Iraq. This law has been significant to the country since its introduction by the parliament back in 2003. Its real effect is its provision of power to the Ministry of Water Resources that allow them to create a necessary legal as well as technical frameworks that guide the use of the country's water resources (The Iraqi Parliament, 2008). The main aspect of this law is that it moves the state and other stakeholders in the country towards the realisation of the goals of the 110th Article of the 2005 constitution. The second implication was the initiation of a new framework that would govern the water resources in the country, with the ministry being responsible for the task. The second Article of this law underlines the other objective of the ministry. Part of the underlined responsibility is the planning of investment in Iraq's water resources. Ground and surface water utilisation are another aspect focused upon by the ministry, see (Appendix E4.).

The ministry declares the aim through the (Article 2 / Item 3) that it affirms "[…] Sponsoring Iraq's rights in shared international waters, maintaining the contacts and exchanging information with the neighbours and riparian countries to ensure fair agreements on its share of water quantity and quality that entering Iraq". Item 4: "Conservation of surface and groundwater from pollution, prioritizing the environment and reviving and sustaining the marshes and other water bodies."

While it shows striving through (Article 3 / Item 7) plans to introduce modern technologies to develop the work methods in the ministry and to train the technical and administrative staff to achieve the management and utilization of water through advanced scientific methods, also, Item 8 strives to achieve its aim to encourage public awareness of the importance of preserving water resources. Additionally, the ministry seeks to expand and improve its work-scale in cooperation with international and regional organizations, including the planning stakeholders and water-consumer sectors that in-line with sustainable manner (The Iraqi Parliament, 2008).

Before the establishment of the Ministry of Water Resources, the fifth cabinet of the (KRG) was the one that successfully established the Water Resources Ministry in 2006. The Kurdistan region passed the Ministry of Water Resources Law no. (9) of 2006 as a way of identifying the strategies of the ministry. The law also served to help the region to establish appropriate plans for developing, investing and improving the region's groundwater and surface water resources. Other responsibilities designed for the ministry as per the law include the construction and operation of dams as well as undertaking irrigation projects. Apart from assessing the integrity of dams and utilise water for the realisation of perfect use of water resources, the ministry also maintains and treat soil within the region's public plants (The Kurdistan Parliament, 2006).

Conserving Water Resources Regulation no. (2) of 2001:

Before the milestone time circumstances passed over the country in 2003, this regulation was the country's most progressive water legislation as issued by the Iraqi Council of Ministers in 2001 (Iraqi Ministers Council, 2001). The importance of water resources in relation to environmental, social, and economic development in Iraq as well as the growing phenomenon of water pollution alongside water resource scarcity had made it necessary to develop regulations on the utilisation of water resources apart from its domestic use, see (Appendix E.5).

Besides, the law underlines rules on management, utilisation, and preservation of Iraq's water resources. Further, it includes the provisions guiding the discharge of waste into public waters as well as the determination of disposing or recycling wastewater. Article 3 of the law, for example, prohibits individuals and industries from discharging or casting wastes into public waters irrespective of the organisation. It is illegal as per the requirement to discharge waste into open waters unless the person or entity intending to do so obtains an approval according to the specifications highlighted by the Environment Protection and Improvement Directorate (EPID) and as detailed in Article 4, Item 3 of the Instructions no. (2) (The Protection of The Environment from Municipal Waste of 2014) (EPIB, 2014). It is important to note that (EPID) is an organisation established in 1986. After its establishment, it remained under the Ministry of Health and continued operating there until the subsequent establishment of the Ministry of Environment in 2003 in both: Iraqi Federal Government and (KRG). The Environment Protection and Improvement Board (EPIB) comprise of many-core organs, with the Environment Protection and Improvement Directorates (EPID)s being one of its affiliates.

The fourth Article of the law prohibits entities from polluting public waters with any form of discharges. The fifth Article of the same law authorizes the (EPID) to issue restrictions governing the quality of discharges made into public water, sewage systems, or rainwater as well. In the same Article, the law provides guidance as to the quality of wastewater with the harmful materials underlined and the effects that the pollutants can have on living matter.

The sixth Article of the law highlights requirements for managing radioactive waste, especially among small private business owners. According to the article, it is imperative for the persons affected to ensure that they treat such materials in a way that they would have very minimal implications to the quality of water resources in the country at the time they discharge their waste into those systems. The Article does not provide any leeway in regard to cost, which means that regardless of the effect that such activity can have on the overall profitability of an entity, the organization has to follow the set rules of treating radioactive materials. As per the provisions of the Article, those entities should provide plans detailing how they would go about in the removal of those radioactive substances. Apart from that, they are also required to apply for licenses that are issued by the EPID.

The importance of the law's ninth Article is second to none. Item (c) of the Article prohibits the disposal of certain materials in water treatment's environs as well as that of a purification station. The materials prohibited by Item (c) include all those that cannot disintegrate with an example being those causing metal erosion. It is also against the law to dispose of any animal product, be it the carcass or the inner materials of the animal, into the waterways in the country. Apart from prohibiting the disposal of any animal product in the waterways, the law also prohibits people from washing anything related to livestock in those waterways.

Another important aspect of this law is that it presents mechanisms relating to the preservation of public water. Chapter 3, Article 12 of this regulation gives provincial councils the authority of protecting and improving the environment according to timetables. It requires them to coordinate with local people's council and make plans that would safeguard public waters from pollution. According to Article 13 of the regulation, it is important for those plans to indicate the areas that lead to water pollution and outline the plans for treatment. It is also necessary for the plans to account for future projects, the funds that people should reserve towards the implementation of these projects, and the timetables for the implementation of the projects related to pollution treatment. Looking through at Article 14, it is evident that the (EPIB) keeps track and follows the water conservation situation in the province by mandating the provincial (EPID) to provide periodic follow-up reports on the progress.

The Law of Maintenance of Irrigation and Drainage Systems no. (12) of 1995:

An essential aspect of this law is that it led to the protection of natural rivers. Article 1 of this law highlights the necessity of facilitating and securing operation management as per the designs that the relevant directorates under both the Ministry of Irrigation and Agriculture approve. The law also aims at protecting agricultural land, ensuring there is no negligence of irrigated lands, protecting them from harm salinity and low fertility, and the identification of the people responsible for protecting those areas. Yet, this law does not ignore the importance of protecting natural rivers, the Article 5 commits the state enterprise of irrigation projects operation and the irrigation directorates responsible for the maintenance of streams, as well as natural rivers, main drainages, estuaries, evaporation basins, and drainage networks delineated in the design maps, their installations and pumping stations located on them (IRCC, 1995).

Irrigation Law no. (83) of 2018:

The highlighted Items and Articles on this law have been tabulated in (Appendix E.9). This Law came basically into existence after the revoking of Irrigation Law no. (6) of 1962. The introduction of the law was mainly for regulating irrigation activities and protecting water resources. The law underlines that it is the responsibility of the state to monitor, operate, and protect lakes, rivers as well as monitor and improve natural and human-made waterways constructed for the storage, distribution, and discharging of water (The Iraqi Parliament, 2018). Additionally, the law has set forth penalties against offenders who pollute water Moreover, hereby the Articles 3, 5, and 6 of this Law the authority of the Ministry of Water Resources has been widening on the surface water resources and its distribution without any intervention from other administrative directorates. Nevertheless, it is worth mentioning that (Article 5 / Item first / A), supports the power of water competent authorities, there is not any statement on the compensations of land-owners who will be taken their lands for the public utilisation, it is seen unfair if there are not amendment article or Items sets that. For instance: if the water competent director has decided to build a number of rainwaters harvesting ponds on suitable watercourses and catchment areas that located on private lands, the government shall compensate the owners based on the equivalent parcels of lands or monetary values.

Law of Beaches Utilisation no. (59) of 1987:

The objectives of the Law of Beaches Utilisation no. (59) of 1987 is to secure floodwater passage and the prevention of pollution-induced to rivers, especially the Tigris, Euphrates, Upper-Zab, and Lesser-Zab. The law does not recognize an individual’s legal ownership of land as per pollution standards and considering the essential nature of rivers in people’s lives and the country’s economic development, it is apparent that the law has some retrospective effects. In accordance to the powers vested in him or her by the law, the Minister of Irrigation can remove the barriers that are affecting the natural flow of rivers to eliminate the possibility that they could narrow waterways. However, the minister does not have the full authority of removing those barriers, as there are circumstances where the president’s approval has to be sought first, see (Appendix E.10).

4.6.3.4. Groundwater Legislations

The Instructions for Groundwater Well Drilling no. (1) of 2010 in KRG:

This instruction had been issued as a necessity to regulate the number and drilling modality of water wells in the region. The instructions had been itemised based on the priorities of issues facing the authorities and the public. It points out the effects of adjacent water wells through article 3, that is not permissible to drill water wells closer to each other than has been set in these instructions as per the aquifers' type. Whereas article 4 considered as a clause to save groundwater reserves through licencing agricultural water wells only in case if there is no room for exploiting surface water. Moreover, the instructions placed the rules of public water wells, which only to be used and employed for the purposes of agriculture, industrial, and drinking through article 5, and it sets that the alternative water wells will only be licensed in case if the previous water well dried up or collapsed. However, in article 6 the procedures to obtain a license for drilling water wells for the private sector is the same with the public sector, but it shall not be granted to petrol stations, car washing garages, factories, worship facilities, commercial buildings, stores, and construction aggregate materials quarries, except in some certain cases. As for the mineral water production plants, the conditions are the same unless satisfies certain conditions. article 7 applies for the agricultural water wells, this Article sets more compulsory conditions than other types of water well use, these conditions are to restrict the farmers to be committed-by aiming to avoid groundwater squandering. Furthermore, it has been assigned only one water well for the specific agricultural land areas for each region. As for the financial penalties and sanctions for those who breach the rules, article 10 set monetary fines ranging from 250,000 to 750,000 Iraqi dinars for illegal drillings (MoWR-KRG, 2010), see (Appendix E.15).

The Amended Instructions of Groundwater Well Drilling no. (1) of 2015 in KRG:

The living necessity and the factors that boomed socio-economic situation have led to a change in the way of life and institutional management year-by-year. Accordingly, the authorities re-organise and update with the current situation including adjusting groundwater issues to be in line with groundwater management conserving principles. therefore, it was necessary to amend the instructions no. (1) of 2010.

It seems this instruction is the repetition of the instructions that issued in 2010 with some amendments have been put in place according to the alterations have been come and the need for better socio-economics in addition to the policy of the government.

Through the review of all articles, it can be seen that there are more restrictions on granting licences, for instance, (Article 7 / Item 2) sets that only one licence shall be granted for every ten Donum of agricultural land whereas based the instruction (1) of 2010 was granting for five Donums.

furthermore, as an attempt to diminish the officially licensed number of water wells, Item 3 has been added another restriction, that is, only one water well shall granted to a number of agricultural land parcels as a shared water well, which their total areas as per what mentioned in Item 2 in this article, and the distances as per the Article 2 in this instruction, moreover, based on item 4 in article 7, consents have to be taken from both directorates: the directorate of archaeology and the directorate of Forests and Pastures, in addition to what has stated in (Article 7 / Item 2) in the instruction of the year 2010. Whereas item 11 in the same article puts more pressure on the licensing process, which gives the directorate-general the absolute authority on either issuing water well licenses or to revoke it, by which it reduces the powers of sub-administrations, justifying that water is a national communal resource that has to be managed by senior-level authorities. Also, article 14 likewise article 10 of previous instructions of 2010 imposes financial fines and administrative penalties but with the different monetary amount ranging from 1,000,000 to 2,000,000 Iraqi dinars for illegal drillings, in addition to the suspension of working ranging from six months to one year, but this needs to be either updated regularly as per financial inflations or within a certain criterion that matches with the day-by-day living standard (MoWR-KRG, 2015).

Through the review of these instructions, it can be noticed that despite these Articles were formed to manage the rationale uses of groundwater, but the climate alterations have not been directly considered within a formulated Article to be as a base for amending the instructions regarding groundwater recharge and discharge amounts, see (Appendix E.16). .

4.6.3.5. Domestic Concern Water Legislations

Law of the General Authority for Water and Sewerage no. (27) of 1999:

This law instructs the authorities in the local area responsible for the water people drink, the discharge of sewage and rainwater, and raw water in the whole country and highlights the need for conducting the processing in a long-term manner while considering the economic, social and health developments. An exciting aspect of the law is that it imposed a water connection to all private properties at a time when drought affected the Middle East region. Article 11 of the law states that;

> *"After sewage and water networks have been installed in an area in which the property is located, then the individual who owns the property is obligated to participate in these networks, and if he/she refuses to do so, the competent department shall work on his/her behalf and collect the expenses from it in accordance with the provisions of the government debt collection law."*

It is important to note that the KRG of Iraq did not have this law because the semi-autonomous nature of the area meant that authorities could not enforce the law there. Besides, the area possessed a legislature that was separate from that of the (IRCC, 1999).

The Regulation on the Maintenance of Rivers and Public Water from Pollution no. (25) of 1967:

This law was introduced as a way of addressing several issues that related to water discharge into public waterways and the sewage systems. According to Article 7 of this regulation, there are some regulations that people seeking to discharge water into those water resources should abide by to guarantee the quality of those resources. For instance, shop owners are to abide by certain levels of trapped oxygen and floating materials outlined by the Minister of Health or an appointee. Further, Articles 8 and 9 highlights the mechanisms that would help with the control of water pollution resulting from the discharge by shop owners. Article 1 of this law also provides a detailed explanation of the word ‘shop,’ as it highlights that it includes any public or private factory, store, or any other industry owned by the state or a private entity.

Article 10 of the law calls for individuals to desist from disposing of animal products and carcasses as well as garbage or any related matter into a public waterway or on the beaches. The law overlaps with Article 9 of the Conservation Regulations of Water Resources no. (2) of 2001 (Iraqi Ministers Council, 2001) though it is still operational, this may bring about confusions for both the authorities and the public to decide which law should prevail although the latter provides more details.

Another area addressed by this regulation is the means of using public water and drinking water as well as problems resulting from polluted water. Further, it holds people caught performing those prohibited activities liable as detailed under Article 15. It also provides methods that can prevent certain adverse effects of the use of water as it prohibits people from casting leftovers into any river as well as discharging wastewater into waterways and channels. Article 11 of the legislation prohibits not only the extravagant use of water resources but also wasteful use of water. Some of the activities that the law prohibits include doing laundry or washing leather in a river, channel or waterway. Another aspect of the law is that it guides the permitted levels of pollution (Iraqi Ministers Council, 1967), see (Appendix E.14). .

Public Health Law no. (89) of 1981:

One chapter of the Public Health Law is dedicated to issues regarding drinking water as a way of alleviating the significant damage that drinking polluted. Article 64 of this law gives procedures that state authorities should observe towards the supply of safe drinking water. Article 65, on the other hand, highlights the need for obtaining approval during the planning of studies and while designing the supply of drinking water. Article 65 also highlights the need for submitting information related to water quality.

A vital issue addressed by Article 67 of the legislation is the level of using purification and water source treatment methods. According to the Article, it is important for all the relevant authorities to ensure that they observe the standards underlined by the Iraqi government and international bodies on the quality of drinking water. The law also emphasises the necessity for all drinking water installation projects to have laboratories integrated with purification units that can conduct chemical, physical, and microbiological tests to ensure that the supplied water corresponds to the underlined standards. The law also requires the provision of results of the drinking water quality tests by the laboratories to the relevant authorities.

Article 105 of the law highlights that there may be the issuance of regulations, instructions and statements as per the legislation. Thus, the law issues many specific guidelines that address several provisions related to environmental protection (IRCC, 1981).

However, this law has been enacted since 1981, upon that it revoked a number of Regulations pertaining to health issues and is a comprehensive law that addresses a wide range of concerned issues on human's health. Nevertheless, it needs to be amended concerning water quality, the current world environment has been threatened by different sources of radiation, that is, the radioactive test should be taken into consideration for water quality, especially, for countries who confronted Wars by adding a detailed Article that affirms the power of law on conducting such lab test. For instance; the Tuwaitha nuclear research plant was robbed, looted and destroyed during the process of Iraqi freedom in 2003 (BBC, 2003; John, 2006), the consequences of that the adjacent waterways and Tigris river flows were polluted, see (Appendix E.12). .

4.6.3.6. Administrative Legislations

The Law of Irrigation Ministry Companies and Bodies no. (44) of 1987:

This Law was enacted to provide logistic supports to the Ministry of Irrigation on maintaining and up keeping water resources projects. Hereby Article 1, there have been established thirteen state companies with different professionals and specialities in order to assist the Ministry in carrying out its duties and objectives. Article 2 states the objectives of these companies: by which removing natural reeds and herbs that hinder the rivers' water flow, land reclamation, construction of dams and hydraulic structures, digging deep wells and installing machines, maintenance of irrigation and agricultural equipment's, and a specialised company for surveying and mapping (IRCC, 1987a). Although establishing such companies reinforces the duties of the ministry and without a doubt, it will create job opportunities and gains incomes to the state's treasury, but this Law lacks some important issues. That is: it has been enacting since 1987, at that time, Iraq states policy was leaning toward socialist states, they organised their structure based on the public sector without participating private sector with the exempts in rare cases. And yet, this Law needs to be amended for better adjustment and adaptation with the current de facto that the privatisation is the most prevailing management policy in the world, see (Appendix E.7).

Law of Studies and Design Centres for Irrigation, Water and Soil Research Projects no. (45) of 1987:

Upon this Law, it has been established three centres for design and studies of Irrigation projects, water, and soil investigations. Article 1 set the title and location of each centre, but all are situated in the capital city and north part of the country, and there is not an Article or items state to authorize the establishment of branches or offices in the provinces along the country or even in the south part of country that both Euphrates and Tigris rivers are passing through, in addition to there were possibilities of developing water projects more. One of the strengths of Articles 4 and 5 this law; is the legal power that been given to the Board of Directors to contract with partners and academic institutions as a synergic and collaboration partnership in order to increase job opportunities on the one hand and to get benefit from the expertise of external consultants on the other hand, not to mention the financial incentives that are given to its employees from the revenues of the centres without consulting the Ministry of Finance (IRCC, 1987b). In contrast, this law lacks the comprehensiveness of water resource disciplines, for instance; there is not specified centre on groundwater studies, as it is a safe dependable sort of water resources in arid and semi-arid regions. Additionally, since the recent decades, the semi-arid areas have been passing through climate alterations and emerged water shortage issues, therefore, climate change research centres have to be placed in the organigram structure within the study and consultation centres according to the law, see (Appendix E.8).

Penal Law no. (111) of 1969 and its Amendments:

The Penal Law has a few Articles and Amendments that deal with issues related to water use. Article 368 is an example, as it criminalises acts that negatively affect the public health sector. For instance, actions like those causing the spread of harmful diseases like cholera are prohibited by the law. The perpetrators of those actions are considered to have committed a crime under the Penal

Law[16]. Article 496 Item 2 underlines that individuals who dispose of animal carcasses and dirty materials with harmful effects in a river or any waterways are subject to punishment. The Iraqi Revolutionary Command Council (IRCC) amended Article 496 of this law twice. The first time was through Resolution no. (77) on 14 January 1982 and the second time was during the IRCC Resolution no. (188) on 7 February 1984 (IRCC, 1969), see (Appendix E.13).

4.6.3.7. Strategic Plans

Regional Development Strategy for Kurdistan Region 2012-2016:

The Ministry of Water Resources through a comprehensive strategic plan calls for a programme that the groundwater exploitation has to be expanded, especially water wells. Statistical results for 2006 indicate that the water wells were mostly used for drinking water provision, 20% used in agriculture, and the rest were exploited for industrial, and agricultural extension and research purposes (MOP-KRG, 2011), see (Appendix E.18).

The Law of the Ministry of Water Resources in the KRG, Iraq no. (9) of 2006:

The Ministry aims to develop strategies, policies and plans for the development and investment in water resources (surface and groundwater) in the region, and to prepare technical feasibility studies, and economic projects for water resources. Additionally, the construction and maintenance of dams and irrigation projects (The Kurdistan Parliament, 2006), see (Appendix E.17).

4.6.3.8. International Water Conventions and Treaties

The International Water Conventions and Treaties, The Resolution no. (25) of 2010:

In view of the lack of recommendations on Iraqi's water shares in the draft of the comprehensive partnership agreement between the Federal Republic of Iraq and the Republic of Turkey, which includes areas of joint work between the two sides. As the most important problem suffered by the country is "water scarcity", and for the purpose of addressing the issue in accordance with international norms and laws, and for the purpose of securing the required water shares in the Tigris and Euphrates River and its tributaries, this resolution proceeded (IPC, 2010). But it seems that the

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[16] The text of this article was amended during Coalition Provisional Authority (CPA) in Iraq in 2003. Under article (3) the CPA Order amended the Penal Code and the Code of Criminal Procedure, no. (31) Date 10 September 2003, and replaced by the following text: Punishable by imprisonment for a term of fifteen years or a fine not exceeding one hundred dinars each of his mistake caused the spread of serious disease is harmful to the lives of individuals. If the act caused death or a permanent disability to a man, the penalty prescribed to the perpetrator as the crime of murder or crime in line with victimization.

agreements did not produce the desired results, and the region remains concerned about this, see (Appendix E.21).

The Ratification of The Convention to Establish the (ACSAD), The Law no. (10) of 1971:

This law was enacted in view of the signing of the Convention by the Republic of Iraq to achieve: the objectives and purposes of the Charter of the League of Arab States, and the desires to develop cultural and economic relations between Arab countries, and also, to recognise the role of the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) in the development of wealth and improving the means of investment (IRCC, 1971). Since its establishment, this institution has been undertaking its activities and conducting scientific research on water issues in the semi-arid region, but still, it seems that (ACSAD) has not yet come to fulfilment to address the issues and remove obstacles aside. And now these areas are passing through water shortages (if not water-scarce or water-stressed). The reasons being behind due to either there is non-rational governing of water, or because of political, administrative, and economic issues, see (Appendix E.22).

Convention on the Law of the Use of International Watercourses:

The International Convention for non-Navigational Watercourses:

In late 1970, the United Nations commissioned the International Law Commission (ILC), the body for the codification of international norms in various fields, to study the rules and laws governing international relations in international watercourses for non-navigational purposes with a view to their progressive development and codification (UN General Assembly, 1971). For this purpose, the commission paid attention to the idea of regulating the international watercourses for non-navigational purposes long ago. The commission's interest was accompanied by discussions and meetings that lasted for many years, during which the committee was keen to listen to the observations and views of all States. These discussions continued until the convention was issued in 1997 as general principles. The long period reason can be interpreted to the fact, that some countries do not agree to join the commission, because their views have not been taken into consideration or that the wording of some texts is not consistent with their orientations.

The uses of international watercourses for non-navigational purposes are different and vary according to the countries need. Therefore, it can be found that the convention did not take the initiative to identify all water uses, the provisions of the wording were flexible to accommodate all uses. Hence, it becomes difficult to implement it or when a legal dispute arises between States over such uses.

There are many causes behind the international watercourse disputes around the world:

1. The upstream countries are using large quantities of water, which in turn affects its runoff and thus deprives the residents of the downstream country of water;
2. The industrial uses cause significant pollution in water;
3. The climate also plays an influential role, because it reduces the flow of water. Thus, it is affecting the watercourse's geographical form, which causes the downstream country to take practical measures that contribute to minimising the negative effects of water flow shortages (McVery, 1997).

Therefore, looking for means to resolve international disputes that arise from the use of watercourses for non-navigational purposes, reflects the keenness of States to resolve disputes arising from watercourses, especially as some of them have reached to very critical stages.

This convention is very important and is now the international reference for the subject of international non-navigational waters and represents the prevailing international custom in this area. Iraq has become a member of this agreement since 2001, as is the case with Syria (Dawood, 2017).

This agreement is the result of a long discussion between different countries and was voted on only after it reached a text that could be accepted by a great majority of the different countries of the world, including major countries. When the Convention was put to a vote at the UN General Assembly in 1997, one hundred and three countries voted for it, including the major powers, while only three countries (Turkey, China and Burundi) voted against it. Twenty-seven countries abstained (UN General Assembly, 1997). Eventually, on 17 August 2014, the Convention entered into force.

Thus, international watercourses have an agreement governing their use, protection and management (Salman, 2012; UNWC, 2019). But still other countries are joining the convention, and others are not committed to the clauses of the agreement, that needs the power to oblige them on the commitment. Therefore, the existence of a framework convention on international watercourses in the world is an important addition to the existence of a large legal heritage of bilateral agreements (Mohammed & Duaa R., 2019), protocols and memorandums on the optimal use of international watercourses. the international and regional organizations are making significant efforts to bring the views of different countries on the uses, despite that, it does not stop the ongoing international arising conflicts due to international watercourses diverse uses. Still, the existence of a framework convention would be an important addition to the existence of a large legal heritage of bilateral agreements, protocols and memorandums of understanding on the optimal use of international watercourses around the world. Further, efforts should be exerted to ensure that the texts are put into practice and that all obstacles and causes are solved, aiming to ensure that water is to be shared across the countries in a reasonable, optimal, and equitable manner, but the crises remain vulnerable as long as there are no common and shared interpretations of international water law.

Disputes Settlement Arising from the Use of International Watercourses:

The conflict that has been being witnessed by Iraq due to the use of international watercourses varies according to the supposed factors, in terms of countries, Iraq's problems with Turkey is the most prominent, since the Tigris and Euphrates rivers constitute the first water resource in Iraq, while water problems with Iran are easier than those with Turkey, and Syria on the other side, because the rivers pass through it. In terms of reasons, the reasons may be technical due to the establishment of many dams, basins and reservoirs by neighbouring countries (Mohammed & Duaa R., 2019).

Iraq delayed in the development of dams on the one hand and not to initiate the establishment of what is necessary to preserve the water entering Iraq. The climate variables that surrounded Iraq's having a continuous role in water problems between neighbouring countries. And finally, the legal aspect of the treaties and common protocols still suffer many problems that need to be reviewed for the contributing purpose to reduce those issues. For instance, the GAP[17] project will potentially profound geopolitical repercussions. Joined by climate change, it risks sparking displacement that could further destabilise both countries and neighbours. Despite that, there are different views from every side of countries:

The Iraqi water authorities accuse Turkey side of using water as a commodity that can be bargained with. Moreover, lack of water causes breaks up gun battles over water between tribes who working in agriculture, therefore leads to socio-problems.

Yet Turkey's side argues the built dams benefit its neighbours. Turkey's cooler temperatures mean water can be stored there, saving downstream countries millions of cubic metres that would

[17] The South-eastern Anatolia Project (GAP) is the largest scale and costliest project in the history of the Republic of Turkey. The project area covers nine provinces located in the Euphrates-Tigris Basin and upper Mesopotamia plains. These GAP provinces constitute, on average, 10.7% of Turkey in both geographical and population terms. The objectives of the GAP include improving the level of income and life quality of the local population by utilizing the region's resources and contributing to national economic development. In the 70'ies the GAP was considered as a programme geared to developing water and land resources of the region and it was planned to launch 22 dams, 19 hydraulic power plants and irrigation investments covering 1.8 million hectares of land in the Euphrates-Tigris basin (Ministry of Industry and Technology-Turkey, 2015).

evaporate. And they add more, it should control the water. The solution is; when precipitation occurs is not the same time as when you need the water. Control shouldn't be a source of conflict. Although, it should be remembered that Turkish diplomats inflamed them in 1992 by warning the country's neighbours that if they could exploit their oil resources, Turkey had similar rights to the water springing from its territory. it seems that there are several internal and external intentions included this project.

On the other side, a 2015 UN report, however, argued that controlling water flows from Turkey had come with "dire consequences", such as higher salinity levels downstream hitting crop yields and damaging the wider ecosystem. Iraqi environmentalists say salinity levels in Iraq's marshes, once about 200 parts per million, are now at 1,900 parts per million (N. Al-Ansari et al., 2014; E. Solomon & Pitel, 2018).

4.7. The technical framework (Adaptation and mitigation propositions)

4.7.1. Introduction

Frameworks are being used in various areas, disciplines and fields, based on the requirements, relations, correlations and areas the structure of any framework can be designed. Sustainable water resources management and sustainable drainage systems in arid and semi-arid regions require a unique, alterable and adjustable frame.

The emerging water crisis in semi-arid regions shows that the current institutional frameworks and policies concerning water resources management are incapable of achieving an effective and satisfactory situation that implies sustainability development goals in the water sector.

A technical framework (Figure 4.32) has been proposed which involves several interconnected steps to support the SWM in arid and semi-arid climate areas and to be as a buffer measure to sustain drought contingency plan.

The components of the framework should be incorporated into the decision-making process to support decision-makers and water managers in making a better decision in short-longer term periods. The proposed technical framework is divided into ten key components: (1) Statutory issues: critical appraisal, amend and propose new regulations and legislation; (2) Establishment of Real-time data monitoring system; (3) Integrated water resources management taking into consideration the climate change impacts; (4) Establishment of water conservation and development board in conjunction with collaborative actions; (5) Short-to-longer term effective capacity building programme; (6) Developing indicators UNSDGs-Agenda 2030; (7) Water quality issues; (8) Promote efficient water use and reduce losses; (9) Quantify current supply-demand gaps and sizing a future gap; and (10) Water policy.

4.7.2. Capacity building

It should be noted that the effective capacity-building programme requires clear identification of gaps, need assessments, constraints and challenges, and identification of the institutional strengthening and human-resources development needs.

4.7.3. Water system and Real-time monitoring

The establishment of a real-time data monitoring system is a crucial component for nation-wide water resources management (Al-Zubari, 2002). Analysis of past extreme events and trends contributes to the determination of climate change threats. O'Donnell, Ewen, & O'Connell, (2011) highlighted the importance of analysing historical extreme rainfall events in formulating mitigation programmes, mainly when such events are likely to become more frequent in the future.

The ongoing management of water resources is possible only under the condition of availability of adequate qualitative and quantitative information about the state of the water body at any time. Such information is necessary for taking decisions about allowable water usage and for substantiation of controlling actions and verification of their observation.

The process of monitoring consists of a collection of information at specific points, in certain time intervals, for obtaining data reflecting the current situation and allowing determining trends in its development. Additionally, it gives indications on the planned and targeted water utilisation based on expected climate trends for the future.

Monitoring is the primary source of feedback data in the system of water resources management. It supports to determine qualitative and quantitative characteristics of water and to decide its suitability kinds of usage

The analysis of the cause-and-effect interactions between certain conditions of vital activity and water usage demonstrates that the water body is a multifunctional entity, and it cannot be considered only as a source of water supply.

For the elaboration of controlling actions in the process of water management, it is necessary to perform continuous verification and analysis of water quality, water use regime, water stage regime, sources of pollutants.

Water resources monitoring process can be conducted at different scales and goals: local monitoring; global monitoring on sites with a low level of anthropogenic influence; comprehensive monitoring performed at the water body observation network for determination of the actual state of the water body, for decision-making on efficient use, protection; and critical monitoring which can be performed at sites of high-risk for immediate warning about unfavourable situations.

4.7.4. NGO's role

Indeed, transparent dissemination and exchange of data and information among stakeholders, particularly during extreme events, is a crucial element. Sharing of information at multi-governmental levels, with non-governmental organizations (NGOs), private sector, local communities, and professional associations and making the information more accessible, is a key to develop adaptation practices and mitigation measures. Adaptation requires facilitating better coordination and strong partnerships across multiple agencies, sectors and scales, suggesting the need for collective action.

4.7.5. Maps for vulnerable areas

Undoubtedly, developing a set of maps for vulnerable areas is a decisive component in the adaptation and mitigation process. Communities, regions, sectors and infrastructure that are at high risk and have a low capacity to respond should be spatially mapped. Recent outcomes from case studies (Corobov et al., 2013; USEPA, 2018) highlighted that identification of the vulnerable areas enables the analysis to be focused on areas likely to be most affected by future changes in climate. Adaptation and mitigation planning and management should apply risk management and ecosystem-based approaches, where relevant, to help identify, assess and prioritize options to lessen vulnerability and increase ecosystem resilience to potential environmental, social and economic implications of the impact.

4.7.6. Legalised RWHS

Literature (Mati et al., 2005; Senkondo et al., 2004; Sonbol, 2006) clearly indicated the importance of SuDS technique like RWHP for various agricultural activities as part of the integrated water-land management practices, particularly in arid and semi-arid regions. Moreover, rainwater harvesting has increasingly been adopted as an adaptation measure to climate change (Environment Agency, 2009; Pandey et al., 2003; T. Singh & Kandari, 2012).

Results indicate that the application of such techniques has various advantages and to varying degrees. Therefore, regulations should be put in place, allowing rainwater harvesting in both urban and rural areas legalised. This technique can be utilised for urbanisation, residential, environmental, and agricultural applications, which guides toward incentive programs that can be built for water conservation, by which local-specific technical codes would be set, based on that, issues like storage capacity, collected water quality, allocating water rights would be stated based on doctrinal of (water appropriation system).

4.7.7. Groundwater issues

The use of managed aquifer storage to augment groundwater resources through setting up artificial aquifer recharge systems such as man-made infiltration basins and injection wells is among committed adaptation arrangements. It has to be remembered that the suitability sites for recharge is decided by water supply source presence, lithological structure, the geological formations characteristics, aquifers' hydrodynamic conditions. Additionally, constructing ponds, injection wells are contributing to rising groundwater levels. Also, assessing the aquifers' storage bearing capacities and defining the period in which optimal water withdrawal can be achieved is of paramount importance in the integrated water resources management. Other encouraging arrangements, such as the natural buffers like the wetlands as a SuDS technique, can play an important role in storing the water in the wet season and feeding the rivers in the dry periods via regulatory structures and conveying schemes. The inter-basin water transfer system is a potential management practice to transfer water from the 'donor' basin to the river basin referred to as the 'receiving' basin to meet growing residential, commercial, agricultural, industrial, hydropower, and recreation and fish farms demands. Managing water use in agriculture is one of the key themes relating to water scarcity and drought. Efficient recycling of irrigation return flow can be considered among possible actions to efficiently use the water resources in water-limited environments.

4.7.8. Private sector coordination

Land use reform and private sector engagements are further promising practices; for instance, dividing the government collective farms into smallholding farm associations fully run by the private sector or jointly with local government authorities. Another example is to shift from a supply-side approach to a more conservative 'demand-side' solution associated with benefit-cost analysis to avoid over-exploitation of limited water resources.

4.7.9. Climate change adaptation

The perception of climate changes currently leave considerable questions by those whom interested in the sustainable use of water resources. However, the ongoing groundwater recharge processes understanding allows some appraisal and to provide a framework for shaping future research. Besides, the amount of recent literature available on these topics tells that this is an active area of research and that the of water managers ability to plan for a changing climate will continue to improve. In essence, the UNECE, (2011) suggested that to adapt to climate change, structural and non-structural adaptation measures are required. The structural measures such as dams, hydraulic diversion structures, flood embankments, and non-structural measures; such as water use efficiency, legislation reform, government authority power. For more forwarded adaptation steps, Al-Zubari, (2002) stated that domestic and irrigation metering and water pricing encourages consumers to use water more efficiently and considered as a pre-condition for the appropriate application of a tariffs policy, in addition to groundwater rational uses. Moreover, techniques of water-saving such drip and sprinkler irrigation have to be applied so that to decrease the groundwater over-uses.

4.7.10. Population rate, and Conflicts

Water supply and rainfall over the case study area is becoming more altered and this is reflected in groundwater recharge and water availability. Because of changes in climate and rise in population, the availability of water is fast decreasing. Most of the districts will experience water stress in the coming years. Available resources are being fast degraded and depleted. Reduction in water availability could leads to several socio-economic issues such as disputes over sharing and migration. National policies do not address the issues seriously. Measures for adaptation often fail because of various social, economic and political reasons. There are possibilities to overcome the growing water crisis through better conservation and management. For this, most of the similar semi-arid areas need a better policies and better institutional mechanism to implement the policy guidelines.

4.7.11. Collaborative actions

Vulnerability assessment, adaptation strategy development and implementation require scientific, technical, planning, financial, and coordination capacity, which many countries, particularly in developing countries cannot provide. This challenge can be addressed by giving government officials and agencies, and civil society increased capacity to mainstream climate change into sectoral plans and incorporate it into the mandate and capabilities of relevant national and local authorities.

The establishment of an information system implies defining specific administrative functions and mandates. In the case of lacks coordination mechanisms for managing water resources, such in the case of the KRG institutional and policy body. It requires reinforced coordination and institutional cooperation among stakeholders involved in achieving sustainable development goals in the water sector. As is the case that the Ministry of Planning is responsible for planning and overseeing the regional development strategies, the water sector falls under the direct authority of MoAWR and Ministry of Municipality. Thus, it is clear that policies of other ministries may have an indirect impact on water resources management.

Equally important, the roles, power and responsibilities of water authorities should be legally strengthened; additionally, cross-sectoral legislation, coordination among institutions, and public participation at all levels have to be strengthened.

4.7.12. Water governance

The water sector as a part of broader political, social, and economic developments and is thus also influenced by decisions by actors outside the water sector. Its governance refers to the political, social, economic and administrative systems in place that influences water’s use and management. Essentially, who gets water, when and how, and who has the right to water and related services, and their benefits.

The determination of the equity and efficiency in the allocation of water resource and services and balances and distribution water use between ecosystems and socio-economic activities should be well-bonded within the applicable framework.

Thus, governing water should include water policies' establishment, formulation, and implementation, institutions and legislation, and the government's roles and responsibilities clarification, private sector and the civil societies concerning services and water resources. The outcomes rely on how the stakeholders play regarding the rules and roles, which have been taken or assigned to them. Here, it should be noted that it requires amendment and perpetual updating of legal acts related to the management and regulation of water affairs within a solid framework adapted to the changeable drivers such as climate change, socio-economic, and technology progressions.

4.7.13. Water conservation and development board

Sustainable water management requires establishment of a body at national level, whose duties are the development of water policy, monitoring the operation, and supervision of research. That is, the policy of rational water management, including measures of water conservation and quality protection, improvement legislation and public education should be adopted. This organisation should have a moral support and advisory authority on the ministries of; water resources, municipalities, and higher education, water research centres, and meteorological centres concerning water issues.

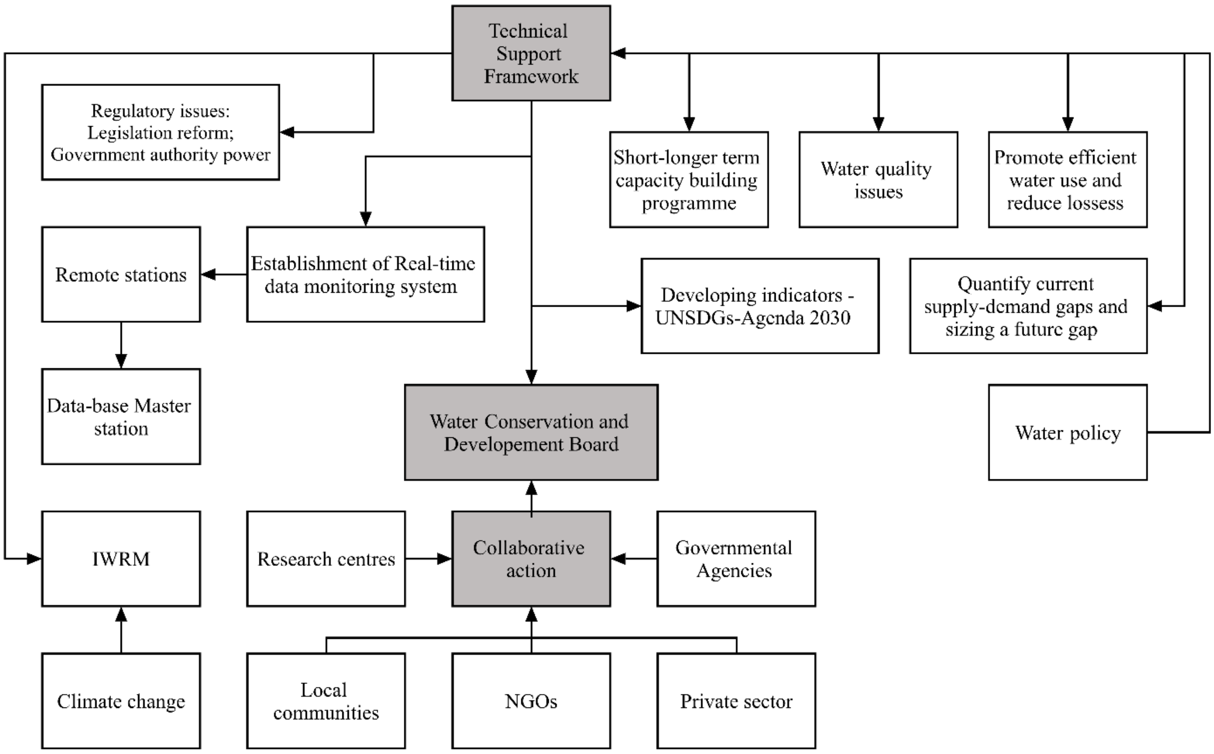

Figure 4.32 The technical support framework

4.8. Summary

To sum up, it can be shown that the arid and semi-arid regions are prone to progressive drought due to climate changes, particularly by decreasing precipitation and a sever raise in temperature rates; these with regardless to other climate variables that cause depression in groundwater level and dire consequences, furthermore, this leads to inconstancy in biodiversity and amenity.

On the other hand, retrofitting of SuDS techniques in such area inspires successfulness and requires further attempts and efforts to tackle the subsequent outcomes to a harsh environment with poor water quality and scarce in water availability.

Equally important, the reforms and amendments in water-related legislation have to be put in place for semi-arid climate condition areas to be copped and adapted with current and future projected expectations in terms of climate alteration, water usages, socio-economic, and population growth rates.

Chapter 5: Conclusion and Recommendation

5.1. Introduction

In accordance reviewing the literature on SuDS concept and water concerning issues in semi-arid regions, it can be inferred that sustainable water and drainage system managements have not received due attention in most semi-arid climatic areas as has to be. Drought spells and frequent flash floods made urbanised and rural areas vulnerable in Erbil province in the study-scoped period.

Most studies on the studied area were limited to technical reports and academic articles, and they have mainly focused on water supply and quality. The available literature on SWM much fragmented and confusing explanations. Much literature is available on water management in different climatic regions, but some being available on the semi-arid areas that have seen the disparity of topics discussed, none of them addressed the (SWM) in semi-arid areas through a solid, comprehensive, and resilient framework. No study has reported how proactive measures, stakeholders, and proper vulnerability assessment of water issues can be used to mitigate the impacts of water shortage, scarcity, and its stress. Thus, it is characterised by a paucity to literature and knowledge.

Drought mitigation policies in most developing semi-arid countries have mostly failed. Most government policies and strategies are introduced at either short-term or has not proceeded due to conflicts or stressors that are out of control. Presently, most of the severely affected regions have drought mitigation policies and strategies that suit their needs. The studies made recommendations for mitigation, which were not reported the governed and the most influencing factors together and comprehensively, and have not been shown how different measures can be applied in affected areas based on their impacts.

Almost all semi-arid developing countries suffer from a perspicuous and well-oriented strategy to overcome water shortage planning management, these seen to be tackled and need to a robust strategy and policy.

The paradigm limitation of research methodology on water management either rely their studies on quantitative data analysis or qualitative data analysis. There should consider pragmatism philosophical stance for (SWM) to answer the research questions comprehensively. The assessment of these effects have been performed through a case study, methodology and methods applied in Chapter Three. Accordingly, a schematic diagram and conceptual framework of this research was designed to incorporate the different effects governing water availability representing as climate change, groundwater depletion, SuDS measures necessity, and legislation power, see (Figure 3.1, and Figure 3.2).

All things considered and in essence, a technical framework has been offered which involves several interconnected themes to support the sustainable management of water resources in arid and semi-arid climate areas and to be as a buffer measure to support a drought contingency plan, see (Figure 4.32).

5.2 Conclusion

The emergence of public attention and concern for the state of water resources gives a timely moment for the field to reorient to meet the interdependent, complex, interdisciplinary, and global nature of today's water problems. Currently, water resources management analysis is limited by low scientific and academic visibility relative to its significant influence in practice and bridled by localized findings that are difficult to generalize (C. M. Brown et al., 2015).

The unmistakable success of water management analysis in practice needs in future to be reinforced by verifying the field as the water resources science, which seeks to predict the variables of water resources and outcomes that are critical to governments, industries, and the public the world over. Doing so advances the scientific reliability of the field, and presents an understanding of the state of water resources and provides the base for prognosticating the impacts of our water choices.

For the purpose of this research, Erbil province the capital of the Kurdistan region, which is located in the northern Iraq, has been chosen as a representative case study for a large number of districts, particularly in semi-arid climate areas. This case is lacking from (SWM) where: experienced a number of drought episodes during the last decades due to severe climate condition; the prevailing practices of groundwater resources utilisation lack of a solid regulatory framework and where monitoring systems are often absent; negligible sustainable drainage systems (SuDS) represented as a rainwater harvesting system (RWHS) measures; water scarcity in decision-making processes; ineffectual legislations and incomplete legal regulatory framework to achieve the targets of (SWM); and the adverse effects of climate change on water systems

As all, these areas have been encountered to a number of issues; lack of sustainable concept in management, more than other climate zones have affected by climate change, mismanagement in water resources, shortages in both surface water and groundwater resources, lack of proper and comprehensive national plan, un-updated legislation issues, and fragile socio-economic situation.

This research has been based on questions, which have been crystallized and generated through reviews of literature and the reality.

This research seeks to help the stockholders as planners, decision-makers, and communities by developing a framework to tackle the problems that these areas are encountering. The research has been adopted on an approach thereby initiating from specific elements toward the general figure of the framework. It based on a number of objectives to achieve the core aim of the research.

Two research strategies were pursued to achieve the objectives: the case study of a province scale and surveys approach. The surveys were relied on questionnaire and focus group interviews as a mixed-method choice, in addition to quantitative data were collected on climate, groundwater, and (RWHP)s.

The findings of this work present that the semi-arid regions have affected by global warming more than most other regions in the world due to the nature of prevailing weather pattern. These regions have limited amount of annual precipitation, implicitly the rainfall amount has been dropping because of the causatives that raise the temperature, which lead to intensify and worsen the situation more.

People have been feeling and aware the concerns of climate alterations, water shortages and the expected aftermaths of environment in both urban and suburbs. The consequence of that will put its marks on different sectors in human's life, administrative, business and decision-making process. Furthermore, the results signify that the implementation of SuDS techniques in these areas will provide positive returns unless planned and managed improperly.

The rapid growths in population, urbanisation, industrialisation and irrigated agriculture have imposed growing pressure on the existing water resources. The public should therefore adopt the concept of sustainability in conserving water resources because water resources have shrunken further with the rising threats of dynamic climate and extreme weather.

Based on the findings of this study, this research concludes and proposes a new drought definition: It states that drought is the shortage of precipitation or water supply that directly affects environment, and indirectly on industry, businesses, and peoples' livelihood.

5.2.1. The strategy of SuDS

Results have shown that people have perception on water management: the challenges to decision-making, findings point out that the highest rate was given to conflicts accounting for nearly 46%, while the lowest proportion was linked to social poverty (12%). About 23.1% and 19.8% were associated with health and economic growth, respectively. Results indicated that nearly 85% of the total risks were related to financial and physical attributes. Approximately 15% of the risks were associated with both regulations and business reputation features. Revisions and amendments of environmental acts, laws and regulations are essential to promote water conservation and investments in integrated water resources management. Urban drainage systems face an increased challenge to meet the demands linked to a growing population, including an increase of internally displaced people.

Moreover, awareness of these problems is fundamental to the search for modern and viable solutions appropriate for such areas, especially in arid and semi-arid regions. Accessible measures need to be considered and developed for implementing SuDS in those cities and features of the technical framework need to be developed that can support the implementation of SuDS.

5.2.2. Climate alteration

Semi-arid regions have affected by global warming more than most other regions in the world due to the nature of the prevailing weather pattern. These regions have a limited amount of annual precipitation, implicitly the rainfall amount drop because of the causatives that raise the temperature, lead to intensify and worsen the situation more.

Climate change has impacts and drawbacks on many aspects of the environment. Studies pointed out that the scarce of surface water resources, the continual enormous demands on domestic and non-domestic waters, what plays the evapotranspiration in the loss of water quantity over vast arable lands, thereby increases the demand on groundwater and decreases its repletion.

Findings show that case study tends to experience drier and warmer weather conditions. An overall precipitation-downward trend and temperature upward tendency were perceived in the study area. This suggests that Erbil province is vulnerable to drought, two dry periods were observed: 1999-2001 and 2007-2008. The year 2008 was found to be the driest year in terms of precipitation over the whole studied area. Despite that, the studied area is characterised by semi-arid climate but the presented results show that the evapotranspiration varies by the topography, the more plains and steppes area, the more evapotranspiration rates occur.

Results of the drought index show that the climate along the studied period was mostly laden to dry than wet. Results display that the ambience along the 35 years scoped period was largely normally distributed and there were 8, 21 and 6 years, which were wet, normal, and dry, respectively. Based on decadal aridity index, the area was tending to change to be an arid zone in the 1980s. The long-term aridity index was being (0.311) classifying as a semi-arid climate, which limited the recharge of groundwater in the area, which caused moisture loss and contributed to drought condition, consequently, it reflected drought crisis that affecting negatively on the recharge of groundwater

5.2.3. Groundwater depletion

The conclusions of groundwater data analysis help the stockholders as, policymakers, planners, decision-makers, and communities by developing a framework to tackle the problems that these areas have been encountering to groundwater depletion. It has been adopted an approach, whereby initiating from specific elements and induced toward the thorough form of the framework, which highlighted a number of aspects: sustainability; regulations and legislations pertaining the SWM; socio-economics situation; climate change; and eco-system issues, which are derived from the themes that have become concerned by hydro-policymakers and who interested in SuDS. The groundwater shortage is coming from over-abstraction, poor management of water resources, population growth, and an increase in global temperature.

Urban and suburb developments are the most affected areas than peri-urbans and outskirts, which need an official posture toward the retrogressive situation. The necessity of mighty management of groundwater is essential through sustainable use of groundwater. The semi-arid regions are most vulnerable to groundwater depletion due to the intensified stress on water demand for multi-purposes, this because of the lack of legislations, recurring drought periods, living levels, and non-sustainable strategies.

Results have shown that all assessed aquifers have been impaired by over-exploitation of groundwater. The amounts of recharge during wet seasons considerably exceeded the one during the dry seasons. Further, the abstractions exceed both recharge and safe yield of the aquifer system.

Current practices of excessive groundwater abstraction for irrigated agriculture and public water supply, pumping of groundwater to store in farm ponds and the competition among smallholder farms and households to drill illegal new and deeper wells have notably dropped the groundwater tables and dried up many wells in the semi-arid case study. The lack of integrated land-use planning and impacts of climate change has exacerbated the pressure on groundwater resources and placed local communities at extreme risk of water shortages as 91% of the observation wells are associated with significant drops in groundwater levels. Therefore, the groundwater reserves of the Erbil basin are exposed frequently to overexploitation.

The results of the monitoring network indicate that continuous depletion is occurring in the urbanised central part of the Erbil basin. The degree of vulnerability of the local communities to water shortages is expected to increase. It has been considering that the current practices of over-abstraction of groundwater cannot be appropriately addressed in the foreseeable future together with the impacts of climate change, decrease in precipitation, and increase in temperature and potential evapotranspiration rates. Therefore, undertaking accurate estimations of groundwater recharge and safe yields for semi-arid region basins are essential.

Regardless of the impact of climate alterations on groundwater, the groundwater itself has impacts on the climate system conditions in terms of evapotranspiration, downwind precipitations, soil moisture and streamflow, so that it seems as an interchangeable process that one maintains the other. The continuation of current practices (i.e. overexploitation of groundwater and illegal drilling of the new and deeper wells) together with a decrease in precipitation and an increase in temperature and potential evapotranspiration rates would severely cripple the socio-economic development and aggravate the existing vulnerabilities of local communities. This warrants long-term sustainable groundwater management transcending status quos and calls for mitigation measures and adaptation to climate changes.

In order to enhance the sustainable management of groundwater resources, it is necessary to strengthen the engagement of the local communities, civil organization societies, and the private sector. In addition, governmental institutions require sufficient financial provisions to support the implementation of the existing regulatory framework. The public should be made aware of the adverse consequences of overexploitation of groundwater and the necessity of long-term sustainable management of groundwater resources. Enforceable management of both surface water and groundwater is required for contiguous aquifers that are sharing between different administrative authorities to protect groundwater from depletion and harness surface water to replenish groundwater. Moreover, a technical framework needs to be re-developed continually to reduce the consumption and wastage of water resources and to limit breaching the rights of others when sharing water resources. A water policy that aims to establish a national groundwater database is also necessary.

The groundwater issues and their solutions tackled can be summarised as below:

- Semi-arid regions in Iraq have experienced significant expansion and the most significant warming during the past decades.
- Semi-arid climate change is affected by land-atmosphere, ocean-atmosphere and dust–cloud–precipitation interactions as well as human activities.
- The warming and expansion in semi-arid regions increase the challenges in dealing with desertification, food security and water supply.
- The semi-arid regions are passing through climate alterations and have had a drastic impact on groundwater abstraction.
- Administrative sluggishness and weak enforcement of the law in developing countries exacerbates the groundwater reserve degradation.
- Robust National database is needed to monitor groundwater exploitations at local and shared aquifers scale.
- A joint comprehensive framework should be developed for sustainable management of water reserves in the threatened semi-arid areas.

5.2.4. RWHS

The semi-arid regions have been encountering to water crisis since their undergoing climate alterations; thus, joint-effect alleviation is needed for both water scarcity and climate variability. The interests of RWHS are essential to avoid most of the environmental, economic and social ramifications.

In an economic perspective, the assessed system is cost-effective. Results reveal that RWHS has a significant role in flood risk reduction. Due to climatic alteration, these regions have been experiencing both: long drought period and combined with extreme rainfall events. The detained rainwater mostly cannot be sufficient along drought seasons for livestock watering and farm irrigation. It can be regarded as a mitigation measure, despite that and as long as the system has been operated, water needs were relatively secure.

For the recreation purposes, it can be utilised along specific season where the climate is moderate. As for biodiversity, despite there was not a satisfactory result, but joint actions are needed to involve Tourism Board, Environment Agency with Water Resources Management. More hydro-geological studies are needed to manage groundwater recharge properly.

5.2.5. Statutory reviews conclusion

There were ineffectual legislations and incomplete legal, regulatory framework to achieve the targets of (SWM); and the adverse effects of climate change on water management.

The tabulated and organised list of in-force-legislations has been reviewed regarding the environment, surface water, and groundwater resources in both authorities; legislations pertaining water quantity and quality management in Federal Iraq and the KRG judiciary sources. To make the conclusion more specific and more explicit, it has been summarised through thematic subsections; also, the inter-relations and intra-relations of concerning issues have been linked, see (Figure 5.1).

5.2.5.1. Islamic Law Related to Water Rights

(Majallah Al-Ahkam Al-Adaliyyah)[18] consisted of sixteen books. Book 10 included several provisions applied to water use and rights that deal with joint ownership. It can be noticed that the basic principles offered in this Book are still in force in the country's jurisdiction (Global Islamic Finance, 2009). Water availability is free and owned jointly by the public, which is stated as a general principle in Article 1234. The next Article asserts that any person cannot exploit the groundwater absolutely, which is an implication on groundwater supply rights that must be taken. Next, the Article 1236 presents that groundwater wells belong to the public if no one has spent on digging the well, inversely, meaning that the well shall be the property for someone who drilled it. Turning to rivers, it has been offered a difference in Article 1239, which is the perennial rivers and ephemeral flow rivers that pass in a few properties. The perennial rivers are owned by the public, whereas the ephemeral rivers can be owned by private.

Section four of Chapter four in Book 10 discusses the right to take water possession for irrigation and drinking. More specifically, Article 1266 states that people and animals can get the benefit for watering. Besides, Articles 1267 and 1268 gives more right over the water that people have full ownership, this Article allows people under certain circumstances to enter any property that these water resources are available to use water.

Article 1265 presents more restrictive rights for irrigation. By which everyone has the right to irrigate farm, utilising the river that no one has owned, and they can trench canals and construct

[18] It was the civil code during Ottoman Empire.

mills. Still, it is not allowable to cause damage over downstream properties by overflowed waters or completely cut off the flowing.

5.2.5.2. Regulatory Laws

Figure 5.1 describe and summarise water management legal themes and the relations between them. There are issues that have not been addressed, yet. They required to be considered in the reform action plans to impress sustainability criteria on water resources management, and to be updated alongside with the progression of the societies and governments.

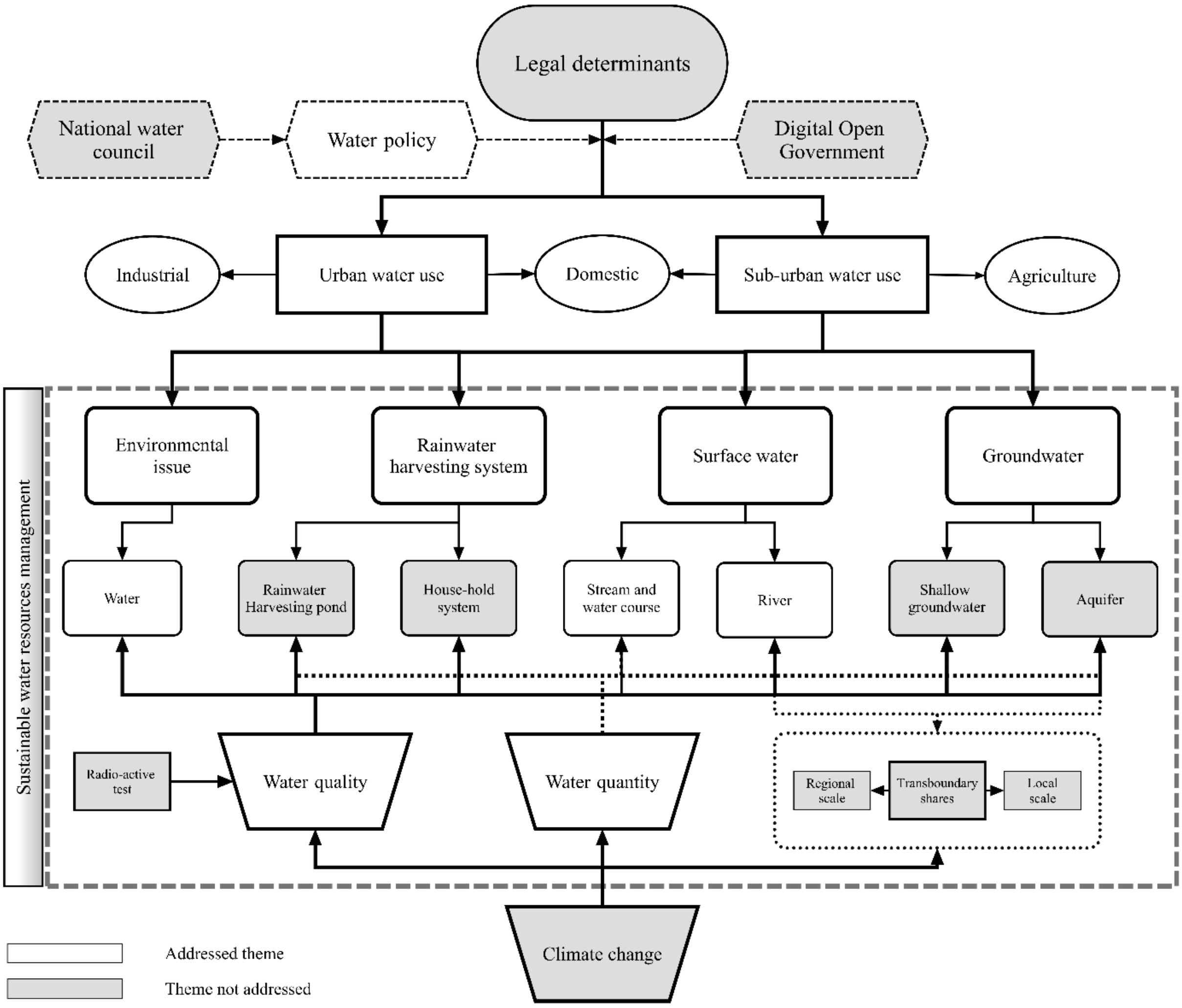

Figure 5.1 The concept map of water management legislations themes

The lawmakers in the area of study have a great awareness of the legal aspects of water resources at various divisions, which is an evidence of their goodwill towards the creation of a useful legal framework for the national water resources. Apart from Article 110 of the 2005 constitution that acts as the Federal Government's landmark in effecting the framework, other laws forming a foundation to the framework have focused on the management, utilisation, and preservation of water as national wealth. Besides, they also determined the proper disposal of waste materials and the processes to follow in processing wastewater.

These current laws and regulations do have their weaknesses as well. For instance, the major flaw noted is the lack of practical and technical details by most of them in guaranteeing the achievement of the obligations regarding the proper management of water resources. Besides that, the drafting of some of the laws follows a general style, with some provisions overlapping one another, others lack detailed mechanisms and scientific dimensions. The barriers face legal analysts and experts in the respective fields, which caused by unreliable texts and insufficient literature highlight another weakness of those laws. Further, due to diverse political assessments by statesmen at this stage, lack of funding and weak monitoring procedures has also acted as factors hindering lawmakers and academic institutions from having a useful contribution to the matter.

It is wealthy to mention; there is a legislative bill called the establishment of the National Water Council. Due to the unrest political situations in the country, this bill has been decelerated for a period, as the region passes through water scarcity and tends to be a water-stressed area. Thus, it ought to accelerate such a legislative bill to set the process on the right path.

5.2.5.3. Governance Power in Charge of the Management of Water Resources

The legislation discussed in this section has the legal mandate of managing water regarding quality, quantity, agricultural use, domestic, and industrial use. The government institutions charged with those responsibilities include Ministry of Municipality, Ministry of Agriculture and Water Resources, and the Ministry of Environment. The government or any of affiliated authorities have been given the power to allocate water rights through the provisions can be argued. Other factors evolving with the daily progress of the society, such as the growth of living standards, increment in water demand, population growth, legal breaches, and unstable political situations must be considered in some laws. Those laws include Article 3 of the Irrigation Law no. (83) of 2018, Articles 14 and 24 of Environmental Protection Law, Article 6 of Instructions no. (1) Groundwater wells drilling of 2010 and the amendments of 2015. Further, Article 7 of the Regulation no. (25) on the maintenance of rivers of 1967, Law no. (27) of Water and Sewerage of 1999, and many others.

Through the review of the authority's responsibility, it can be noticed and inferred that neither commitments nor an obligation on farmers, landlords, and even cattle herders on restrained and reasonable consumption of groundwater abstraction. There should be set water rations table configurations based on itemised categorisations on soil type classifications, sorts of crops planted, and seasons under the law.

The executive authority observes the mandate of requiring those owning agricultural lands to acquire licenses for the drilling of water wells. In Iraq, the Ministry of Water Resources is the one oversees the activity.

It is seen that revisions and amendments of environmental acts, laws and regulations are essential to promote water conservation and investments within an integrated water resources management. Urban drainage systems face an increased challenge to meet the demands linked to a growing population, including an increase of internally displaced people. Therefore, a capacity assessment should be conducted to identify the current capacity gaps and potential future needs. Developing a concrete action plan for short- to long-term capacity building programmes, and put into practice a coherent monitoring and evaluation process and measures to ensure that the implementation is thoroughly followed-up.

It is essential that a strategic framework should be put-in-place in semi-arid regions, people have been feeling and aware the concerns of climate alterations, water shortages and what will be as aftermaths in both urban and suburbs. The consequences of that put their marks on different sectors in people's livelihood and administrations and decision-making process.

5.3. Recommendation

Based on the findings of this research, along with the challenges and lessons learnt throughout the research process, several recommendations can be made for research and practice, which can be subsequently used in future research and official applications, and beyond, in the other semi-arid regions more widely. Therefore, the purpose of this section is to highlight the lessons learnt from this research, and the research process, that may be relevant to consider in future research and practice, referring to the investigation and analysis of the current state of water management.

Overall, it is recommended to undertake more case studies on other arid and semi-arid areas to develop other paradigms of sustainable water management frameworks by relying on influential factors besides to the elements that have been considered in this research.

The Authorities should focus on how to promote individuals' patriotic belonging to preserve the available natural resources in their country and minimize their wastages. Therefore, persuasion of public awareness is needed through different means either media or others on water shortage risks and its consequences.

I would say, that for better policymaking, decisions-making, and robust planning of water resources management, there would be needed a dynamic and vibrant framework, that can be resilient, and adaptable to spatial-temporal circumstances compatible for all semi-arid climate conditions. Additionally, it requires systematically update and upgraded to be adapted to the current and upcoming circumstances.

5.3.1. The strategy for SuDS

There are need calls for exclusive meetings and forums in countries situated in semi-arid areas to share knowledge and reach common goals and results to apply sustainability in water management within an integrated and comprehensive technical framework.

A capacity assessment should be conducted to identify the current capacity gaps and potential future needs, develop a solid action plan for short- to long-term capacity building programmes, and put into practice a coherent monitoring and evaluation process and measures to ensure that the implementation is thoroughly followed-up.

The capacity building development programmes are needed on water management to raise the individuals' performance and ability in water sector.

It is also recommended to prepare an inclusive curriculum on primary health care, which highlights the importance of hygiene and the urgent need to access safe drinking water and basic sanitation facilities. This should be incorporated into short-, medium- and long-term media campaigns that utilise all possible measures including the internet, television, radio and newspapers.

More and more studies and researches are needed to explore the adverse impacts of drought and water shortage on livelihood aspects , and also on unexpected consequents.

5.3.2. Climate change adaptation

The mitigation and adaptation strategies development to tackle anthropic and climate changes impacts is becoming a priority in drought-prone areas. For this reason, there is necessity to think of a new and resilient paradigm and framework of managing and decision-making on facing water shortage, scarcity, and stress in semi-arid areas to be adapted to climate change at global as well as national levels.

Shortage of rain is certainly not limited to Iraq; neighbouring countries are similarly suffering from unprecedented lack of rain. One main factor is human's intervention in nature. Warming rate studies are needed, therefore:

- Expansion rate of aridity in semi-arid areas are needed;
- Studies to be undertaken on dust aerosols in semi-arid regions that may have altered precipitation by affecting the local energy and hydrological cycles;
- Cautions need to be taken that semi-arid regions are projected to continuously expand in the 21st century, which will increase the risk of desertification in the near future.

5.3.3. Recommendations for sustainable groundwater management

Understanding the potential effects of climate variability, as well as repletion situation on groundwater availability and quality, is more complex than with surface water, and needs more studies that are comprehensive. Therefore, there is a need to develop a robust framework that be based on sustainability concepts to manage water resources and drainage systems as an interrelated component for maintained groundwater.

The case study's groundwater under-drain towards both Greater Zap and Lesser Zap rivers can later be estimated from the processes of monitoring and follow-up actions, gathering data for a long-spanned time series are required of all the variables; precipitation, effective rainfall, effective infiltration, evapotranspiration, discharge (well extractions), recharge, aquifers storage. By adopting the approach of cumulative storage and relying on both methods; storage change from groundwater levels via reported observation wells records at the site, and the data-driven from the aforementioned parameters. Hence, we can generate two charts, the difference between them will be the under-drain toward rivers.

Thus, the development of a local groundwater database linked to regional databases is strongly recommended for sustainable management purposes. Despite uncertainties in predicting future climate alterations in semi-arid areas, most researchers predict that the up-coming decades will be characterised by severe droughts. Thus, groundwater reserves must be maintained.

Groundwater over-exploitation and depletion (specifically in arid and semi-arid areas) leads to lower groundwater levels, storage reduction, and sea water intrusion in coastal areas, quality degradation and land subsidence. Therefore, stakeholders such as the government, communities, civil society organisations, and lawmakers need to agree on sustainable plans for the future.

There is a need for identifying the most threatened groundwater zones for decision-makers and local authorities to implement their strategies for long-term sustainable use of groundwater.

Therefore, mapping of recharge areas and groundwater protection zones are crucial and should be considered as an integral part of long-term integrated watershed management, particularly for the sustainable management of groundwater resources.

Groundwater in shared aquifers should be regarded as common to all parties. Active and enforceable management of both surface water and groundwater is needed to prevent groundwater depletion by harnessing surface water to replenish it.

Moreover, a technical framework is required to be developed to sustainably manage the water resources in an integrated manner through focusing on a number of issues: Legislation reform, government authority power, effective and efficient real-time data monitoring system, water quality, supply-demand gaps, research support centres, climate change, UNSDGs indicators, water policy, and also the collaborative action should be well considered in the developing of technical framework.

To manage groundwater in a safe and sustained manner, researchers on semi-arid areas should develop their studies on a long-time series spanned for several decades in order to get more reliable results, as these areas have been being subjected to unsteady, unpredictable, and unsettled climate alterations.

It is recommended a resilient strategy, which increasingly introduces more restrictive policies in alliance with local traditional systems of water delivery. Therefore, the option of forming water user associations, as applied worldwide, should be tested at the first stage. The survey conducted in this research points out that a groundwater regulatory framework for sustainable conservation and protection of groundwater resources is lacking.

In order to enhance the sustainable management of groundwater resources, it is necessary to strengthen the engagement of the local communities, civil organization societies, and the private sector. In addition, to strengthen the governmental institutional and management capacitates and provide sufficient financial provisions to support the implementation of the existing regulatory framework. High attention should be given to the enhancement of public awareness on the adverse consequences of overexploitation of groundwater and the necessity of long-term sustainable management of groundwater resources.

Both climate and socio-economic change have consequences of future changes of groundwater recharge, this should be valued. Synergic efforts between hydrogeologists and researchers from other disciplines should come together. thus, the socio-economic will have affecting in terms of the government's budget and publics' earnings.

Joint consolidated planning is seen as a pivotal requirement among the water resources authorities, agriculture, municipalities, environment agency, climatology-monitoring department, in terms of planning, implementing, legislation, and good governance at high levels. Besides, a National Ground-Water Monitoring Network is needed to follow-up the spatial and temporal fluctuations in groundwater levels.

Several pieces of research have checked GRACE-derived groundwater variations with field-data that were obtained from observation wells and boreholes. These ground verification practices have been undertaken in different environments around the world, namely in (India and Bangladesh), humid tropics (Brazil), and in semi-arid regions (Niger and the High Plains aquifer, Australia, Central United States) with similar climate to Erbil. This offers a good fit between GRACE-derived groundwater variations and in situ observation well records, with discrepancies between the two datasets ranging from 2.1-3.5 cm (Rodell et al., 2007; Swenson et al., 2008; Syed et al., 2005; Voss et al., 2013). In this regard, the GRACE satellite data can safely be used for semi-arid areas assessing seasonal fluctuations of groundwater.

5.3.4. RWHS necessity

Actions are required as attempts to successfully apply RWHP in a sustainable manner based on developed strategies that should be considered. In semi-arid areas, a comprehensive database of all the components that can be incorporated into SuDS and water resources management is needed. On the other hand, a strategic planning is also needed to better understand the philosophy of SuDS supported by a solid action plan.

It is recommended that the RWHP should be categorised up to their functionality:

Recreational ponds

1. Cannot be used for watering animal chattels
2. The land area should be public ownership
3. Situated at outskirts to avoid insect and mosquitoes spreading in hot seasons
4. Surrounded by handrails to save people.

Recharging groundwater resources

1. The land should belong public authority
2. Suitable soil cover and stratifications in order to facilitate and accelerate water percolation into the ground

3. Can be located in any site
4. Avoiding silt settling by selecting suitable catchment soil cover.

Livestock watering

1. The site should be situated at suburbs
2. The land ownership can be private or public
3. The only use is for animals and agricultural uses
4. Avoiding silt settling by selecting suitable catchment soil cover

Flood risk mitigation

1. Avoiding silt settling by selecting suitable catchment soil cover
2. Site selection is important for best performance and functionality.

Biodiversity purposes

1. The site has to be selected that matches with environmental and touristic guidelines
2. Avoiding silt settling by selecting suitable catchment soil cover.

5.3.5. Statutory recommendations

5.3.5.1. Legislative Amendments

Amendments and updating are needed on water pertained Acts, laws and regulations to cope with changes and spatial and temporal challenges such as climate alteration challenges, socio-economic, and politics. Besides, there is a need of power of the authority to support the laws and regulations.

The amendments for laws, regulations, and instructions are alteration or additions can be made to a resolution, legislative bill, statute, or even constitution offered to bills in the course of their passage through a legislature. The statutory status of water resources management is being affected by the socio-economic conditions, climate alterations, and technology developments. Therefore, the water legislation in this case study area lacks a few components that strengthen the pillars supporting the process of regulated water resources management:

> Firstly, the most significant issue that the semi-arid areas facing is climate change and alterations, there needs to order laws and regulations that justifies actions that would partially overcome the adverse impacts to climate change on the water the region.
>
> Secondly, there is not any distinct Law or Article declares the need for sustainable drainage systems based on the particular criteria that have to be committed by local authorities to save the quality and the quantity of water.

Thirdly, the severe climate conditions oblige amendments that should be done on water resources rights and allocations, that is a decision-making process, which needs to be empowered by legal supportive. The distribution of available surface water and groundwater resources should be in respect to:

- temporality (when water can be abstracted);
- spatiality (where it can be used and from where it can be taken);
- users (who can abstract it and who can use it);
- purposes (what it can be used for and how it should be used).

Lastly, droughts, water supply worries and population changes serve as catalysts for semi-arid regions to consider legislation related to water conservation and alternative sources of water including rainwater harvesting. The legislatures in semi-arid developing countries should consider bills to allow, define and clarify when, where and how the harvesting of rainwater may occur. Harvesting of rainwater is generally described as the act of a system utilization (either tanks or ponds) to collect and use rainwater for different consumptions. That is, the necessity of regulations enactment is seen required within the water conservation law, this regulation is to reflect the significances of water conservation law over sustainable drainage systems, this by legalising rainwater harvesting systems at both scales: the urban areas (household scale) and the suburb areas. Besides, the legislatures should consider factors, such as water rights, quality standards and public health, that rainwater harvesting may impact. These laws should clearly state that the rainwater belonged to the existing owners of water-rights, and that water needs to flow to join its water drainage paths, of course, according to fair rights for all residents and owners in the administrative area. Legislators also should guarantee public health concerns and water quality standards are met when enacting rainwater harvesting legislation. For example, collected rainwater may be used for non-potable purposes (e.g., watering indoor or outdoor plants) but may be restricted for potable purposes (e.g., drinking water, cattle watering).

5.3.5.2. Frameworks for Water Law Reform

- The laws could improve in their presentation of both virtue and inadequacy of the legal structure of water management. Some few factors that could be considered for improvement include increasing the cooperation and coordination between various government entities, especially if scientific and technical research, and particularly when enactments vitally define the methods for regulating water resources. Another recommendation is that there is a necessity for focussing on the increase in social awareness in a way that coordinates with the behaviour of the community considering that the global nature of water deficits, especially in semi-arid Middle East, calls for the need for efficient use of the resource, its protection, and its conservation as well, which is possible through developing strict legislatures. Thus, the best solution available would be the maintenance of water resources, especially groundwater at both qualitative and quantitative levels.

- There is a need to contingency plans for semi-arid regions water management and drought. There would be necessitated to programming potential demand management, drought contingency plans, budget allocations from the annual gross domestic product (GDP), Integrated water resource management and river basin planning, and other issues based on legislating bills that should be enacted.
- Joint consolidated planning is seen to be required among the water resources authorities, agriculture, municipalities, environment agency, climatology monitoring department, in terms of planning, implementing, legislation, and good governance at senior levels.
- Laws and Regulations are needed to legalise the use of emerging technologies for water management. Keeping up with regarding such technologies that can be used for rational water management.
- Model-based legislation should be formulated based on the annual groundwater reserves estimations to sustain the depletion of groundwater in a strict manner.
- It is required the enactment of laws on transboundary groundwater shares at the regional scale.
- It is seen that it is necessary to accelerate to conclude agreements and treaties that would require legislation on transboundary surface water shares locally and regionally.
- Recently, a new philosophy has emerged in a number of governments that called Digital Open Government (DOG), by which people can access to the data and information that belongs to government departments. Stack-holders and communities can take participation in the decision-making process as partners along-side governmental authorities. The Open Government Data Project (OGDP) is increasingly a set of policies that promotes accountability, transparency, and value creation by making government data available to all. Water resources bodies can make commission and produce huge quantities of information and data. Making public institutions shift to more transparency and accountable to citizens by making their datasets available. It is recommended to prepare a legislative bill to legalise such project in the semi-arid area to improve water management condition.

As a platform, the Open Government Partnership (OGP) potentially reform water governance helps people to have access to clean water, avoid people from epidemics caused by contaminated waters. thereupon, and to achieve the global 2018 Sustainable Development Goals (Clean Water and Sanitation) SDG 6 targets, it has to be work on the right track.

- Recommendations on Convention on the Use of International Watercourses
  - Countries like Turkey and Iran refused to enter the international watercourse convention justifying that the rules set out to regulate the use of the convention are not suitable for some types of watercourses. additionally, Egypt has not also joint pushing that it has historical rights on the Nile River. it can be suggested that the arguments of states should be studied and discussed with a view to their adoption in the Convention in order to minimize the volume of conflicts arising out of the world's watercourses due to non-adherence by States.
  - A permanent institutional framework should be established to settle, solve problems, follow up, and emphasize on the parties the need to resolve them peacefully. This can only be achieved through the establishment of an international water organisation denominated as the World Water Organization or the World Water Association.
  - Iraq should review all its water policy and indicate its weaknesses, including the review of irrigation techniques (that already been ratified by the Law The Law no. (10) The Ratification of the Convention to establish the ACSAD of 1971, (Article 3 / Items 2, 6, and 8) and maintenance of dams and management of water resources by international methods adopted, as the departure of Iraq from these affairs is a negative aspect of the violation of Iraq's international obligations, which was committed to it under international treaties, especially since the Framework Convention has explicitly included that.

5.3.6. Recommendation on framework

The framework is incomplete structure, but loose, which gives a place for other practices and mechanisms to be included but provides much of the process required that is, re-updating the framework is considered as a continual process targeting to achieve the optimal results based on the current needs.

Stakeholders can implement any framework that suits their needs while the government should implement the Integrated Framework.

The framework should be evaluated and reviewed over time, to evaluate the effectiveness and improve the frameworks. If the frameworks are successful, they should be transformed into projects and long-term programs.

Undertaking regular analyses are indispensable at some hotspot areas within the framework. To assess that, the vulnerability of linked themes to climate is crucial for appropriate identification of how adaptation investments can most effectively boost the resilience level of communities in response to the collective adverse influence of climate change at the case studies level.

5.4. Contributions to knowledge

The crystallisation of this research was to develop a quasi-existing fact, or a technical framework for improving water management policies. It has been performed by attempting to examine the key factors critically that affecting water resources management in specific conditions and circumstances of semi-arid Erbil province case study. There is limited research on the development of the technical frameworks, which are only bounded to the transboundary water resources that have not been taken sustainable water resources comprehensively or nearly all aspects of water management in semi-arid areas. Therefore, this research is the first study to do so. Although the contribution to knowledge surly validated to the scope of this research spatially and temporally, the integrate methods into a durable technical framework, which can support decision-making for mitigation to and adaptation with the collective impact. The novel approach, which was successfully developed in this thesis, is cast to form a solid framework that can support the sustainable management of water resources scarcity. It can be developed further depending on the challenges of the existing factors and the anticipated circumstances that encounter to water resources management in the future. Besides, the outcomes might be significant to some other developing countries to manage their water resource management system sustainably based on the circumstances of the conditions and of that country.

The developed frameworks can facilitate mitigation of water scarcity and drought effects in Erbil province. The data, information, and knowledge collated in the study have produced identifiable contributions, to theory, methodology and practise.

5.4.1. Theory contribution

Many studies have defined drought differently depending on the situation and context. (Dracup et al., 1980; Lloyd-Hughes, 2014; Mishra & Singh, 2010) admitted that there is no standard definition of drought, making it difficult to understand. Considering that, several definitions of drought have not been used or mentioned specific attributes of drought. Based on the findings, this research concludes and proposes a new drought definition: It states that: *"Drought is a phenomenon that there is less precipitation than evapotranspiration or shortage in the water supply or both, which directly affects the environment, and indirectly on the industry, businesses and financial basis, which triggers conflicts as risks to the government and an overall threat to people's livelihood."* It is foreseen that this definition will support drought knowledge which has to be widened further.

This research has also offered two conference articles and submitted three journal articles (Appendix B). These publications will serve as additional sources of information SWM. This research has extensively studied the problems of SWM and drought for the semi-arid regions and presented related issues from Erbil case study.

5.4.2. Methodology contribution

The government undertook most efforts on water management and for drought mitigation, which were limited to technical reports and articles, and the comprehensive sources of data have not been adequately involved. This research used both sources of data: the primary and secondary sources and both the quantitative and qualitative sorts of data; both were analysed from a perspective of pragmatism philosophy stances, by which embraced interpretivism, constructivism, and objectivism philosophies. As all, the research tracked an approach of deductive reasoning.

All these have been narrowed down, targeting toward data collection to support developing the technical framework, which is seen as a unique methodology that has never been taken up before.

This research helped to show the importance of SWM and drought impacts' alleviation, its influence on policy and how SWM is perceived among decision-makers.

5.4.3. Practise contribution

This research developed an (SWM) framework for Erbil province, which can be used and adopted within the semi-arid climatic areas. The study explored the complications and difficulties. It has also identified different coping strategies on various frameworks viewpoints that can be adopted. The research has contributed to the search for solutions for coping with drought by encouraging policymakers, planners, decision-makers, water managers, water expert cohorts, and even containing civil societies and local communities to think in more resiliency. Moreover, by involving all concerned and contributory stakeholders giving them responsibility as an interacted and inter-related system, rather than merely relying on the sole independent system working.

The adoption of framework adaptability and resiliency re-generating it would support the water sector more adapted to drought-prone. If these are practised, the future of such climate areas will be unthreatened and non-vulnerated, which will improve drought mitigation strategies. Three sector frameworks were developed, considering groundwater, SuDS, and statutory issues were involved in drought mitigation. Considering all relevant parties is vital in achieving the desired objective of reducing the impacts of drought Erbil province. This research developed a framework that KRG-Iraq can implement as part of water management and drought policy. There was no joint compatible SWM and drought mitigation and management policy in Erbil province before this research. The study produced a comprehensive framework that can potentially ameliorate the effects of water scarcity and to buffer water stresses in the future. The research achieved its main aim by developing a comprehensive technical framework to avoid and mitigate drought and SWM.

5.5. Areas of further research

Abdullah bin Salama (550-663 A.D.) in his poem that been cited in (Al-Zubaidi, 1984) says :

“Tell the one that believes contemporary science is nothing

And (that person) recommends the antecedent science instead

Indeed, the previous researches at its time were novel ....

Inevitably, today's science will be considered outdated in the future …”[19]

Also, (Lebrun, 2011) in his book says that, *"My work ends here, and now yours start"*. Hence, scientific research is a continuous process that requires advancement, and demonstrating future works in scientific research is crucial. In previous chapters, the researcher has not addressed some of the potential areas of study that require further investigation for the future. I recommend the following topics to be taken in consideration for future works sections:

[19] This poem translated from Arabic.

- It can be recommended to develop another technical framework by employing an optimisation model that meets the semi-arid climate characteristics using the same component variables that been chosen in this research.
- As this research has adopted an abductive approach, further researches can be conducted on inductive approach adoption, or a reversed direction that is a deductive approach, by which the developed framework can be tested. Additionally, There is a potentiality for further works, which is to carry out research following abductive approach, by which, an integration of both aforementioned approaches would be used in one package.
- In a rapidly changing water resources management, (dynamic models approach)[20] based on the notion of systems thinking can serve as useful analytical tools for scientists and policymakers to study changes in key system variables over time. Both quantitative and qualitative data sources can jointly be involved and analysed within a novel paradigm methodology.
- Studies can be undertaken on groundwater storage changes and level variations in a specific area, which are less than the specified 50000 sq.km. GRACE data can be used, this by adopting downscaling statistics method from neighboured around areas, this is to verify and assess the degradation of groundwater, and to find out the extent of climate change impact rate on excessive groundwater reserves depletion.
- Sustainable water management should be adaptable spatially and temporally. It is seen that by applying agent-based modelling[21], it would be necessary to explore and examine the performance of the influential items. Thus, the pragmatic management framework needs to be active for a specific region, which affected by human decision-making and behaviours.

5.6. Limitations of the study

Although this research has accomplished its core aim, there were some unavoidable limitations. Firstly, due to the prolonged military actions and unrest political situation in the study area, there were insufficient ground-based (MS)s. And also, unavailability and incomplete data record for the

[20] System dynamic approach is a set of interactive elements that perform independently of each other to achieve some particular objective through the control and distribution of material resources and information.

[21] The agent-based model is a class of computational models for simulating the actions and interactions of autonomous agents (effective factors, or collective entities such as organizations or groups, or individuals) with a view to assessing their effects on overall the system.

period before the Second-Gulf-War. The virtual weather data point records have been employed (NCEP, 2015), which are reliable and used by preceded research studies.

Secondly, as the virtual weather data points have been generated based on (Global Circulation Models), which been assigned as a regular data points network, only seventeen (MS)s have coincided with the boundary of the study area,

Thirdly, the researcher hoped to get a more extended time-span climatic data, rather thirty-five hydrologic years and more data points rather than seventeen (MS)s. However, the data were available only from 1979 to late 2014.

Fourthly, for future studies, it would be recommended that longer time-span data acquisition seen to be preferred, and also to generalise the obtained conclusions more meteorological stations should be involved.

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Appendices

Appendix (A): Summary of reviewed studies (gaps in representative case studies)

No.	Selected reference	Methodology: Philosophical stance and method choice	Methodology: Research strategy	Key finding	Recommendation and Further research opportunity	Region
1	(Bhangaonkar, 2018)	Mixed method choice; Quantitative and some qualitative data	Survey Questionnaires; Interview	The natural resource constraints are hard to overcome even with resource rejuvenation programmes.	The possibility of developing detailed databases at the cluster level and/or watershed level through a framework will permit a more holistic understanding of sustainable water management to ensure better and more stable rural livelihoods; Understanding the potential of institutions in the local sphere to encourage resource management and thereby livelihood sustainability.	The semi-arid districts of Ahmednagar and Jalna in the state of Maharashtra in India
2	(Gebremariam, 2011)	Mixed method choice; Quantitative and some qualitative data	Survey Questionnaires; Interview	Developed model frameworks useful for pre-identification, early warning of and preparedness for the effects of local water conflicts.	local water conflict preventive measure can be studied; Establishing an academic scientific journal homepage on conflicts; Establishing an international advocacy group; Instructional/teaching media on sustainable development information preparedness, tolerance capacity and interaction water conflict parameter.	Afar region, Ethiopia
3	(Gana, 2018)	Mixed method choice; Quantitative and some qualitative data	Questionnaires; focus group	Drought has affected people, with losses of ~70-80% of their harvests and livestock; Drought management and mitigation programms were developed for Yobe State in Nigeria; Drought coping strategies have also caused environmental degradation; Several efforts to mitigate the impacts of drought by the Nigerian Government have failed.	It is envisaged that the findings would be used as a reference for policymaking and legislation; It is necessary to use and implement developed frameworks as a means of drought mitigation and management; Weather data, technology and expertise need to be considered to help investigate drought impacts and preparedness processes needs to be studied more; The role of all stakeholders should be included in the process of drought mitigation in order to achieve sustainable growth; Research on how drought affects both subsurface and surface water bodies is required;	Semi-arid Yobe State in Nigeria.

					climate parameters should be used to develop a weather model that can analyse the severity and magnitude during and after droughts for planning and preparedness purposes; A comprehensive study is important to study and evaluate the successes of these policies and make recommendations on the outcome of Government policies on drought.	
4	(Chabalala, 2017)	Interpretivism philosophical stances; multi method choice; Qualitative data	Focus groups; document reviews; semi-structured interviews	Five major challenges impede the formation of a comprehensive water resources management system namely; lack of financial resources, lack of skilled human resources, poor governance structure, ineffective stakeholder engagement, and inefficient data management; The main recommendations made include institutional reform and enabling legislation which form the basis upon which any development efforts can be pursued to achieve sustainable water resource monitoring;	The creation and/or optimization of water resource monitoring databases is one of the viable ways for sustainable water resource management to be realized; Research can be conducted to assess the challenges in water resource monitoring and provide sustainable solutions; Research can be done with the aim of quantifying the impact of policy reforms in the water sector; Research can be done on how effective regulation and co-operative governance for water sector can be achieved through participatory processes that aim at developing priority water research questions.	South Africa
5	(Furat Ahmed Mahmood Al-Faraj, 2015)	Mono method choice; Quantitative data	Case study strategy	A generic statistical tool is also developed, as part of the technical support framework, to separate the relative effect of upstream development from the combined impacts. The proposed method supports water managers in unbiased, timely and spatially relevant decision-making processes; The proposed methodology offers a solid tool to support water managers and decision-makers in shaping better management plans and strategies for water resources that are anticipated to be available in the short to long term; A shift from the traditional irrigation approach (e.g. gravity irrigation) to modern techniques (e.g. drip and sprinkler irrigation) and improved conveyance efficiency would reduce irrigation demands, but in return, it will be	Perform analysis to assess the effectiveness of some of the adaptation practices and mitigation measures, such as rainwater harvesting systems, optimizing storage reservoirs and inter-basin water transfer systems. This can be conducted at some existing pilot projects; Perform drought forecasting analyses and studies of high reliability at transboundary basin-wide scale, particularly in arid and semi-arid regions, considering the potential spectrum of uncertainties. This could benefit from the developments in global drought monitoring and forecasting.	Diyala Transboundary river basin, Iraq

				more expensive and requires experience and continuous maintenance; The novel tools and approaches, which were successfully developed in this thesis, are casted to form a solid framework that can technically support the sustainable management of transboundary basins of scarce water resources.		
6	(Bitterman et al., 2016)	Mono method choice; Quantitative data	Multi-criteria approaches	The causal network identifies the key components, causal linkages, and outcomes of water security processes, and is used to derive a suite of indicators that reflect the multiple economic and socio-ecological uses of rainwater harvesting systems.	Future research should focus on knowledge gaps highlighted by the causal model, including component interactions, scale, and data availability.	Semi-arid Tamil Nadu, India
7	(Gupta et al., 2017)	Mono method choice; Quantitative data	Geostatistical modelling	Results of this study clearly indicate that the annual rainfall in the western arid region is under a deficit condition with very high temporal variability. Thus, agriculture enterprise in this water-short region of the country is under severe threat not only due to limited availability of the rainwater but also owing to high uncertainty to get assured water supplies under the scenario of extreme rainfall variability.	There is an urgent need for managing the scarcely available rainwater in a sustainable manner by adopting appropriate planning and management strategies such as the implementation of rainwater-harvesting and groundwater recharge structures in the region, adoption of water-saving micro-irrigation methods, cultivation of crops having less water requirement, among others; The formulation of appropriate strategies and policies to conserve and efficiently utilize water through water management frameworks may serve as a scientific guideline for decision-makers, planners, researchers and resource managers.	Arid region and north-west semi-arid region of India
8	(Adamo et al., 2018)	Mono method choice; Qualitative data	Archival research review	It is very clear that the climate change impacts are negatively affecting socio-economic developments; Agriculture in Iraq has been declining for variety of reasons with climate changes; the climate change impacts contribute to a broad range of destabilizing trends within states; The decrease of water resources due to natural climate change impacts coupled with the unfair sharing of water by Turkey and Iran may lead to armed conflicts; The migration from rural areas to urban centres due to the shrinkage of cultivated land areas	there is the need to develop a comprehensive and continuous plan to limit the expected consequences of Global Change Impacts and to put it into application immediately; One of the elements is to introduce radical changes to all water and soil management policies and practices. The water sector in Iraq currently is suffering from endemic problems Strengthening the administrative and management framework with better monitoring and control of water sharing and supported by effective legislation and strong authority for their implementation.	Iraq

				and the declining output will be exasperated and adds further difficulties to the local authorities.		
9	(Xue et al., 2015)	Mono method choice; Qualitative data	Archival research review (system-based analysis)	An example paradigm shift design for the urban water system is presented, not as the recommended solution for all environments, but to emphasize the framework of system-level analysis and the need to visualize water services as an organic whole; This review also emphasizes a system thinking approach for evaluating alternatives that should include sustainability indicators and metrics such as energy to assess global system efficiency; It is encouraging to find that many communities around the world are taking steps towards more sustainable solutions.	To integrate the monitoring, modelling, assessment and management of water resources, drinking water, wastewater, and stormwater using a systems approach and watershed perspective, it is important to understand the historical background of current water systems, analyse their various issues as components of a larger system, and layout the argument for a conceptual framework and potential tools for such comprehensive analysis; The new water system will also require a new operating structure and governance framework to accommodate complexity and uncertainty	Estimated (City of Tomorrow)
10	(Gamboa, 2014)	Positivism and interpretivism philosophical stance; Mono method choice; Qualitative data	Case studies and interviews, Soft Systems Methodology	The research supports the achievement of a major societal goal which is to gain trust among all groups of stakeholders and the community served by the river basin, which can lead to improved contribution and commitment to reach good water governance; A conceptual model is presented aiming to guide decision-makers to solve the identification of gaps in stakeholders' participation in the river basin management; Proposals to various policy maker stakeholders	Researches could be undertaken to conduct more river basin management studies in other regions where water framework directive is still applicable;	Semi-arid Portugal
11	(K. E. Lee et al., 2016)	Interpretivism philosophical stance; Mono method choice; Qualitative data	Case study; Archival research	RWH has emerged as one of the measures to enhance the resilience of human society towards water shortage problem; RWH has yet to be mainstreamed into the national water and climate change policy as an adaptation strategy to climate change, especially in urban areas where water resources are fast depleting due to rapid increase in population and water consumption.	It is suggested that inter-ministerial and multi-stakeholders cooperation are needed to promote the development of RWH in the country to be authoritative and organized as an alternative water resource.	Malaysia

12	(Rashid, 2014)	Mixed method choice; Quantitative and qualitative data	Questionnaire; Archival research	The increase of domestic water consumption, agricultural, hydropower and industrial uses all affect the increase of water shortage. Drought has also affected negatively the water coverage and allowable amount of drinking water that is provided for the population; Results revealed that the drought was constraining, more the farmers from province to province in different rates; Also, the flooding mentioned as a constraining issue.	The necessary adjustments can be made to receive the optimum effective management design, in order to prepare the national "water policy" regulations governing water abstraction, the economic price of irrigation water, and the strategic water management plan of the Kurdistan Regional Government; This research can be repeated by determining other welfare measures such as willingness to accept (WTA) in rural areas. It even has implications for urban areas and other sectors which are linked to the economic value of market and non-market goods and services of the Kurdistan Regional Government.	Semi-arid Kurdistan region, Iraq

Appendix (B): The published articles

The first published article paper

water

MDPI

Article

Strategic Framework for Sustainable Management of Drainage Systems in Semi-Arid Cities: An Iraqi Case Study

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Abstract: For the purpose of this paper, Erbil city, located in the northern part of Iraq, has been chosen as a representative case study for a large number of cities, particularly in semi-arid areas, lacking sustainable drainage systems (SuDS). The study assesses (a) the role of SuDS as a measure in areas with a water shortage; (b) water scarcity in decision-making processes; (c) the lack of legislation to implement SuDS; (d) the adverse effects of climate change on the urban drainage system; and (e) the effects of an increased population on SuDS implementation. An integrated methodology that incorporates a self-administrated questionnaire, workshops, face-to-face communication and interviews, as well as electronic media interactions, were used to achieve the objectives. A generic platform that consists of thirteen pillars, supporting the short to long-term national policies and strategies towards a sustainable urban drainage system, has been developed. Results showed that environmental laws need to be introduced. Findings also indicate that a growing population, which is partly due to an increase of internally displaced people, is a major challenge to an early application of SuDS, due to a rise in land demand and a lack of financial resources.

Keywords: climate change; flooding; legislation; population growth; sanitation; socio-economic; sustainable framework; sustainable drainage system; urban inundation; urban ecology

1. Introduction

1.1. Background

Decades of wars combined with economic sanctions, armed conflicts, and the current insecure atmosphere has left deep scars on Iraq's environment, socio-economic features and infrastructure. A large proportion of the water supply and sanitation services are malfunctioning, which greatly intensified water-related challenges and exacerbated the size of the problems [1,2]. This has threatened human life, the environment, and the safe access to water supply and basic sanitation practices. Most people have limited or inadequate access to safe drinking water and basic sanitation facilities. Poorly trained personnel, an intermittent power supply, a sharp decrease in spare parts availability and chemicals needed to maintain the safe running of water treatment plants, inefficient operation and maintenance programmes, and a prolonged tendency that relies on curative rather than long-term sustainable solutions have intensified the problems of the water-related service delivery systems, particularly the sustainable governance of drainage systems [2–4].

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The second article paper

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Estimating Ground water Balance in the Presence of Climate Change Impact: A Case Study of Semi-Arid Area

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Abstract

The exploitation and management of groundwater in an integrated manner is gaining global interest. Rapid population growth is frequently linked to climate change.In order to meet the growing demand for public water supply and irrigation, especially in arid and semi-arid climate regions, groundwater is used excessively. This paper considers Erbil province of the Iraqi Kurdistan Region as a representative case study for semi-arid climate areas where current practices of groundwater resources utilisation lack a solid regulatory framework and where monitoring systems are often absent. The role of climate change in the assessment of aquifers is assessed. Long-term average recharge and extraction rates in relation to groundwater storage have been evaluated with the aim to avoid adverse long-term impacts on groundwater resources. A groundwater balance method has been used to quantify the storage of groundwater within aquifers. Results revealed that there is a considerable imbalance between the input (groundwater recharge) to the Erbil province aquifers and corresponding output (groundwater withdrawn). The reduction of losses in water use, increases in irrigation efficiency, raising of public good water-use practices, and the establishment of a regulatory framework to appropriately manage groundwater resources are outlined.

***Keywords**:Arid and semi-arid region; Climate change; Groundwater depletion; Groundwater storage and recharge; Effective infiltration;Effective precipitation; Regulatory sustainable groundwater strategic framework*

The third-unpublished article paper

EWRA *European Water* 60: 279-285, 2017.

Sustainable management of rainwater harvesting systems: A case study of a semi-arid area

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Abstract: In this paper, Erbil province in Iraqi Kurdistan has been chosen as a representative case study for a large number of provinces in semi-arid areas, lacking imbalance between water demands and supply. Climate change is expected to bring higher average temperatures and lower precipitation, which would intensify the pressure on water resources and increase the environmental concerns. A set of fifty-five detention ponds in Erbil were investigated, with storage capacities ranging from nearly 49,000 m^3 to 250,000 m^3. These ponds were constructed to mainly supply smallholding farms, watering livestock, and for groundwater recharge. The paper seeks to examine the function and necessity of retention ponds, as a sustainable drainage system measure in semi-arid areas, to mitigate the growing combined impacts of a water shortage and inter-annual climate variability. A set of indicators was adopted: (a) the cost of construction; (b) harvested water volume; (c) irrigated farms; (d) the number of beneficiaries; (e) the number of livestock kept; (f) groundwater recharge; (g) recreation activity; and (h) biodiversity, in addition to checking its materialising by concerned authorities and residents. A detention pond application plan has been developed to support the sustainable functioning of Rainwater Harvesting System (RWHS).

Key words: Detention pond; climate change; supportive strategy; water shortage; integrated water resources management

1. INTRODUCTION

In the World Economic Forum 2017, it has been pointed out that environment-related risks also stand out in this year's global risk landscape. The most frequently cited of these being the pairing of "water crises" as well as "failures to climate change mitigation and adaptation". Furthermore, The World Bank expects that water stress could cause extreme societal overstrain in regions like the Middle East, where the economic effects of water scarcity could reach at risk 6% of Gross Domestic Product (GDP) by 2050 (Van Der Heijden, 2015).

Water shortages problem can affect the daily life needs in its various forms, agricultural, industrial and then to varying degrees the economic activities. In large cities, rainwater storage tanks can be used to save rainwater, but in peri-urban development and suburb areas, different rainwater means such as tanks or ponds are used as a unique water supply for many households and families to support agricultural livelihoods, mitigate water insecurity, and enable ecosystem services.

Amin et al. (2012) have pointed out that an increasing maximum rainfall with decreasing annual rainfall has been observed for the cities signifying the more extreme rainfall events and resulting floods for short durations. The assessments of any systematic changes in view of the increased rain intensities and extreme climate events are viewed to demonstrate the harvested rainwater value and management as a local adaptation to the climate variability and extreme. In Iraq, the semiarid Kurdistan region is suffering from water shortages problem. Erbil province has been chosen as a representative case study for a large number of provinces that suffers from water shortage, climate variability and the consequences associated with drought problem (Figure 1).

The fourth published article paper

EWRA *European Water* 57: 451-457, 2017.

Towards sustainable management of groundwater: A case study of semi-arid area, Iraqi Kurdistan region

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Abstract: In this paper, Erbil province the capital of Iraqi Kurdistan has been chosen as a representative case study for a large number of provinces in semi-arid areas, lacking imbalance between water demands and supply. Climate change is expected to bring adverse impact on water availability, which would intensify the pressure on water resources and increases the environmental concerns. Sustainable water use and prudent management prefer the rational water use and to preserve groundwater exploitation. The study aims to develop a framework considering sustainability aspects. A total of twenty wells have been selected among ninety-nine observation wells across the province along a period of 16 years from 2000 to 2015 to assess water level depression. The groundwater level had been falling nearly by half, this highlights the issues that the groundwater level has been significantly affected by impacts of the non-sensible usages of groundwater, dry spell periods, mismanagement of water resources, and unsustainable planning. Urban areas and suburbs were more exposed to water insecure than outskirts The results also suggest that the management of water resources and drainage systems would get worse if there was not adoption on a clear policy to manage it by relying on a robust framework based on sustainability concepts.

Key words: Groundwater depletion; Sustainability; Water management; Climate change; Framework

1. INTRODUCTION

Groundwater has a substantial role in agriculture, water supply and health, and the elimination of poverty in both urban and rural areas, thus, it is regarded as a vital and the sole resource in most of the studied semi-arid regions. Currently, Iraq is dramatically disturbed by complex political and socio-economic problems. In its northern part, i.e. the Kurdish-inhabited region, fast urbanization and economic expansion are visible everywhere. Monitoring and water management schemes are necessary to prevent aquifer over-exploitation in the region. Artificial recharges with temporary runoff water, construction of subsurface dams and several other aquifer management and regulation measures have been designed, and some implemented, in order to improve the water situation (Stevanovic and Iurkiewicz, 2009).

Recently, the World Economic Forum 2017 within its global risk report has pointed out that Environment-related risks also stand out in this year's global risk landscape. The major risk interconnections of Global Risks Perception Survey (GRPS) involve environmental risks, the most frequently cited of these being the pairing of "water crises" as well as "failures to climate change mitigation and adaptation". The World Bank expects that water stress could cause extreme societal overstrain in regions like the Middle East, where the economic effects of water scarcity could reach at risk 6% of gross Domestic Product (GDP) by 2050 (Heijden et al., 2015).

Population growth associated with accelerated social and economic activities and developments as well as expanding irrigated areas for agriculture purposes are main drivers for an ever-increasing demand for water worldwide (Wada et al., 2010). On the other hand, climate change has put additional pressure on water resources in arid and semiarid areas, which are naturally facing water

The fifth published article paper

Assessment of models predicting anthropogenic interventions and climate variability on surface runoff of the Lower Zab River

R. Mohammed, M. Scholz, M. A. Nanekely & Y. Mokhtari

Stochastic Environmental Research and Risk Assessment

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32:223-240
DOI 10.1007/s00477-016-1375-7

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Appendix (C): Questionnaire form

I am Mohammed A. Nanekely, currently studying PhD degree at the University of Salford-Manchester (UK) as a case study for Kurdistan Region, conducting a research project on Sustainable Drainage systems (SuDS) and Sustainable Water Management (SWM). You are invited for addressing a number of questions. There is no right or wrong answers. These questions are used for purely academic and scientific purposes. The respondents' names and any information you give will be anonymous, and would be treated with professionalism and strict confidentiality. Answering all questions accurately, will help the researcher a lot in this area.

Many thanks for your co-operation and efforts to serve the scientific process.

Q1: Are you interested in water issues or one of the following cohorts? If yes, please answer the rest of questions. If no, thank you so much for your well-intention and generosity.

- Civil Engineers
- Hydrologists
- Environmentalists
- Ecologists

Q2: Give your view on the seriousness of water scarcity in the 21st century.

Please indicate, on a scale from 1 to 5, where 1 is not at all serious and 5 is extremely serious.

Insert your entry here: ___

Q3: Which aspect is most related to water scarcity, resulting in a challenge to government? *Please choose only one aspect.*

☐ Conflict

☐ Economic growth

☐ Health

☐ Social poverty

Q4: Which risk does water scarcity pose to business?

Please select only one risk that indicates the highest threat.

☐ Financial risk (e.g., rise of prices and low investment)
☐ Physical risk (e.g., drought and/or flooding)
☐ Regulatory risk (e.g., change of laws due to water scarcity)
☐ Reputational risk (e.g., loss of customers)

Q5: Which environmental phenomenon is most related to water scarcity?

☐ Dust storm increase
☐ Green area reduction
☐ Pollution rate increase
☐ Wilderness increase

Q6: Which of the following risk has the greatest impact on human life?

☐ Risk to business
☐ Risk to environment
☐ Risk to government

Q7: Which sustainable urban storm water management benefits are important for you?

Please indicate, on a scale from 1 to 5, where 1 is not at all serious and 5 is extremely serious.

Groundwater recharge: ___
Increase in public amenity: ___
Increase in biodiversity: ___
Supporting sustainability: ___
Water quality improvement: ___
Water quantity management: ___
Water recycling: ___
Other benefits (please state and rate):

Q8: Do you think that the use of Sustainable Drainage Systems will contribute to addressing the issue of water scarcity?

☐Yes

☐No

Q9: In your opinion, to what extent can the use of sustainable drainage systems be considered as an influential factor in water re-use?

Please select only one option or indicate your estimation below:

☐ about *25% (i.e. one of many important factors)*

☐ about *50%*

☐ about *75%*

☐ about *100% (i.e. the most and virtually only factor)*

Alternatively, insert your entry here: ___ %

Q10: Do you believe that the use of sustainable drainage systems in semi-arid regions will be successful, despite of global climate change challenges?

☐*Yes*

☐*No*

Q11: In your opinion, to what extent is the use of sustainable drainage systems likely to be successful in cities that have not yet taken these systems into consideration (i.e. not yet part of the master planning or design sector planning)?

Please select only one option or indicate your estimation below:

☐ about *25% (i.e. one of many potentially successful options)*

☐ about *50%*

☐ about *75%*

☐ about *100% (i.e. absolutely certain to be successful)*

Alternatively, insert your entry here: ___ %

Thank you for your valuable time.

Appendices (D): Tables and figures

Appendix D.1: LTmin, max, mean P, T, and PET

Meteorology station (MS)	**Coordinates (Decimal degree)**			**Long-term mean annual precipitation (mm)**			**Long-term mean annual temperature (°C)**			**Long-term mean annual potential evapotranspiration (mm)**		
	Longitude	**Latitude**	**Altitude**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
1	44.0625 E	36.9991 N	2306	237.5	1372.3	621.6	11.6	15.6	13.8	1430.7	1816.6	1612.7
2	44.3750 E	36.9991 N	682	241.5	1063.2	615.7	9.4	13.6	11.7	1251.0	1587.7	1434.8
3	44.6875 E	36.9991 N	1783	313.9	1378.5	814.2	7.4	12.1	9.7	**1097.8**	**1442.8**	**1295.0**
4	44.3750 E	36.6869 N	1053	213.2	1150.1	607.9	13.0	17.6	15.5	1543.8	1948.3	1736.5
5	44.6875 E	36.6869 N	1154	370.4	1625.3	980.9	9.4	13.7	11.8	1238.4	1602.7	1440.2
6	43.7500 E	36.3747 N	401	191.8	1126.9	637.4	18.6	22.4	20.6	1628.9	2072.8	1850.7
7	44.0625 E	36.3747 N	507	182.9	1136.6	605.4	17.9	21.7	19.9	1582.7	2192.1	1937.2
8	44.3750 E	36.3747 N	977	189.0	1551.9	652.4	16.0	19.9	18.1	1487.8	2176.9	1905.7
9	43.4375 E	36.0624 N	261	100.8	928.8	492.6	18.9	22.6	20.9	1653.0	2017.4	1823.7
10	43.7500 E	36.0624 N	278	130.1	1070.4	570.2	18.5	22.3	20.6	**1619.3**	**1962.0**	**1789.1**
11	44.0625 E	36.0624 N	439	134.9	985.2	575.2	18.2	21.9	20.1	1656.3	2051.0	1851.9
12	44.3750 E	36.0624 N	605	128.0	1005.4	533.6	17.8	21.6	19.9	1573.6	2225.3	1965.1
13	44.6875 E	36.0624 N	648	145.1	1022.0	552.9	16.0	20.0	18.4	1579.5	2204.4	1936.6
14	43.4375 E	35.7502 N	252	44.5	526.5	294.4	19.6	23.2	21.6	1835.7	2200.5	1998.9
15	43.7500 E	35.7502 N	306	55.4	666.7	360.4	19.2	22.9	21.2	1747.1	2075.1	1898.3
16	44.0625 E	35.7502 N	483	63.2	720.5	389.6	19.1	22.8	21.1	1746.8	2080.9	1897.9
17	43.4375 E	35.4380 N	175	31.5	392.2	201.5	20.4	24.0	22.3	**1986.1**	**2347.1**	**2145.1**
S.D.				80.594	312.86	185.22	0.81	0.65	0.737	72	88	98

Appendix D.2: The data on groundwater observation wells across study area

No.	Well name	Coordinate			Annually mean reading															
		Altitude	Longitude	Latitude	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Barbian Gichka	555	419115	4024775	22	23	23	22	19	19	20	21	24	28	29	29	32	34	42	45
2	Betrma/3	970	440516	4027720	28	30	31	26	24	25	25	26	29	34	36	57	68	68	53	66
3	Chaluk Gichka	441	389514	4009669	84	86	36	74	75	80	84	90	90	92	96	99	101	102	103	102
4	Daldaghan	315	399950	3992662	25	27	28	28	29	29	29	28	30	32	32	33	33	31	38	61
5	Dorabakra	395	414587	3978012	35	34	35	35	35	35	35	35	36	37	37	37	38	42	44	44
6	Dugirdkan	355	405026	3981462	20	21	22	22	23	25	25	25	26	27	27	28	29	34	39	39
7	Gird Azaban	291	394907	3985195	10	10	11	11	12	13	13	14	15	15	15	16	18	24	28	29
8	Gird Mala /3	424	415047	3985161	26	27	27	28	28	28	28	28	29	30	30	30	32	34	41	42
9	Hareer factory	739	441794	4049346	30	31	30	28	27	27	27	27	29	32	33	35	22	21	33	34
10	Hawdian	718	452989	4061133	33	36	34	34	33	33	29	31	39	45	45	45	82	80	79	81
11	Jadida Zab /3	327	391058	4016989	40	40	40	41	41	42	42	42	43	44	45	47	48	47	47	48
12	Kardiz	458	420013	3983689	25	27	28	28	29	29	29	28	28	28	29	29	31	36	39	46
13	Kawer Gosk/1	299	391724	4023482	31	32	36	38	33	33	31	31	32	35	36	76	70	55	58	55
14	Kore /3	819	433119	4028858	8	12	23	17	9	10	13	13	33	27	25	24	29	30	45	70
15	Lajan	656	427157	3990399	19	21	22	23	19	15	13	14	17	20	21	21	26	27	34	38
16	Mala Omer	624	421968	4017449	19	30	40	33	21	22	23	24	29	41	57	75	98	100	100	100
17	Murtika Shahab	411	413106	3988512	26	27	27	28	29	29	29	28	30	31	31	31	32	40	45	50
18	Peerdawood	350	402916	3987145	18	18	19	19	20	21	21	22	22	23	24	24	24	35	40	68
19	Shawais/4	532	418245	4012167	35	41	46	52	50	48	45	45	45	49	53	92	93	67	67	67
20	Tandora /1	318	395410	3662610	11	11	12	12	12	13	13	13	14	15	14	14	15	20	24	30
21	Aziana	447	427595	3974850	20	21	21	20	13	10	11	14	21	25	25	25	26	30	36	35
22	Darato/8	447	414564	3998258	46	46	48	51	52	53	54	55	57	58	58	58	60	65	69	71
23	Gainj Gawra	291	393461	4020700	29	29	30	31	31	32	32	32	33	33	34	37	38	38	37	38
24	Harir /5	748	441436	4046456	17	16	15	13	12	12	13	13	15	17	18	26	36	33	21	32
25	Hujran Girdachal	874	434575	4029769	16	18	17	17	16	16	16	16	17	18	17	18	18	18	19	21
26	Jolamerg	774	445141	4049346	30	31	11	21	28	31	44	59	65	69	68	100	74	74	73	75

27	**Khabat /10**	298	380292	4015039	42	42	42	42	42	43	43	43	44	44	44	110	50	50	50	50
28	**Kundak**	335	380128	4011401	44	46	50	57	57	58	58	59	60	61	60	58	62	64	65	70
29	**Mastawa**	312	393610	3993035	14	14	15	16	16	16	16	17	18	19	18	19	19	23	27	32
30	**New Armawan**	789	429486	4029154	29	29	25	21	18	19	23	26	45	59	54	54	54	51	48	44
31	**Qafar/3**	444	407704	4028062	44	45	46	45	43	42	42	42	45	47	48	50	53	53	53	54
32	**Qoritan Chukul**	361	405465	3993267	21	24	25	25	27	27	27	27	28	29	29	29	30	36	42	48
33	**Qultapa Yaba**	395	412842	3978071	34	35	35	36	36	37	36	36	38	40	39	39	38	46	50	52
34	**Qurshakhlo**	346	402891	3976079	17	17	18	18	19	19	20	20	21	22	22	22	22	27	32	33
35	**Qushtapa/12**	413	413550	3982290	31	32	33	34	34	34	33	34	36	62	36	36	36	44	50	59
36	**Chama**	557	430580	4090781	18	17	15	14	15	16	14	16	19	20	13	17	13	11	11	12
37	**Sebiran Gawra /6**	366	402119	4012035	29	29	31	32	33	33	34	34	36	37	38	38	43	42	42	43
38	**Shekh Sherwan**	305	386085	3989625	8	8	9	10	10	11	11	11	12	13	12	13	14	16	17	19
39	**Tikalo**	347	397390	3967445	25	27	28	29	30	34	34	35	35	36	36	36	36	43	45	48
40	**Zaga**	258	371460	4003327	18	16	14	14	14	15	14	15	16	16	15	18	19	18	18	18
41	**Zorgvan**	494	417664	4078259	30	28	26	26	26	27	25	26	29	30	26	29	28	26	25	25
42	**Abassia**	262	43.663	36.126	11.3	11..2	11.5	11.5	11.8	12.6	11	11.4	12	13	13.7	13.6	16.4	16.5	16.7	16.9
43	**Armawan/1**	804.5	44.221	36.397	25.4	26.3	25.8	26	26.5	25.8	34	42.3	60	63.9	61.5	62.1	58.6	50.2	33.3	38.4
44	**Bahar**	398	44.017	36.180	34	34	34.2	35	35.4	38.7	38.4	40.2	42.8	45.6	49.0	57.2	66.5	72.1	74.3	73
45	**Banaman /1**	778.5	44.181	36.355	29	29.1	30	30	30.8	31.9	37.5	40.8	54.3	67.0	64.6	66.5	63.8	61.3	62.0	55.7
46	**Berabat**	308	43.893	35.823	33.5	34.5	34	34.8	35.6	36.3	36.3	36.3	37.1	38.0	37.2	37.3	37.3	46.2	48.0	49.9
47	**Bestanay gawra**	436	44.181	36.077	23.7	24.9	24.3	24	24.5	19.9	18.9	17.4	20.0	41.6	44.1	44.1	53.6	64.9	68.5	71.0
48	**Chaghamira**	285	43.765	35.770	33.2	33	34	34.2	34.9	33.5	33.8	34.0	34.6	34.6	34.4	34.7	34.8	36.9	39.9	42.5
49	**Dugirdkan**	354.5	43.947	35.973	22	22.7	22.3	22	22.7	24.5	24.9	24.7	25.7	27.0	27.1	27.4	28.0	33.7	40.4	42.4
50	**Gulan/8**	478	44.049	36.197	80	82.3	81	82	82.3	80.3	80.5	80.0	73.7	74.2	77.7	77.7	79.0	92.6	95.9	97.3
51	**Kawraban**	424	43.771	36.225	35	36.1	36.5	37.2	37.7	39.5	40.1	41.1	43.9	46.2	48.8	62.0	72.2	74.3	74.2	74.7
52	**Khazna**	298	43.536	35.690	15	15.3	16	16	16.2	17.1	17.1	16.9	17.9	18.8	18.6	19.3	20.9	20.7	21.0	21.8
53	**Malaqara**	272	43.645	35.942	13.5	13.8	14	14.2	14.7	16.0	15.5	15.8	16.6	17.2	17.0	17.6	17.4	19.0	19.1	19.5
54	**Minara**	330	43.888	35.970	13.8	14	14.2	15	15.2	15.9	16.0	16.3	17.3	18.7	18.3	18.7	18.9	28.0	34.9	41.1

Appendix D.3: The collected data on RWHS detention ponds

No.	Pond ID	Construction cost (Iraqi Dinar)	Pond area (m^2)	Livestock's watering (no.)	Harvested water volume (m^3)	Irrigated area (Donum)	Groundwater recharge (%)	Flood risk management (%)	Beneficiaries & socio-economic	Recreation (%)	Bio-diversity (%)
1	Du Shiwan	431,115,000	61502	425	154,485	100	5	100	300	90	75
2	Harajay Gijka	684,670,000	36056	250	143,351	200	5	100	130	80	70
3	Binaslawa Gijka	686,620,000	20843	1000	63,599	200	5	100	750	75	75
4	Balaban (Rulka)	784,280,000	22395	625	89,797	220	5	100	200	10	25
5	Shiwa piran	439,560,000	15388	2625	49,104	250	5	100	200	70	75
6	Bani Maran	524,580,000	33785	1250	139,409	1,000	5	100	400	80	50
7	Smaq Shireen	704,725,000	26388	1000	113,805	200	5	100	116	80	75
8	Baqlen	611,564,000	17536	275	74,524	200	5	100	100	60	50
9	Mawaran	832,535,000	13677	1200	59,414	1,500	5	100	150	70	75
10	Qadiana	660,875,000	23679	3500	110,089	1,000	5	100	500	45	50
11	Zebarok	535,545,000	25006	1150	117,041	1,000	5	100	220	90	100
12	Duwin	627,490,000	16317	1750	50,790	1,000	5	100	60	80	100
13	Sule	448,370,000	19282	2300	82,122	4,000	5	100	100	80	100
14	Barbiani Nue	745,870,000	25899	1500	113,033	300	5	100	1000	90	100
15	Khra	573,105,000	20070	575	54,371	1,250	5	100	450	80	100
16	Khra Nue	464,395,000	21165	475	65,975	50	5	100	100	60	50
17	Piraza	505,890,000	17000	1000	65,206	500	5	100	100	30	25
18	Derona	533,170,000	18291	2076	76,638	200	5	100	400	20	25
19	Drameer	772,650,000	15539	325	85,393	40	5	100	133	60	50
20	Chala Grdala	658,650,000	28004	800	105,201	100	5	100	200	40	50
21	Kani Gani	667,455,000	26365	875	103,870	160	5	100	130	70	75
22	Mam Choghan 1	598,245,000	20381	1625	92,837	100	5	100	350	50	50

23	Mam Cnoghan 2	546,287,000	16211	1625	89,342	100	5	100	350	30	25
24	Aliawa	945,625,000	18756	675	60,035	100	5	100	250	60	50
25	Palka Rash	521,985,000	33686	500	133,762	200	5	100	200	80	75
26	Hiran	469,033,000	21106	500	84,637	250	5	100	500	85	75
27	Bayez Beg	750,985,000	11300	500	49,636	200	5	100	50	90	100
28	Qashqa	523,675,000	35703	1750	161,399	100	5	100	300	10	25
29	Mam Khalan	716,980,000	15882	1000	78,773	100	5	100	600	30	25
30	Zarwaw	499,960,000	28846	375	120,326	150	5	100	400	60	50
31	Dara Shakran	575,220,000	18846	750	96,593	60	5	100	100	20	25
32	Wasu Khuaru	810,225,000	13052	500	67,037	50	5	100	70	50	50
33	Wasu saru	546,655,000	17435	750	83,699	300	5	100	500	50	50
34	Kurdalalan	427,635,000	31149	525	94,150	30	5	100	250	30	25
35	Hababan	691,005,000	12984	313	61,972	90	5	100	250	20	25
36	Kudaryan	682,576,000	12799	750	56,111	200	5	100	5000	20	25
37	Zargazawi	447,627,000	22631	1250	57,765	350	5	100	1550	40	50
38	Azhga	674,562,000	9889	288	50,877	50	5	100	150	70	75
39	Sarkand Khailan	717,115,000	13263	550	74,220	500	5	100	900	50	50
40	Kawer jisk	794,160,000	19698	650	92,399	600	5	100	200	90	100
41	Shekh Wasan	1,044,075,000	13821	138	97,588	500	5	100	500	100	100
42	Ziarat	794,985,000	20816	163	118,307	200	5	100	290	80	75
43	Beshekh	1,289,295,000	27724	138	97,894	200	5	100	2000	60	50
44	Kabur	715,205,000	30386	325	129,490	86	5	100	250	20	25
45	Makerdan	606,033,000	22252	488	93,242	400	5	100	300	20	25
46	Kalachn Khailani	829,880,000	11487	875	64,734	100	5	100	500	60	50
47	Talajar	725,438,000	20007	300	112,013	300	5	100	200	50	50
48	Babajisk	771,955,000	24249	200	130,888	250	5	100	175	70	75
49	Ali Rash	734,842,000	40256	350	98,891	15	5	100	25	40	50
50	**Majidawa**	490,843,000	50257	725	124,109	900	5	100	425	20	25

51	**Lawar**	927,201,000	17733	575	82,784	30	5	100	400	15	25
52	**Karitan**	464,005,000	47828	1750	132,303	30	5	100	2540	20	25
53	**Sharabot bchuk**	475,800,000	28500	150	250,000	15	70	100	0	0	0
54	**Sharabot gawra**	555,100,000	27000	0	220,000	0	100	100	0	0	0
55	**Rulka**	312,131,250	38000	0	104,000	0	100	100	0	0	0

Appendix D.4: Annual, Decadal, and Long-term Aridity Index

Water year	MAP	MAPET	Annual aridity index	10-year aridity index	35-year aridity index	Annual zone class	Decadal zone class	Long-term 35-year zone class
1979-1980	850	1700	0.500	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1980-1981	668	1734	0.385	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1981-1982	743	1701	0.437	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1982-1983	755	1663	0.454	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1983-1984	595	1767	0.337	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1984-1985	793	1782	0.445	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1985-1986	621	1825	0.340	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1986-1987	659	1789	0.368	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1987-1988	924	1731	0.534	0.402	0.311	Dry sub-humid	Semi-arid	Semi-arid
1988-1989	434	1837	0.236	0.402	0.311	Semi-arid	Semi-arid	Semi-arid
1989-1990	602	1749	0.344	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1990-1991	580	1765	0.329	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1991-1992	751	1623	0.463	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1992-1993	757	1746	0.434	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1993-1994	670	1813	0.370	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1994-1995	639	1734	0.369	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1995-1996	473	1802	0.263	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1996-1997	450	1781	0.253	0.325	0.311	Semi-arid	Semi-arid	Semi-arid

1997-1998	648	1835	0.353	0.325	0.311	Semi-arid	Semi-arid	Semi-arid
1998-1999	229	1995	0.115	0.325	0.311	Arid	Semi-arid	Semi-arid
1999-2000	254	1980	0.128	0.197	0.311	Arid	Arid	Semi-arid
2000-2001	315	1947	0.162	0.197	0.311	Arid	Arid	Semi-arid
2001-2002	433	1873	0.231	0.197	0.311	Semi-arid	Arid	Semi-arid
2002-2003	507	1843	0.275	0.197	0.311	Semi-arid	Arid	Semi-arid
2003-2004	505	1851	0.273	0.197	0.311	Semi-arid	Arid	Semi-arid
2004-2005	450	1818	0.248	0.197	0.311	Semi-arid	Arid	Semi-arid
2005-2006	434	1925	0.225	0.197	0.311	Semi-arid	Arid	Semi-arid
2006-2007	367	1855	0.198	0.197	0.311	Arid	Arid	Semi-arid
2007-2008	163	1947	0.084	0.197	0.311	Arid	Arid	Semi-arid
2008-2009	300	1849	0.162	0.197	0.311	Arid	Arid	Semi-arid
2009-2010	466	1931	0.241	0.349	0.311	Semi-arid	Semi-arid	Semi-arid
2010-2011	563	1712	0.329	0.349	0.311	Semi-arid	Semi-arid	Semi-arid
2011-2012	541	1657	0.327	0.349	0.311	Semi-arid	Semi-arid	Semi-arid
2012-2013	829	1614	0.514	0.349	0.311	Dry sub-humid	Semi-arid	Semi-arid
2013-2014	602	1696	0.355	0.349	0.311	Semi-arid	Semi-arid	Semi-arid

Appendix D.5: Different climate conditions & total annual precipitation

Water years	(Long term annual precipitation (mm)	Climate conditions
1980	849.5	Wet
1981	668.2	Normal
1982	743.5	Wet
1983	754.5	Wet
1984	595.0	Normal
1985	792.8	Wet
1986	621.2	Normal
1987	659.0	Normal
1988	924.4	Wet
1989	433.9	Normal
1990	602.0	Normal
1991	580.2	Normal
1992	750.9	Wet
1993	756.9	Wet
1994	670.4	Normal
1995	639.3	Normal
1996	473.4	Normal
1997	449.7	Normal
1998	647.6	Normal
1999	229.0	Dry
2000	254.0	Dry
2001	315.5	Dry

2002	432.8	Normal
2003	506.8	Normal
2004	505.5	Normal
2005	450.3	Normal
2006	433.7	Normal
2007	367.4	Dry
2008	163.2	Dry
2009	299.7	Dry
2010	465.7	Normal
2011	563.2	Normal
2012	541.2	Normal
2013	828.9	Wet
2014	601.7	Normal

Appendix D.6: The standard deviation, the upper and lower thresholds of year conditions

Statistical variables	**Values**
Mean	559.2
Standard Deviation	185.2
Mean+0.75 S.D.[22]	698.1
Mean-0.75 S.D.[23]	420.3

[22] 0.75 of standard deviation + mean has been regarded as the threshold of wet years

[23] 0.75 of standard deviation - mean has been regarded as the threshold of dry years (Furat A. M. Al-Faraj & Al-Dabbagh, 2015; Furat A.M. Al-Faraj & Scholz, 2014)

Appendix D.7: Mann–Kendall trend test of groundwater levels depression

Time series data record of 145 months (from January 2004 to January 2016)

No.	Well name	(Correlation coefficient) Kendall's tau	P-value range	P-value	Trend at 5%
1	Abassia	0.677	< 0.1%	0.000	Significant
2	Armawan-1	0.146	< 1%	0.009	Significant
3	Aziana	0.787	< 0.1%	0.000	Significant
4	Bahar	0.899	< 0.1%	0.000	Significant
5	Banaman-1	0.410	< 0.1%	0.000	Significant
6	Barbian_Gichka	0.846	< 0.1%	0.000	Significant
7	Berabat	0.701	< 0.1%	0.000	Significant
8	Bestanay_Gawra	0.677	< 0.1%	0.000	Significant
9	Betrma-3	0.789	< 0.1%	0.000	Significant
10	Chaghamira	0.568	< 0.1%	0.000	Significant
11	Chama	-0.282	< 0.1%	0.000	Significant
12	Daldaghan	0.740	< 0.1%	0.000	Significant
13	Darato8	0.858	< 0.1%	0.000	Significant
14	Dorabakra	0.769	< 0.1%	0.000	Significant
15	Dugirdkan	0.818	< 0.1%	0.000	Significant
16	Gainj_Gawra	0.775	< 0.1%	0.000	Significant
17	Gird_Azaban	0.814	< 0.1%	0.000	Significant
18	Gird_Mala-3	0.772	< 0.1%	0.000	Significant
19	Gulan-8	0.190	< 0.1%	0.001	Significant
20	Harir-5	0.784	< 0.1%	0.000	Significant
21	Hujran_Girdachal	0.684	< 0.1%	0.000	Significant
22	Jadida_Zab-3	0.801	< 0.1%	0.000	Significant
23	Kardiz	0.459	< 0.1%	0.000	Significant
24	Kawer_Gosk-1	0.629	< 0.1%	0.000	Significant
25	Kawraban	0.899	< 0.1%	0.000	Significant
26	Khabat-10	0.719	< 0.1%	0.000	Significant
27	Khazna	0.758	< 0.1%	0.000	Significant
28	Kore-3	0.705	< 0.1%	0.000	Significant
29	Kundak	0.668	< 0.1%	0.000	Significant
30	Lajan	0.692	< 0.1%	0.000	Significant
31	Mala_Omer	0.828	< 0.1%	0.000	Significant
32	Malaqara	0.735	< 0.1%	0.000	Significant
33	Mastawa	0.723	< 0.1%	0.000	Significant
34	Minara	0.814	< 0.1%	0.000	Significant
35	Murtika_Shahab	0.739	< 0.1%	0.000	Significant
36	Nawroz-8	0.902	< 0.1%	0.000	Significant
37	New_Armawan	0.452	< 0.1%	0.000	Significant
38	Peerdawood	0.851	< 0.1%	0.000	Significant
39	Pemarabir	0.708	< 0.1%	0.000	Significant
40	Qafar-3	0.752	< 0.1%	0.000	Significant
41	Qoritan_Chukul	0.746	< 0.1%	0.000	Significant
42	Qultapa_Yaba	0.755	< 0.1%	0.000	Significant
43	Qurshakhlo	0.811	< 0.1%	0.000	Significant
44	Qushtapa-12	0.696	< 0.1%	0.000	Significant
45	Saadawa	-0.015	> 5%	0.796	Non-significant
46	Salahaddin	-0.318	< 0.1%	0.000	Significant
47	Sebirani_Gawra-6	0.838	< 0.1%	0.000	Significant
48	Shadi	0.913	< 0.1%	0.000	Significant
49	Shekh_Sherwan	0.727	< 0.1%	0.000	Significant
50	Shorsh-8	-0.121	< 5%	0.032	Significant
51	Tandora-1	0.693	< 0.1%	0.000	Significant
52	Tikalo	0.841	< 0.1%	0.000	Significant
53	Zaga	0.644	< 0.1%	0.000	Significant
54	Zorgvan	-0.019	> 5%	0.734	Non-significant

Correlation significant at the 0.01 level (2-tailed)

Appendix D.8: Existing wells in Erbil province after MoAWR-KRG (2016)

Groundwater wells		of which are legal	estimated illegal wells***	by well status:		by well depth (m):					by purpose:			
				In use	Dry/ unused	<50	50–<100	100–<150	150–<200	>200	Drinking	Irrigation	Livestock watering	Industry
Dataset up to March 2011	Total number	5241	2922	4348	893	170*	611*	104*	1360*	677*	2229	2787	108	117
	Percentage of total (%)	64.2	35.8	83	17	5.8**	21**	3.5**	46.5**	23.2**	41.95	51.65	3.6	2.8
Dataset up to December 2016	Total number	8037	4237	6667	1370	195*	986*	144*	2118*	794	3679	4056	142	160
	Percentage of total (%)	65.48	34.52	83	17	4.6**	23.25**	3.4**	50**	18.75**	45.8	50.5	1.7	2
5 years differences	of total numbers	2796	1315	2319	477	25	375	40	758	117	1450	1269	34	43
	Percentage (%) of the first dataset	53.34	45	53.3	53.4	14.7	13.4	61.4	55.75	17.3	65	45.5	31.5	36.75
Average yield (l/s)		9.1												

* Only legal well depths have been considered due to the unavailability of reliable data regarding drilling of illegal wells.

** % with respect to the total number of legal wells.

*** No further data are available for the purposes of use, depth and status.

Appendix D.9: Estimated recharge volume, aquifers' status, and permissible well numbers for the average long term 35 water years

Soil cover[24]		Estimated annual I_{eff} (%)	Precipitation					Aquifer			LTSMPET (mm/season)		Recharge rate (l/sec)			Recharge volume x 10^6 (m^3/year)			Aquifer status	Estimated permissible well number
Soil type	Area (Km^2)		LTSMP (mm/season) W.S.	LTSMP (mm/season) D.S.	P_{eff} (mm/season) Equation (4) W.S.	P_{eff} D.S.	P_{eff} Total	Formation (Mostly are corresponding to the soil covers)	Productivity rating	Productivity (l..sec)	W.S.	D.S.	W.S.	D.S.	Total	W.S.	D.S.	Total		
A	139	35	542	53	190	18	208	intergranular	High	12	435	1440	0	0	0	0	0	0	Un-safe	0
B	1052	15	420	49	63	7	70	intergranular	High	12	465	1414	0	0	0	0	0	0	Un-safe	0
C	4059	20	449	50	90	10	100	intergranular	Moderate	10	471	1430	0	0	0	0	0	0	Un-safe	0
D	4193	50	603	62	301	31	332	karstic fissured	Low	1	363	1333	0	0	0	0	0	0	Un-Safe	0
E	149	60	712	92	427	55	482	karstic fissured	Low to moderate	2	261	1129	785	0	785	25	0	25	Safe	392
F	1276	55	646	69	355	38	393	karstic fissured	Low to moderate	2	315	1256	1622	0	1622	51	0	51	Safe	811
G	1131	25	372	44	93	11	104	intergranular	Moderate	10	481	1451	0	0	0	0	0	0	Un-safe	0
H	420	30	635	63	191	19	210	Aquitard	Ver low	0.1	373	1382	0	0	0	0	0	0	Un-safe	0
I	2670	35	538	50	188	18	206	intergranular	Moderate	10	437	1453	0	0	0	0	0	0	Un-safe	0
	15089														**2407**			**76**		**1203**

I_{eff} Effective infiltration
LTSMP: Long term seasonal precipitation
P_{eff}: Effective precipitation
LTSMPET: Long term seasonal mean potential evapotranspiration
W.S.: Wet season
D.S.: Dry season

A: Lithosolic soil in limestone
B: Gypsiferous alluvium
C: Brown soil, deep phase
D: Rough broken and stony land
E: Rough mountainous land, alpine phase
F: Rough mountainous land
G: Lithosolic soils in sandstone and gypsum
H: Chestnut soil, shallow, stony and sloping phases
I: Brown soils, medium and shallow phase over Bakhtiary gravel

[24] Reference: (Buringh, 1960; Hameed, 2013)

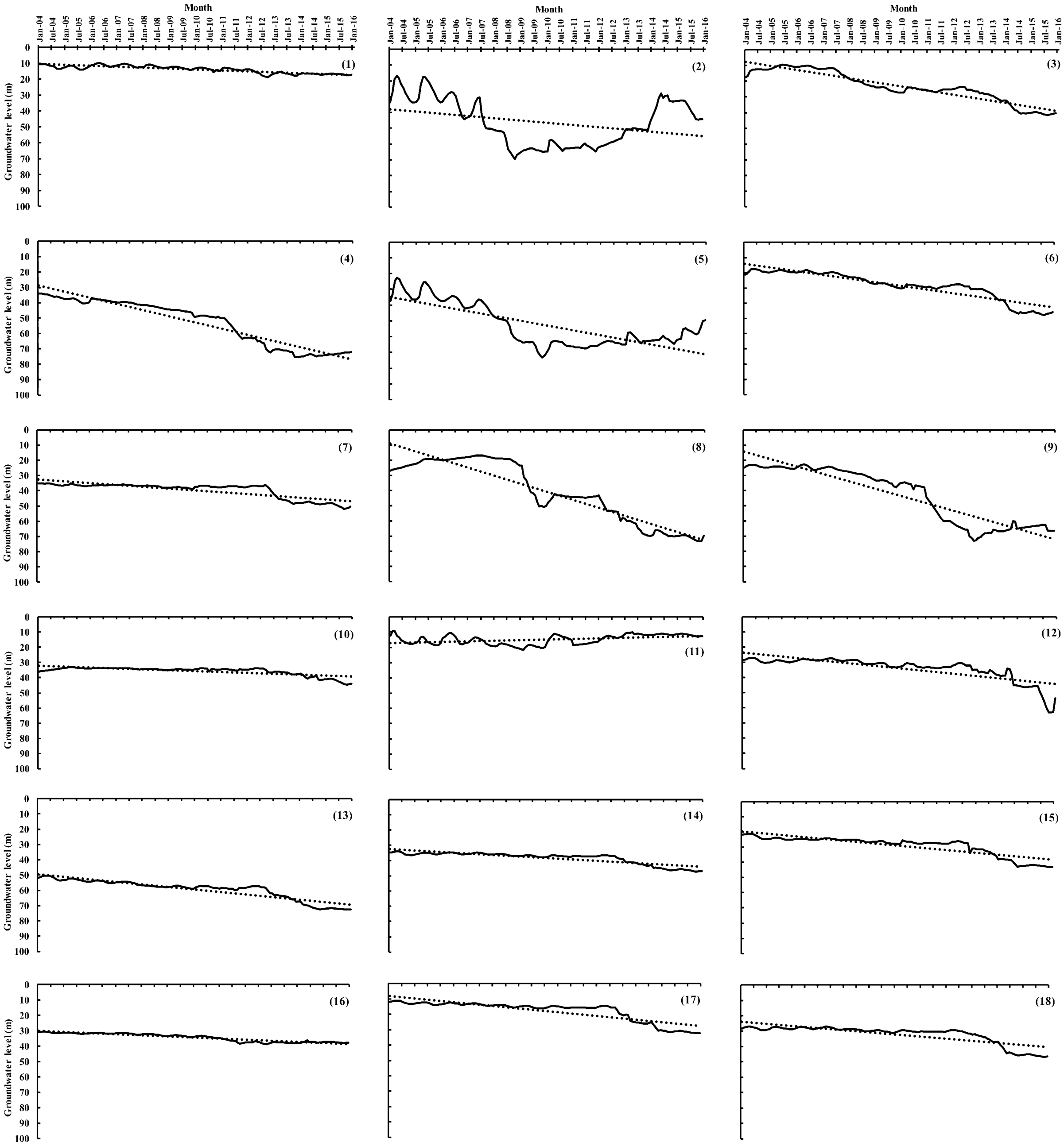
__Appendix D.10: A sample calculation table for estimated recharge volume, aquifers' status, and permissible well numbers for the water year (2013-2014)__

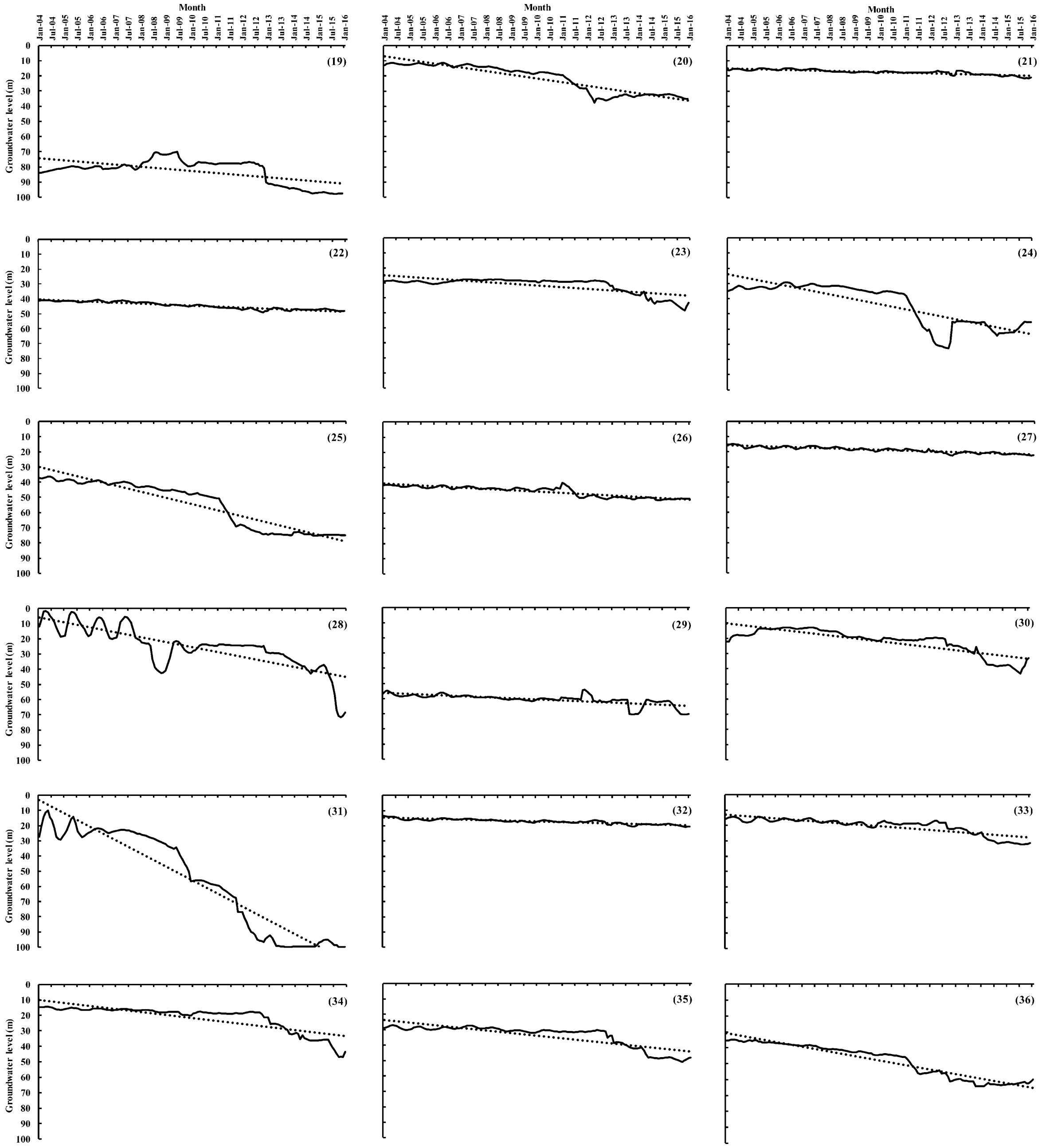
Soil cover		Estimated annual I_{eff} (%)	Precipitation					Aquifer			LTSMPET (mm/season)		Recharge rate (l/sec)			Recharge volume x 10^6 (m^3/year)			Aquifer status	Estimated permissible well number
Soil type	Area (Km^2)		LTSMP mm/season W.S.	LTSMP mm/season D.S.	P_{eff} (mm.season) W.S.	P_{eff} (mm.season) D.S.	P_{eff} (mm.season) Total	Formation	Productivity rating	Productivity (l/sec)	W.S.	D.S.	W.S.	D.S.	Total	W.S.	D.S.	Total		
A	139	35	693	18	243	6	249	Intergranular fissured	High	12	391	1317	0	0	0	0	0	0	Un-safe	0
B	1052	15	351	4	53	1	53	intergranular	High	12	448	1403	0	0	0	0	0	0	Un-safe	0
C	4059	20	466	8	93	2	95	intergranular	Moderate	10	431	1383	0	0	0	0	0	0	Un-safe	0
D	4193	50	753	20	377	10	387	karstic fissured	Low	1	347	1219	3884	0	3884	122	0	122	Safe	3884
E	149	60	689	19	413	11	425	karstic fissured	Low to moderate	2	288	1079	592	0	592	19	0	19	Safe	296
F	1276	55	779	20	428	11	439	karstic fissured	Low to moderate	2	324	1170	4205	0	4205	133	0	133	Safe	2103
G	1131	25	329	4	82	1	83	intergranular	Moderate	10	459	1428	0	0	0	0	0	0	Un-safe	0
H	420	30	796	23	239	7	246	Aquitard	Ver low	0.1	357	1246	0	0	0	0	0	0	Un-safe	0
I	2670	35	752	21	263	7	271	intergranular	Moderate	10	388	1308	0	0	0	0	0	0	Un-safe	0
	15089														**8681**			**273**		**6283**

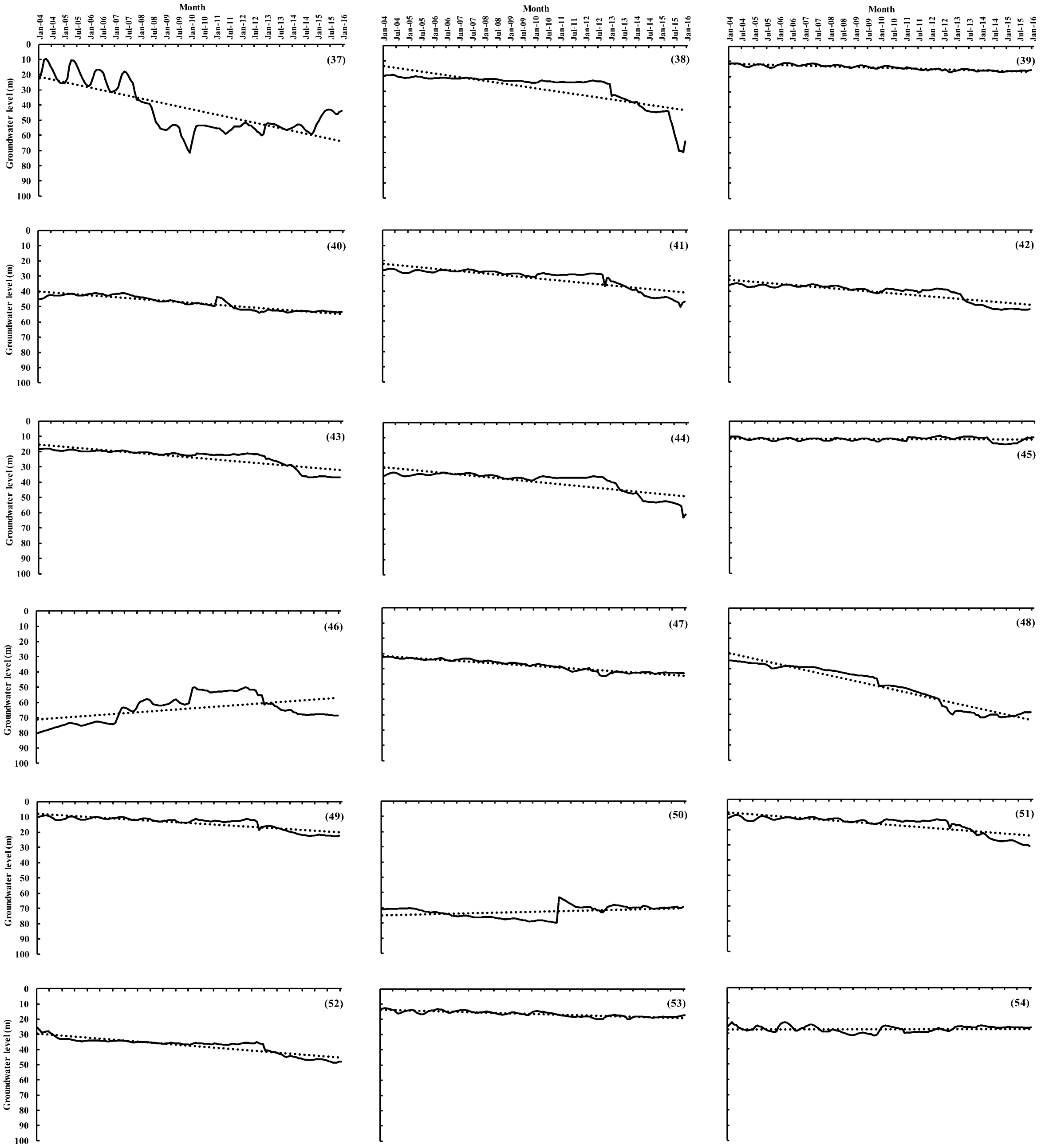
I_{eff} Effective infiltration
LTSMP: Long term seasonal precipitation
P_{eff}: Effective precipitation
LTSMPET: Long term seasonal mean potential evapotranspiration
W.S.: Wet season
D.S.: Dry season

A: Lithosolic soil in limestone
B: Gypsiferous alluvium
C: Brown soil, deep phase
D: Rough broken and stony land
E: Rough mountainous land, alpine phase
F: Rough mountainous land
G: Lithosolic soils in sandstone and gypsum
H: Chestnut soil, shallow, stony and sloping phases
I: Brown soils, medium and shallow phase over Bakhtiary gravel

Appendix D.11: Boxplot of groundwater level for the observation wells (1-54)




Month
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Groundwater level (m)
0
10
20
30
40
50
60
70
80
90
100
(19)
(20)
(21)
(22)
(23)
(24)
(25)
(26)
(27)
(28)
(29)
(30)
(31)
(32)
(33)
(34)
(35)
(36)



Month
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Groundwater level (m)
0
10
20
30
40
50
60
70
80
90
100
(37)
(38)
(39)
(40)
(41)
(42)
(43)
(44)
(45)
(46)
(47)
(48)
(49)
(50)
(51)
(52)
(53)
(54)

Appendix D.12: Groundwater levels from 2004 to 2015 of observation wells

Observation wells	GWL in 2004	GWL in 2015	Depression 2000-2015 (m)	% of differences
1	22.10	43.21	21.11	48.85
2	28.32	66.36	38.04	57.33
3	35.00	102.45	67.45	65.84
4	25.65	60.68	35.03	57.73
5	34.73	44.63	9.90	22.18
6	19.32	42.45	23.13	54.49
7	9.78	31.75	21.98	69.21
8	26.46	45.90	19.44	42.36
9	29.99	33.80	3.81	11.28
10	33.39	81.20	47.81	58.88
11	39.51	48.12	8.61	17.89
12	25.08	45.58	20.51	44.99
13	31.06	55.35	24.29	43.88
14	8.14	70.35	62.21	88.42
15	19.45	37.60	18.15	48.28
16	19.32	99.83	80.51	80.64
17	26.20	49.69	23.49	47.27
18	17.82	67.65	49.83	73.66
19	34.57	67.23	32.66	48.58
20	30.25	74.60	44.35	59.45
Minimum	**8.14**	**31.75**	**3.81**	**11.28**
Maximum	**39.51**	**102.45**	**80.51**	**88.42**
Mean	**25.81**	**58.42**	**32.62**	**52.06**
STDEV.	**8.37**	**20.19**	**20.55**	**19.53**

Appendix D.13: The value and trend of depression of observation wells

Observation wells	X	Y	Water table depression (m)	(b_value) depression slope	R^2_value	r_value
1	44.09839221	36.36467652	21	1.3446	0.7006	0.837018518
2	44.33669657	36.39278699	38	2.9117	0.6671	0.816761899
3	43.77063837	36.22557472	67	5.2344	0.8892	0.942974019
4	43.88889284	36.07340540	35	1.1844	0.4737	0.688258672
5	44.05300266	35.94273674	10	0.6063	0.7536	0.868101377
6	43.94660020	35.97295365	23	1.2122	0.8224	0.906862724
7	43.83389102	36.00557007	22	1.1897	0.7746	0.880113629
8	44.05733607	36.00722789	19	0.9275	0.6653	0.815659243
9	44.34932353	36.58781552	4	0.0529	0.004	0.063245553
10	44.47373760	36.69468797	48	3.534	0.6878	0.829337085
11	43.78679062	36.29172897	9	0.614	0.9455	0.972368243
12	44.11258808	35.99437844	21	0.8607	0.6035	0.776852624
13	43.79330401	36.35032385	24	2.2625	0.5102	0.714282857
14	44.25412163	36.40255456	62	2.6318	0.6125	0.782623792
15	44.19122138	36.05542923	18	0.8701	0.3813	0.617494939
16	44.13092451	36.29886824	81	5.8343	0.7389	0.859592927
17	44.03543847	36.03726026	23	1.1801	0.6806	0.824984848
18	43.92250434	36.02397447	50	1.9185	0.5244	0.72415468
19	44.09001171	36.25094563	33	2.5882	0.5261	0.725327512
20	43.83849553	36.07246328	44	4.6192	0.7597	0.87160771

Appendices (E): Summary of the basic statutory references on water management

Appendix E.1: Law No. (27) Environmental Protection and Improvement of 2009 in the Iraqi Federal Government

Article	Item	Content
Article 14	1	It is prohibited to dispose any household, industrial, or agricultural liquid wastes into inland water resources, surfaces or underground, or Iraqi maritime areas unless passed through necessary treatments that have to be done that are consistent with specific specifications in national environmental legislation and international conventions.
	2	It is prohibited to connect household wastewater, industrial wastes other activities to rainwater drainage networks.
	3	It is prohibited to dispose of solid wastes or animal wastes to water resources bodies.
Article 24	1	The Minister shall appoint an Environmental Superintendent from among the Ministry's employees to implement the provisions of the Law to control the activities affecting the environment subject to its provisions and to organize reports to be submitted to the Ministry to take the necessary action.
	2	The environmental Controller shall be granted the status of a member of the judicial control who shall be assisted in the performance of his duties by elements of the environmental policeman, and activities controlled by him/her during and after official working hours.
	3	The Environmental Controller shall carry out the following legal oath in front of the head of the competent department: (I swear by Great Allah to do my job faithfully and honestly and I pledge to keep the confidentiality of the information that I have seen by virtue of my official work).
Punitive Provisions		
Article 33	1	The Minister or his delegates shall be entitled to give notice to any establishment, plant, or any other polluting entity or source to remove the affected material within (10) ten days from the date of notification of the warning. this extendable until the removal of the legal offence.
	2	Subjecting to the provisions specified in item (first) of this Article, the Minister or his delegate shall impose fine ranging from (1000000) million dinars to (10000000) ten million dinars repeated monthly until the removal of the violation. Whoever contravenes the provisions of this Law and the regulations, instructions and statements issued pursuant thereto.

Appendix E.2: Law No. (8) Environment Protection and Improvement of 2008 in the Iraqi Kurdistan Region

Article	Item	Content

Article 5	Fifth	All administrative agencies, each in their way, must ration the utilization of natural resources to achieve sustainable development.
Article 22		The harmful substances must be treated based on criteria, and measures before throwing them into water bodies or drainage systems. The action is forbidden unless treated.
Article 23		The regional criteria are followed for the management of surface water, groundwater, and drinking water
Article 24		The (EPIB) Environmental Protection and Improvement Board will prepare standards for drinking water, irrigation water and industrial waters
Article 29		The general directorate of urban planning have to request consents of (EPIB) for Urban progression
Article 40		Managements of steering committees are needed to face environmental challenges

Appendix E.3: Law No. (6) The Municipalities Directive Act in KRG, Iraq with amendments of 1993

Article	**Item**	**Content**
Article 27	1	Filling Marshlands, ponds and water collection sites resulting from leakage and low and unhealthy areas
Article 28	2	The Municipal Council shall decide to take action for the streets; settling, paving, planting, and watering.
	4	The municipality shall issue ordinances and take actions to Establish, expand and classify of green areas and public parks
	6	Based on the public interest, the municipal council shall decide to implement the approved master plans and the detailed designs, as well as the implementation of the streets, services and other uses upon it.

Appendix E.4: Law No. (50) Ministry of Water Resources of 2008

Article	**Item**	**Content**
Article 2 The Ministry aims to:	1	Planning for the investment of water resources in Iraq and the exploitation of surface and groundwater for optimal use of water resources.
	2	The development of water resources, their development, their sources and use.
	3	To safeguard Iraq's rights in shared international waters and to maintain contacts and exchange of information with neighbouring and riparian countries in order to guarantee fair agreements to divide the quantity and quality of water entering Iraq.
	4	Conservation of surface and groundwater from pollution, giving priority to the environmental aspect and reviving and sustaining the marshes and other water bodies.

Article 3	5	Coordination with international, regional, Arab and non-governmental organizations specialized in water and environmental resources.
	6	Coordinate the Ministry's plans with the planning bodies and the water-consuming sectors in line with the sustainable development in Iraq for all sectors.
	7	Introducing modern technologies and geographic information systems (GIS) to develop the work methods in the ministry and train technical and administrative staff in order to achieve the management and exploitation of water through advanced scientific methods.
	8	Raising public awareness of the importance of preserving the water resources and investing them in the best way, protecting them from pollution, and to expand the base of public participation and civil society organizations in the ministry's activities.

Appendix E.5: Regulation No. (2) Conserving Water Resources of 2001

Article	**Item**	**Content**
Article 3		It is forbidden to discharge or throw the waste from the shops or stores into the public water, whatever its quality or quantity or the nature of the discharge, whether discharging continuously, intermittently or temporarily, for any reason, except with a license from the (EPID) or whoever authorizes it.
Article 4		It is prohibited to throw or discharge any pollutants, including toxic or radioactive materials, into the public waters or to dump to underground them unless authorized or authorized by the (EPID).
Article 5 The (EPIB) shall issue environmental determinants of the following:	A	Public water quality in terms of physical, chemical and biological aspects according to the nature of each and their uses.
	B	The quality of wastewater discharged to public water, sewage networks or rainwater systems, from the physical, chemical and biological aspects according to nature and uses of each.
	C	The quality of disposed of wastewater that containing toxic substances to be discharged into public water, sewage networks or rainwater networks from the physical, chemical and biological aspects, depending on the nature of those substances, considering the following factors: First - the severity of the impact of the contaminant. Second: Stability of the contaminated toxic substance. Third: Changes in the toxic substance when entering the human body. Fourth - the extent of the impact of toxic substance on the neighbourhoods and the importance of the affected neighbourhoods.
	D	Treatment and management of wastewater containing radioactive materials.
Article 6	A	The business owner, which produces waste containing radioactive materials, is obliged to use the best techniques to treat it before discharging it into public water, whatever the cost.
	B	The business owner shall be obliged to treat the residual water from the shop in a way that conforms to the determinants issued under the provisions of Items B and C of Article 5 of this Law and not to exceed those limits before discharging them to public water, sewage networks or rainwater networks.

Article 9	C	Washing of animals, leather, intestines, wool, clothing or any material that causes contamination and damage to the environment or public health in water, defecation, urination or on its banks.
Article 12		The provincial councils for the protection and improvement of the environment, in coordination with the local people's councils, shall draw up plans for each governorate to protect the public water from pollution and improve its quality according to a timetable
Chapter 3, Article 13	A	The plans of the provincial councils in the field of public water protection shall be implied: Sources of pollution of public water.
	B	Requirements for treatment of contaminated sources.
	C	Planning for future projects and to allocate financial needs.
	D	Timetables for the intended projects to address contaminated sources.
Article 14		The provincial (EPIB) shall submit periodic follow-up reports to EPIB on the progress made in the field of public water conservation.

Appendix E.6: Law No. (4) The Protection and Development of Agricultural Production in the KRG, Iraq of 2008

Article	**Item**	**Content**
Article 2 The competent authorities in the region shall:	2	Educating the farmers and directing them to invest the best agricultural lands.
	3	Construction of earth dams and lakes to provide irrigation water and face droughts.
	9	Work to compensate the owners of plantations and agricultural projects in case of damage or damage as a result of natural disasters or force majeure.
	10	Contribute to increasing irrigated areas and providing equipment to be used for rational use of water.

Appendix E.7: Law No. (44) of Irrigation Ministry Companies and Bodies

Article	**Item**	**Content**
Article 1 Companies and organizations are hereby established	1	Al-Rafidain Dams Construction Company.
	2	Al-Salahuddin Company for Land Reclamation.
	3	Al-Nahrawan Land Reclamation Company.
	4	Al-Palestine Company for Land Reclamation.
	5	Al-Khathra Company for the cultivation of reclaimed land.
	6	Al-Zawraa Company for Reclaiming Lands.

	7	Al-Muthanna Irrigation Projects Maintenance Company.
	8	Al-Hadba Irrigation Projects Maintenance Company.
	9	Al-Nasr Company for the maintenance of irrigation projects.
	10	Water Well Drilling Company.
	11	Machinery and equipment repair company.
	12	General Authority for Survey.
	13	General Organization for Oasis and Soil Maintenance.
Article 2 Aim to carry out the works and related issues, inside and outside the country as contractors	1	The construction of dams and large dams on major rivers and streams.
	2	Conducting irrigation and reclamation projects of various types.
	3	Executing the contracting of washing and cultivating the reclaimed lands and improving its soil for agricultural purposes.
	4	Implementation of contracts for clearing irrigation rivers, irrigation and drainage networks, as well as maintenance of hydraulic structures and related facilities.
	5	Digging water wells and installing pumps.
	6	Perform the repair of machinery and equipment.
	7	Surveying works and printing maps and related issues.
	8	The development and reconstruction of deserts through the establishment of oases and the stabilisation of sand dunes and maintenance of soil.

Appendix E.8: Law No. (45) of Studies and Design Centres for Irrigation, Water and Soil Research Projects of 1987

Article	Item	Content
Article 1 The following centres shall be established under this law, and their headquarters shall be as described below:	A	Al-Furat Centre for Studies and Designs for Irrigation Projects (in Baghdad).
	B	Dijla Centre for studies and designs for irrigation projects (in the province of Nineveh).
	C	Water and Soil Research Centre (Baghdad)
Article 4 The objectives of the centres shall be as follows:	First	Al-Furat and Dijla centres for studies and designs for irrigation projects: 1: Conducting engineering consultancy works for irrigation, reclamation and groundwater projects inside and outside the country, including preparing studies, designs, documents and general supervision of their implementation.

		2: Working on developing the engineers and increase their professionality in the field of consultancy, studies and designs.
	Second	Water and Soil Research Centre: 1: Conducting research and studies that help to develop irrigation and reclamation work and conduct laboratory experiments on hydraulic models and methods and techniques of field irrigation inside and outside the country. 2: Conducting researches and studies related to soil problems of various kinds. 3: Study and updating the water resources budget of the country.
Article 5 In order to achieve its objectives, the Centre may follow the available means and means that do not contradict the provisions of the law.	1	Entering contractual relations with various Iraqi, Arab and foreign parties.
	2	Participation and cooperation with companies, consultation and training institutions and others within the country to achieve its various activities.
	3	Preparation of training courses for engineers and the improvement their levels of both theoretical and application in various fields of engineering.
	4	Documenting scientific and technical information developed in the field of engineering work to benefit from it in the activities of the Ministry.

Appendix E.9: Law No. (83) Irrigation Law of 2018

Article	Item	Content
Article 2	First	The Ministry is committed to carrying out the work of public water resources, repair, maintenance and supervision, and the establishment, maintenance or improvement of rivers, streams, drainages, water flow regulators, dams, buildings, reservoirs and their edge banks.
Article 3		The Ministry or the competent department shall appoint and supervise the water shares and local governments shall not interfere with the work of the Ministry.
Article 5	First	A: If the competent department finds that an act of water resources projects or private water project must be established, maintained, repaired, closed, lifted or removed, it shall notify the beneficiary or the landlord to do so within (10) ten days from the date of notification.
Article 6 The competent department may temporarily cut off the water supply in one of the following cases:	First	Execute or organize water resources work.
	Second	Water distribution alternation.
	Third	Preventing damage or fears on human life, money or water resources works.
	Forth	Lack of water.
	Fifth	Abuse of the user or neglect of water in a manner that leads to waste.

	Sixth	Violating the orders or warnings issued by the competent department in accordance with the provisions of this law.

Appendix E.10: Law No. (59) of Beaches Utilization of 1987

Article	Item	Content
Article 2	A	This law aims to regulate the exploitation of the beaches of the Tigris and Euphrates and the main rivers and their tributaries, lakes, reservoirs and adjacent lands, and also to ensure the passage of floodwaters and to prevent pollution regardless of the type of the lands owning.
Article 3		No land covered by the provisions of this law may be exploited for agriculture, planting, or construction therein, except with the approval of the Ministry of Irrigation and the Ministry of Agriculture.

Appendix E.11: Natural Pastures Law No. (2) of 1983

Article	Item	Content
Article 1	Forth	Conservation of water resources in natural rangelands and regulation of their exploitation.
Chapter 3 Grazing organizing **Article 7**	Fifth	Establishing water barriers to retain rainwater in valleys and other grazing areas.
	Sixth	Ensuring the provision of guidance, veterinary, marketing and other facilitation services to grazing areas.
Article 9	First	Artesian water wells may not be drilled in natural pastures and rainfed lands that privately owned or state-owned property that gained action right, which is allocated for grazing purposes, except with the approval of the competent department.
	Second	The competent department, in coordination with the Ministry of Local Government and the General Establishment of Groundwater, shall organize operating periods of water wells in the natural pastures and in accordance with the provisions of this law.
Article 11		Authorities of the competent department, responsible for the management of natural pastures, shall be empowered to take immediate measures to extinguish the fires in which they occur in cooperation with other competent departments and agricultural cooperatives in the region. They may, when necessary, request the administrative authorities to provide the supplies necessary to prevent danger in accordance with the provisions of the Law on Emergency Use No. (37) of 196.

Appendix E.12: Law No. (89) Public Health Law of 1981 (Chapter Five)

Article	Item	Content
Article 30		Expanding the establishment of environmental laboratories specialized in conducting various physical, chemical and biological laboratory tests to investigate water, air and soil contaminants.

Article 64		The competent health authority approval is needed on the validity of drinking water sites and intake sources at the stage of study and design of the drinking water supply project, that information on the quality of the water source has to be of samples taken from the source point and based on governmental laboratory tests.
Article 65		The health authority certifies on the validity of the site and the method of filtering used in a water project in cooperation with the competent government departments on the filtration process, by which the biological, chemical and physical contaminants must be removed.
Article 66		Iraqi or international standards are adopted to determine the quality of drinking water and its suitability for human consumption for drinking water projects all over the country.
Article 67	First	Each newly established drinking water purification project should contain an integrated laboratory for microbiological, chemical and physical tests to determine the efficiency of the filtering stages and ensure that the processed water meets the required specifications in the country.
	Second	The authority responsible for the existing drinking water projects should work to open an integrated laboratory as mentioned in the above paragraph during a period specified by the health authority with special instructions that the projects are equipped with basic laboratory equipment (devices to measure the turbidity, residual chlorine, pH and others). Within six months from the date of publication of this law in the Official Gazette.
	Third	The authorities responsible for supplying drinking water are committed to providing the health authority in the region by the results of the tested water.
Article 68		Public health laboratories and environmental laboratories in all governorate centres shall conduct periodic checks on the quality of processed water and ensure its conformity with the specifications adopted in the country
Article 71		The consent of the health authority is obligatory on the discharged wastewater sites, agricultural, industrial and human, to the water source to ensure the control of water quality of intake sites for drinking water purification projects
Article 105		Regulations, instructions and data may be issued to facilitate the implementation of the provisions of this law.

Appendix E.13: Penal Code No. (111) of 1969 and the Amendments

Article	**Item**	**Content**
Article 368		Punishable by imprisonment for a term not exceeding one year or a fine not exceeding one hundred dinars to anyone whose mistake caused the spread of serious disease that of harmful to the lives of individuals.
Article 496	Second	Any person who dumps (the body of animal or dirty materials) that harmful to the health into a river, canal, trocar or any other watercourse shall be punished by imprisonment for a period not less than one month and not more than six months and a fine of not less than one hundred dinars and not more than five hundred dinars.

Appendix E.14: Regulation no. (25) the maintenance of rivers and public water from pollution of 1967

Article	Item	Content
Article 1	2	The Shop is the public or private shop, factory, department or any other private or governmental establishment.
Article 7 It is forbidden to discharge the wastewater from the shop into the public water in the following cases:	1	If each of the absorbed biological oxygen or suspended or floating substances exceed the rates determined by the health authority instructions that the maximum limit does not exceed 60 parts per million (ppm).
	2	If it contains hydrogen sulfide or toxic substances in harmful amounts or harmful germs or substances that may produce toxic substances when interacting with chemical elements that may be present in public waters.
	3	If the ion concentration of hydrogen (pH) is less than (6) or more than (10).
	4	If the temperature affects the discharged into water.
	5	Any other case determined by the health authority in accordance with instructions issued by it.
Article 8	1	If the analysis shows that the percentage of pollution in the wastewater is contrary to the percentages mentioned in Article 7 of this Law, the owner of the shop shall, within three months from the date of the registered notification that sent to him by the health authority, to establish filtration centre that to be approved by the mentioned authority. This centre shall start operating within a period not exceeding twelve months from the date of the approval of the health authority provided that the owner of the shop or factory follows the instructions issued by the health authority to mitigate damages during the period of filtration centre.
	2	If the owner of the shop does not apply the provisions of Item (1) of this article, the health authority shall prevent the discharging of wastewater from his business.
Article 9		If the health authority finds that there is a risk on public health from the waste discharged into the public waterways, it shall notify the owner of the licensed store or the person in charge of a registered letter requesting that the discharge of such waste be discontinued until the provisions of Articles 7 and 8 of this Law are applied and follow the instructions and orders issued thereunder.
Article 10		No person shall dump the bodies of animals, secretions, faeces, or any rotten, rigid or liquid material or garbage of any kind or any other harmful substance in any stream of public water or on its shores or permit or order it.
Article 11		Animals, skins, intestines, wool, contaminated clothing, or any material that may cause harm to public health in public waters, or defecate, urinate or shore, shall not be washed.
Article 15		The violator of the provisions of this Law or the statements or instructions issued pursuant thereto shall be punished in accordance with Article 11 of the Public Health Law No. 45 of 1958.

Appendix E.15: Instructions No. (1) Groundwater Wells Drilling of 2010 in the Kurdistan Region Government (KRG)

Article	Item	Content
Article 2		The distance between neighbour water wells identified for Karstified[25] formations should be within 450 to 600m, and for inter-granular formations, they should not be less than 200m
Article 3: The water well's distance from Springs, Kahariz [26] and water resources projects:		Water wells shall not be drilled - in any way - near Springs, Kahariz, and water resources projects. The water well shall not be less than 500 meters from these projects. In the case of a Spring dried up, the well shall be 500m away.
Article 4		It is permissible to drill agricultural water wells when there is no room to benefit from the use of surface water, and this is through a letter of support from the Directorate of Irrigation and Surface Water in the province.
Article 5 Instructions for drilling public water wells (for the purposes of drinking water, agriculture, industry):	1	Applying a request by the beneficiary to the groundwater directorate in the governorate and supporting it from the administrative units (the district administration of the judiciary, (the district directorate, or the municipality), then submitting it to the governorate to dig the water well on the designated land, if there is no dispute over it.
	2	Detecting the location of the water well by a specialised committee from the directorate of groundwater with the collaboration the representative of the administrative units of the region, then determining the number of beneficiaries, and preparing a geological report accordingly.
	3	Next, the report of the above committee will be sent to the Directorate-General for the approval.
	4	After granting the license, the beneficiary is allowed to drill the water well.
	5	The license of drilling of an alternative water well is granted according to the geological report and site detection to make sure that the water well has dried or rehabilitated.
Article 6: Drilling instructions for the private sector	1	An application by the beneficiary to the Directorate of Groundwater of the governorate, with the support of the district mayor or the director of the municipality or the presidency of the municipality and the approval of the province to dig the water well.
	2	Detect the location of the water well by a committee from the Directorate of Groundwater in the governorate to prepare a geological report.
	3	The report of the aforementioned committee will be sent to the Directorate-General for approval.

[26] Underground water canals

<table>
<tr><td></td><td>4</td><td>After obtaining the approval of the General Directorate and granting the license, the applicant shall be allowed to dig the water well.</td></tr>
<tr><td></td><td>5</td><td>The license shall not be granted to petrol stations, car wash garages, small factories, worship places, commercial buildings, private sector stores and others, except by a support letter of endorsement or clarification from the water departments in the regions that not being able to provide water to them. The land use is defined by the mayor or the real estate directorate in the governorates.</td></tr>
<tr><td></td><td>6</td><td>No license shall be granted for digging a water well for gravel and sand quarries.</td></tr>
<tr><td></td><td>7</td><td>Granting water well-drilling license for mineral water production plants and other beverages shall be within the following conditions:
• If the plot of land allocated to the plant is far from suitable surface water sources or springs.
• The allocated piece of land should be outside the boundaries of the municipalities of cities, districts, towns and villages.
• Mineral water production water wells should be drilled in granular geological formations, especially the Bakhtiari formations and modern sediments, and in the appropriate karst formations.</td></tr>
<tr><td></td><td>8</td><td>In any way, it is forbidden to make-trade by groundwater and to install taps on the water wells of the private sector. A written pledge has to be taken from the applicant by the notary public.</td></tr>
<tr><td rowspan="4">Article 7
Instructions for drilling Agricultural wells:</td><td>1</td><td>The beneficiary shall apply a request to the agricultural department requesting to dig a water well in his land. An inspection by the surveyors will be done for the purpose of determining the land's type, boundaries, and its area, in addition, to assign the existing water wells near the land on a map. The land area should not be less than (5) dunums[27] in the mountainous areas. And, In the plain areas, it should not be less than (20) dunums.</td></tr>
<tr><td>2</td><td>The real estate directorate or groundwater directorate in the region shall send a letter to a few directorates related to the drilling of water wells for the purpose of obtaining their approval. These directorates shall reply to the request letter and clarifying the condition of:
A. The Directorate of Irrigation and Surface Water (for the purpose of obtaining their support not to benefit from surface water).
B. Directorate of roads and bridges (for the purpose of determining the location of the water well and distance from the roads and public streets at a distance of (75) meters.</td></tr>
<tr><td>4</td><td>The beneficiary (owner of the land) must use an appropriate watering system or make an undertaking to use it. The quality of the irrigation system shall be determined by the Surface Water Directorate.</td></tr>
<tr><td>5</td><td>The Groundwater Directorate committed to explore the site for the purpose of detection and determine the appropriate place to dig the water well by using (G.P.S) device, but the depth of the water well will be</td></tr>
</table>

[27] Donum was the Ottoman unit to measure area and is equal to 2500 square metres. The unit is still in use in many areas previously ruled by the Ottomans empire.

		determined according to the specificity and structure of the aquifer and based on the report of the Commission on Discovery.
	8	The (license holder) must finish the water well drilling within (6) months, and if delayed more than this period, he/she must request a new inspection with a new committee from the groundwater Department.
	9	The land-owner should place a water flow meter for water abstraction.
	10	In case of digging a water well in an Artesian aquifer such as the plain (northern Erbil, Shahrazur, Aqra-Bardarsh), the digger has to take into account not to penetrate the Artesian layers and work on the instructions of the Groundwater Department and the geologist competent until reserving the shallow groundwater. A valve has to be placed on the water well in case if the Artesian layer's water flows.
	11	The Ministry of Agriculture and Water Resources has the right to refrain drilling water wells in any part or underground basin when the studies prove a sharp drop in groundwater level, pollution or a rise in the proportion and density of salts and nitrates.
	12	The applicant shall not have the right to claim the water well drilling license after one month has elapsed on the inspection date.
	13	The license for drilling an alternative well shall be granted in the case that the water well has dried or been filled, and this according to the geological survey attached with a report, and after ensuring that the dried well has been filled.
Article 8 Licensing water well drillers and examination equipment for private sector companies (Contractors)	6	The digger's license shall be granted to the contractors and companies through an application process that requires to obtain the approval of the Director-General.
	7	The contractors must have a supervisor geologist with experience in the field of inspection of water wells and the support of the Association or the Kurdistan Geological Union and visit the site of the water well for the purpose of examining the water well, and then to fill the examination form
	8	The contractor should implement all technical conditions issued by the groundwater directorates in the province.
	9	The contractor should submit the inspection form around the water well to the groundwater directorate in the governorate one month after the completion of the water well inspection process.
	10	The Directorate of Groundwater in the provinces has the right to carry out the process of inspection on the devices and tools and the number of the contractors - at any time - to check the machines and their ability on undertaking the work.
Article 10 Financial fines and administrative penalties	1	If the contractor or company (which has diggers license) undertaking to drill water well, which has not got an official license by the groundwater directorate will be fined by (250,000) two hundred and fifty thousand Iraqi Dinars in addition to the suspension of working for one month, this is for the first time.
	2	In case of a repeat the offence for the second time, an amount of (750,000) seven hundred and fifty thousand Iraqi Dinars shall be fined in addition to the suspension of the work for six months.

	3	In case of offence repetition for the third time: the work of the contractor or company is suspended with the withdrawal and revocation of the license.
	4	In case the contractor or company violate the Item (10) of the Article (7) of these instructions, the contractor or company equipment shall be suspended for three months.
	5	Contractors or companies violating the points (9.8.7) of the three sections of Article (8) of these instructions are suspended for three months for the first time, in case of repetition for the second time the device is suspended for 6 months, and for the third time is the license is withdrawn and invalidated.
	7	licenses are not granted to water wells that the formerly drilled of the private sector, which did not obtain the approval from the relevant authorities, especially the groundwater directorates in the governorates.
	12	The drilling of water wells shall be prohibited by hammering devices. in case these devices are used for digging water wells, they shall be confiscated and become the property of the regional government.

Appendix E.16: Amended Instructions No. (1) Groundwater Wells Drilling of 2015 in the Kurdistan Region Government (KRG)

Article	Item	Content
Article 2 The distance between groundwater wells	E	The water wells that been drilled for the public beneficiaries and strategic projects are not abiding by the Article 2 restrictions, in condition do not affect the groundwater level
Article 7 Instructions for drilling Agricultural water wells:	2	The land area should not be less than (10) dunums in the mountainous areas. And, In the plain areas, it should not be less than (20) dunums.
	3	A license for only one water well shall granted to a number of agricultural land parcels as shared water well, which their total areas as per what mentioned in Item 2 in this Article, and the distances as per the Article 2 in this instruction.
	4	The real estate directorate or groundwater directorate in the region shall send a letter to a few directorates related to the drilling of water wells for the purpose of obtaining their approval. These directorates shall reply to the request letter and clarifying the condition of: C: Directorate of archaeology D: Directorate of Forests and Pastures
	11	1. Water is a national communal resource, therefore, the directorate-general has the absolute authority on either issuing water well licenses or to revoke it for the public benefit.
Article 14	1	If a contractor or company (which has diggers license) undertaking to drill water well, which has not got an official license by the groundwater directorate will be fined by (1,000,000) one million Iraqi Dinars in addition to the suspension of working for six months, this is for the first time.

Financial fines and administrative penalties	2	In case of a repeat the offence for the second time, an amount of (2,000,000) two million Iraqi Dinars shall be fined in addition to the suspension of the work for one year.

Appendix E.17: Law No. 9 (2006) of the Ministry of Water Resources in the Kurdistan Region, Iraq

Article	**Item**	**Content**
Article 2		The Ministry aims to develop strategies, policies and plans for the development and investment in water resources (surface and groundwater) in the region, and prepare technical feasibility studies, and economic projects for water resources. Construction and maintenance of dams and irrigation projects.

Appendix E.18: Regional Development Strategy of KRG 2012-2016

Article	**Item**	**Content**
Chapter 4	4	Calls for groundwater exploitation have to be expanded, especially water wells. Statistical results for 2006 indicate that the water wells were mostly used for drinking water provision, 20% used in agriculture, and the rest were exploited for industrial, and agricultural extension and research purposes

Appendix E.19: Instructions No. (2) The Protection of The Environment from Municipal Waste of 2014

Article	**Item**	**Content**
Article 4 It is forbidden to:	Third	dispose of municipal wastes into water resources or on its banks

Appendix E.20: Regulation No. (3) National Determinants of Wastewater Treatment in Agricultural Irrigation of 2012

Article	**Item**	**Content**
Article 3 This Regulation aims to:	First	Preventing the use of wastewater in a manner that directly or indirectly damages public health or surface and groundwater resources, or damages degrade or contaminate the soil and affect its productive capacities, the food chain and its aesthetic aspects.
	Second	Identify the acceptable methods and levels for wastewater treatment and reuses for irrigation.
	Third	Set the standards to achieve safe limits of treated wastewater for irrigation.
	Forth	Protect the public health from the harmful effects of wastewater pollution used for irrigation.
	Fifth	Make the most of treated water as a non-traditional source of water.

	Sixth	Monitoring the wastewater treatment plants and the quality of treated wastewater used for irrigation.
Article 4 The use of treated wastewater for agricultural irrigation shall be as follows:	Third	The water used for agricultural irrigation shall comply with the standards of wastewater provided in Tables (1) and (2) attached to this Regulation.
	Ninth	Not to use the treated water to recharge groundwater utilised for drinking purposes
Article 6	Third	The observers of the Ministries of Agriculture and Environment authorized to enter the farms and fields that get benefit from the treated water. the farmers or the field owners or on his behalf has no right to prevent them from doing so.

Appendix E.21: Resolution No. (25) The International Water Conventions and Treaties (IWCAT) of 2010

Article	Item	Content
Article 1		The Federal Government shall include a clause in the draft of the comprehensive partnership agreement between the Federal Republic of Iraq and the Republic of Turkey to secure and determine Iraq's water shares in the transboundary rivers of Tigris and Euphrates rivers and their tributaries based on historical rights acquired in accordance with international law.
Article 2		The Federal Government shall consider the incorporation of partnership agreements between Iraq and Syria and Iran to secure Iraq's share of the water in the transboundary rivers, which will ensure the national public interest in water.

Appendix E.22: Law No. (10) The Ratification of the Convention to establish the Arab Center for the Studies of Arid Zones and Dry Lands of 1971

Article	Item	Content
Article 3 The Centre aims to carry out regional studies related to arid areas in the Arab countries, the following major studies:	1	Studies related to water sources, whether the water in the air, the surface water, groundwater, including metrological studies such as water vapour in the air, types of rainstorms, annual distribution and so on.
	2	Studies of surface and groundwater in order to make good use.
	3	Studying the means of utilizing water resources in light of the hydrological balance of the water basin.
	4	Study the geological and geomorphological aspects of different regions.
	5	Studying the economics of the exploitation of arid lands.
	6	Studies related to soil and cartography illustrating their types, grades and priorities for agricultural investment, with the proposal of appropriate methods for each region.

	7	Studying the extent of soil erosion by wind, floodwater, irrigation water and rain and conducting experiments to determine the best ways to preserve and maintain the soil.
	8	Studying the best irrigation and drainage methods in these areas
	9	Study the best ways and means to improve the investment of soil and water.
	10	Study the effect of salinity on soil and plants and means of treatment.
	11	Examining the problems related to the deterioration of agriculture and vegetation, and the means to deal with this deterioration.
	12	Studies of the environment and localization of plants and animals.

Appendix E.23: Law No. (40) Iraqi Civil Law of 1951

Article	Item	Content
Article 1052		The lowland endures the water that descends from the high topography of it, such as rainwater and natural springs, neither the owner of the lowland cannot build a dam to harvest water, nor can the landowner of the highland come to increase what the lowland should bear within the limits set by the law.
Article 1053	1	The owner of the land may use the rainwater coming down in his land and the natural water of the springs flowing therefrom. If the use of this water or the method of directing it would increase the burden of the canal that the low-land should bear in accordance with the preceding article, the owner shall be compensated.
	2	If the owner of the land receives water in his land by digging or otherwise, the low-land shall bear the flow of such water and the owner shall have the right to be exposed to the damage caused by it.
Article 1054		If the owner of the land wishes to construct buildings therein, he shall make the roof of the building in a way that the rainwater flows on his land or on the main road, not on the neighboring road, in accordance with the laws and regulations in force in this regard.
Article 1055		Any person may irrigate his land from the waters of rivers and public canals, and he may establish a schedule for taking this water to his land, all in accordance with the relevant laws and regulations.
Article 1056		Any person who constructs an irrigation or drainage canal in accordance with the laws and regulations in force shall have the right to use it.
Article 1057	1	The buffers areas of water wells, springs, canals, drainages are the property of their owners. It is not permissible for others to act in any way. Whoever drilled a water well in the buffer area of a well owned by someone else was forced to fill it, but if the well dug outside this buffer, it is not forced to backfill even if the well takes the water of the first water well.
	2	There is no buffer area for a water well dug by a person in his property, and his neighbour can also dig a water well in his own land, even if the water drafted from the first well.

Article 1058	1	The owner of the land shall allow sufficient water to pass through his land to irrigate other distant lands from the water supply, and there is no water for agriculture and no direct water passage to it, as well as the drainage water coming from neighbouring lands to be dumped in the nearest public drainage, provided that the landowner shall be paid in advance. If the land inflicts damage on its land or bank, whether due to pollution or poor condition of bridges, dams or otherwise, the landowner may seek compensation for the damage caused by the landowner.
	2	The owner of the land shall also permit the construction of the necessary technical constructions on the land that is necessary for the sewage and discharge required for the distant lands, provided that he shall collect an annual wage in advance and benefit from such constructions, provided that he shall bear the expenses of its establishment and maintenance in a manner commensurate with his benefit.
	3	If the parties do not agree on the remuneration, the Court shall at its discretion.

Appendix E.24: Majallah Al-Ahkam Al-Adaliyyah

The civil code of the Ottoman Empire (Book 10)

Article	**Item**	**Content**
Chapter IV. Jointly owned property which is free. **Section I.** Things that are free and things that are not free.		
Article 1234		Water, grass and fire are free. The public are joint owners of these three things
Article 1235		Water flowing underground is not the absolute property of any person.
Article 1236		Wells that have not been made by the labour of any particular person, the benefit of which may be enjoyed by the public, are the jointly owned and free property of the public.
Article 1237		Seas and large lakes are free.
Article 1238		Rivers which belong to the State and are not the property owned in absolute ownership of any person, are those rivers the bed of which does not pass through the property of a group of persons owned in absolute ownership. All such rivers are free. Examples of such rivers are the Nile, the Euphrates, the Danube and the Tonja.
Article 1239		Rivers which are the property of individuals owned in absolute ownership, that is to say, rivers which, as stated above, flow through the property of persons owned in absolute ownership are of two categories
Section IV. Rights of Taking Water and Right 0f Drinking Water.		
Article 1265		Any person may water his lands from rivers that are not owned in absolute ownership by any particular person, and, in order to irrigate them and to construct mills, may open a canal or water channels, provided that he does not thereby inflict injury on any other person. Consequently, if the water overflows and causes injury to the public, or the water of the river is entirely cut off, or boats cannot be navigated, such injury must be stopped.

Article 1266		All persons and animals have a right to drinking from water, possession of which has not been taken by any other person.
Article 1267		The right of taking water from rivers which are privately owned, that is to say, the course of which are privately owned belongs to the owners thereof. Other persons have a right to drinking therefrom. Consequently, no person may, without permission, water his land from a river which is appropriated to a group of persons, or from a watercourse, or a water pipe, or a well, He may, however, drink water therefrom, since he has a right of drinking water. He may also water his animals, by reason of the large number thereof, from such river, water-course, or water-pipe, provided there is no danger of destroying the same. He may also bring the water to his house or to his garden by means of jugs or buckets.
Article 1268		Any person having in his property which he owns in absolute ownership a tank, a well, or a river, from which water alternatively enters and leaves, may prevent any person who wishes to drink water from entering his property. If, however, there is no free water to be had in the neighbourhood, the owner of the property is obliged either to draw off water or to give such person permission to enter his property and take it. If he does not draw off the water, such person has the right of entering and taking it, subject, however, to no injury being caused, that is to say, provided that no injury is done, such as destroying the edge of the tank, or of the well, or of the river.

Appendix F: Support letters

University of Salford MANCHESTER

January 15, 2015

To: The ministry of the interior affairs, Kurdistan Regional Government - Iraq, Erbil Governorate

Subject: *Facilitation for obtaining the required information from your relevant departments*

Dear Sir,

We have a number of students' worldwide working towards their PhD degree under my supervision here at the University of Salford, Greater Manchester, UK. **Mr. Mohammed A. Nanekely** is one of our students who work toward this. We highly appreciate if you could help us in gathering some of the information concerning an approach for possibility of applying the sustainable urban drainage system in Kurdistan region and Erbil city.

We assure you that any information we collect will only be used for research purposes and we are happy to sign Non-Disclosure agreement with you, if any.

The outcomes of the research may be given to you if you need it.

Many thanks and looking forward for your help.

Yours Sincerely,

Prof. Miklas Scholz

cand ing, BEng (equiv), PgC, MSc, PhD, CWEM, CEnv, CSci, CEng, FHEA, FIEMA, FCIWEM, FICE, Fellow of IWA

Chair in Civil Engineering and Head of the Civil Engineering Research Group

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t: +44 (0)161 295 5000 www.salford.ac.uk

University of Salford
MANCHESTER

January 15, 2015

To: Ministry of Municipalities - General Directorate of Urban Planning

Subject: *Facilitation for obtaining the required information from your relevant departments*

Dear Sir,

We have a number of students' worldwide working towards their PhD degree under my supervision here at the University of Salford, Greater Manchester, UK. **Mr. Mohammed A. Nanekely** is one of our students who work toward this. We highly appreciate if you could help us in gathering some of the information concerning an approach for possibility of applying the sustainable urban drainage system in Kurdistan region and Erbil city. The information we may need are as following:

- Aerial photo of Erbil city
- Geospatial database of the city
- Layers of GIS system concerning to urban planning

We assure you that any information we collect will only be used for research purposes and we are happy to sign Non-Disclosure agreement with you, if any.

The outcomes of the research may be given to you if you need it.

Many thanks and looking forward for your help.

Yours Sincerely,

Mr. Mohammed Abdulwahid has presented a seminar on SUDS at our Directorate General of Municipalities in Duhok Governorate / KRG

Prof. Miklas Scholz

cand ing, BEng (equiv), PgC, MSc, PhD, CWEM, CEnv, CSci, CEng, FHEA, FIEMA, FCIWEM, FICE, Fellow of IWA

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Web: http://www.salford.ac.uk/computing-science-engineering/cse-academics/miklas-scholz

University of Salford MANCHESTER

January 15, 2015

To: Environmental board - KRG

Subject: *Facilitation for obtaining the required information from your relevant departments*

Dear Sir,

We have a number of students' worldwide working towards their PhD degree under my supervision here at the University of Salford, Greater Manchester, UK. **Mr. Mohammed A. Nanekely** is one of our students who work toward this. We highly appreciate if you could help us in gathering some of the information concerning an approach for possibility of applying the sustainable urban drainage system in Kurdistan region and Erbil city. The information we may need are as following:

- The studies on sustainable water / wastewater resource /usage

We assure you that any information we collect will only be used for research purposes and we are happy to sign Non-Disclosure agreement with you, if any.

The outcomes of the research may be given to you if you need it.

Many thanks and looking forward for your help.

Yours Sincerely,

Prof. Miklas Scholz

cand ing, BEng (equiv), PgC, MSc, PhD, CWEM, CEnv, CSci, CEng, FHEA, FIEMA, FCIWEM, FICE, Fellow of IWA

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دەستەی پاراستن و چاککردنی ژینگە
هيئة حماية و تحسين البيئة
Board of Protection & Improving Environment
فەرمانگەی ژینگەی هەولێر
دائرة بيئة أربيل
Erbil Environment Office

University of Salford MANCHESTER

Salford, 2 September 2015

Ministry of Agriculture and Water Resources-KRG-General Directorate of Dams and Reservoirs,
Ministry of Agriculture and Water Resources-KRG-Dokan Dam Directorate,
Ministry of Planning-KRG, and
Ministry of Environmental-KRG

To Whom It May Concern

Dear Sir or Madam,

Request for information on the impact of climate change on water resources availability in Iraq.

We have several Iraqi students (funded by the Iraqi Ministry of Higher Education) working towards a PhD degree under my supervision here at The University of Salford. We would highly appreciate, if you could help us in gathering some of the information related to the impact of climate change on water resources availability in Iraq and corresponding adaptation and mitigation strategies. The information we may need include:

1. Daily and monthly records for the following meteorological variables:
   a. Precipitation,
   b. Maximum and Minimum Temperature,
   a. Humidity,
   b. Wind Speed,
   a. Solar, and
   a. Evaporation

   from the stations: Sulymanyah, Erbeel, Salahddin, Kirkuk, Makhmoor, Halabcha, Soran, Halabcha, and Tus.

2. Daily and monthly flow at the following gauging stations along Little Zab River: Little Zab at Dokan, Little Zab at Dokan Village, and Little Zab at Altun Kupri-Goma Zardela.

3. All information related to Dokan dam and its reservoir such as:
   a. Daily and monthly:
      a.1 Inflow and outflow from Dokan dam,
      a.2 Evaporation from Dokan reservoir, and
      a.3 Precipitation at Dokan reservoir
   b. The tabulated values of the relationships between storage, surface area, and water level
   c. The dam hydraulic properties such as maximum, minimum, normal and dead water level
   d. The dam structural properties such as length, width, height and type
   e. A diagrammatic scheme for the dam

4. Hydrological studies about the Little Zab River Basin

5. All local studies done to analysis climate change and drought impacts on the Little Zab River Basin water resources

6. All available FAO (and other UN organizations) studies carried out on water resources availability as well as the effect of drought and climate change on Little Zab River Basin

7. Actions that were taken by local authorities to tackle and mitigate climate change and drought influences on the Little Zab River Basin water resources

8. Proposed and planned irrigation projects upstream and downstream of Dokan dam.

We assure you that any information that we collect will only be used for research purposes and we are happy to sign any non-disclosure agreement with you if necessary. The outcome of the research will be supplied to you for free.

Yours Sincerely,

Prof. Miklas Scholz
cand ing, BEng (equiv), PgC, MSc, PhD, CWEM, CEnv, CSci, CEng, FHEA, FIEMA, FCIWEM, FICE, Fellow of IWA
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University of Salford MANCHESTER
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02 SEP 2015

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Salahaddin University-Erbil
College of Engineering
Department of Civil Engineering

زانكۆی سەلاحەددین – هەولێر
كۆلێژی ئەندازیاری
بەشی ئەندازیاری شارستانی

Post-Graduate Research Panel
Subject: Research Ethic Consent
Date: July 12, 2015

To: Mohammed Abdulwahid Abdullah Nanekely

Based on the information you provided, and following your request that submitted to the college, there is no objection on undertaking interviews and addressing questionnaires (as a part of your research method) toward targeted people represented as (Decision-makers, Managers, Engineers, and Water Professionals, Notables).

Regards,

Asst. Prof. Dr. Shuokr Q. Aziz
Head of Civil Engineering Department
College of Engineering,
Salahaddin University -Erbil, Iraq.
E-mail: shuokr.aziz@su.edu.krd

Cc:
- Dean's Office
- The Local Advisor
- Department of Scientific and Postgraduate Affairs
- Archives

College of Engineering, University of Salahaddin, Kerkuk road, Erbil, Kurdistan Region, Iraq, Zip code 44001

University of
Salford
MANCHESTER

January 15, 2016

To: The Ministry of Agriculture and Water Resources, General Directorate of Water Resources

Facilitation for obtaining the required information from your relevant departments

Dear Sir/Madam,

We have a number of worldwide students, are working towards their PhD degrees under my supervision here at the University of Salford, Greater Manchester, UK.

Mr. Mohammed A. Nanekely is one of our students who work toward this. We would highly appreciate if you could help us in gathering some of the information concerning an approach for possibility of applying the sustainable urban drainage systems in Kurdistan region, and Erbil city has been chosen as a case study.

We assure you that any information we collect will only be used for research purposes and we are happy to sign Non-Disclosure agreement with you, if any.

The outcomes of the research may be given to you if you need it.

Many thanks and looking forward for your help.

Yours Sincerely,

Professor Miklas Scholz

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School of Computing, Science & Engineering
University of Salford
MANCHESTER
20 JAN 2016

for whom concerned
we support that water resources
data upto 2016 is given them
by our G.D. of W.R.
(both surface & groundwater)
for decataining

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اقليم كوردستان – العراق مجلس الوزراء وزارة الزراعة و الموارد المائية المديرية العامة للري والموارد المائية مديرية ري محافظة اربيل	**Kurdistan Regional Government** Council of Ministers Ministry of Agriculture & Water Resources General Directorate of Water Resources	هەرێمی کوردستان - عیراق ئەنجومەنی وەزیران وەزارەتی کشتوکاڵ وسەرچاوەکانی ئاو بەڕێوەبەرایەتی گشتی سەرچاوەکانی ئاو بەڕێوەبەرایەتی ئاودێری پارێزگای هەولێر ((پلان و بەدواداچون))

Date: October 1, 2017 No: 816

To: University of Salford-Manchester
Sub.: Consent Approval

This is to certify that Mr Mohammed A. Nanekely as a PhD student at your venerable University has submitted a request to this directorate, intending to undertake interviews with professionals and stakeholders who involving in sustainable water resources management for gathering information and data on Rainwater Harvesting Ponds and Sustainable Drainage System. Upon that, the consent has been given to him for the academic research purposes.

Sincere regards…

Sardar Omer Qader
Director of Irrigation
1/10/2017

Cc:
- Planning and Follow-up Dept.
- Internal Affairs Dept.
- Dossier

Email:awderihawler1994@gmail.com
Erbil - Azadi Road

ناونیشان : هەولێر - ئازادی / چوارڕیانی پیشانگاکانی ئۆتۆمۆبیل
تەلەفۆن : 2504278 -66 -00964

University of
Salford
MANCHESTER

بەڕێوەبەرایەتی ناودێری پارێزگای هەولێر
دەرچووەکان

January 15, 2016

To: The Ministry of Agriculture and Water Resources, G.D. of Water Resources, Erbil Irrigation Directorate

Facilitation for obtaining the required information from your relevant departments

Dear Sir/Madam,

We have a number of worldwide students, are working towards their PhD degrees under my supervision here at the University of Salford, Greater Manchester, UK.

Mr. Mohammed A. Nanekely is one of our students who work toward this. We would highly appreciate if you could help us in gathering some of the information concerning an approach for possibility of applying the sustainable urban drainage systems in Kurdistan region, and Erbil city has been chosen as a case study.

We assure you that any information we collect will only be used for research purposes and we are happy to sign Non-Disclosure agreement with you, if any.

The outcomes of the research may be given to you if you need it.

Many thanks and looking forward for your help.

The data on the drainge systems have been given to the researcher based on his request from planing devision.

بەڕێوەبەرایەتی ناودێری پارێزگای هەولێر
دەرچووەکان

Yours Sincerely,

M. Mr

Professor Miklas Scholz

cand ing, BEng (equiv), PgC, MSc, PhD, CWEM, CEnv, CSci, CEng, FHEA, FIEMA, FCIWEM, FICE, Fellow of IWA

Chair in Civil Engineering and Head of the Civil Engineering Research Group

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University of Salford MANCHESTER
School of Computing, Science & Engineering
20 JAN 2016