ASSESSMENT OF WATER RESOURCES IN WADI SIHAM BASIN, YEMEN

MAJED AHMED ABDULLAH AL-WARD

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By

MAJED AHMED ABDULLAH AL-WARD

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LIST OF ABBREVIATIONS AND SYMBOLS

A	Area
AREA	Agricultural Research and Extension Authority
Cl	Chloride
CV	Coefficient of Variation
D	Drainage Density
DRP	Drought Response Plan
E	Eastern
EC	Electrical Conductivity
Ep	Potential Evapotranspiration
F	Fluoride
FAO	Food and Agriculture Organization
Fs	Stream Frequency
GIS	Geographic Information System
I	heat index
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
km^2	Kilo Square Meter
LDCs	Least Developed Countries
L_u	Total Stream Length
Lsm	Mean Stream Length
M	Middle
m.a.s.l	Meters above Sea Level
MDB	Murray Darling Basin
MERIP	Middle East Research and Information Project
MK	Mann–Kendall
mm	Millimetre
Mm^3	Million Cubic Meters
MWE	Ministry of Water and Environment
N	Factor Depending On Latitude
Na	Sodium
NaCl	Sodium chloride

NO_3	Nitrate
N_u	Stream Order
NWRA	National Water Resources Authority
OECD	Organisation for Economic Co-operation and Development
P	Rainfall
P	Perimeter
Q_1	Recharge Due To Rainfall
Q_2	Lateral Groundwater Fluxes
Q_3	Stream Bed Infiltration
Q_4	Recharge due to Irrigation Returns
Q_5	Domestic Water Uses
Q_6	Irrigation Water Use
Q_7	Industrial Water Use
Q_8	Subsurface Outflows
Q_{in}	Groundwater Recharge
Q_{out}	Groundwater Discharge
Rb	Bifurcation Ratios
Rc	Circularity Ratio
Re	Elongation Ratio
Rf	Form Factor Ratio
SD	Standard Deviation
SO_4	Sulphate
SPSS	Statistical Procedures for Social Science
S_t	Water Surplus
T	Texture Ratio
T	temperature
TA	Alkalinity
TDA	Tihama Development Authority
TDS	Total Dissolved Solid
TH	Total Hardness
Tukey-HSD	Tukey Honestly Significant Difference
UAE	United Arab Emirates
UNEP	United Nations Environment Programme

UNESO	United Nations Educational, Scientific and Cultural Organisation
WDM	water demand management
W	Western
WHO	World Health Organisation
YMAFR	Yemeni Ministry of Agriculture and Fisheries Resources
Z_{MK}	Standardised Statistical Test
%	Percent
μ	Micro
mg	Milligram
kg	Kilogram
cm	Centimetre
°C	Degree centigrade
ha	Hectare
mg/L	Milligram/Litre

PENILAIAN SUMBER AIR DI LEMBAH WADI SIHAM, YEMEN

ABSTRAK

Lembangan Wadi Siham di barat Yemen merupakan kawasan pertanian yang paling penting. Kajian ini bertujuan untuk menilai sumber air dari sudut sumber, kuantiti dan perubahan ruangan dan masa. Tumpuan utama kajian ini ialah imbangan air tanah di samping penialian juga dilakukan bagi menilai trend hujan dan air larian tahunan dan musiman dan penilaian kualiti dan kuantiti air tanah. Pertalian antara kewujudan dan penggunaan air tanah dan keseimbangan air juga dinilai. Keputusan kajian mendapati purata hujan tahunan adalah 346.39 mm/tahun dari 1979 hingga 2008 manakala jumlah isipadu hujan adalah 1711.26×10^6 m^3. Purata air larian tahunan dari 1990 hingga 2009 adalah sebanyak $82.92\times10^6 m^3$ iaitu 4.85% daripada jumlah seluruh isipadu hujan yang turun di dalam Lembangan Wadi Siham. Kehilangan air yang banyak adalah melalui sejatpeluhan iaitu sebanyak 1480.81×10^6 m^3 (86.53%) sementara hanya 147.53×10^6 m^3 (8.62%) hilang ke dalam tanah. Sebanyak 570 kejadian banjir telah direkod dari 1990 hingga 2009 dengan purata banjir tahunan sebanyak 53.10×10^6 m^3. Trend hujan dan air larian berdasarkan Ujian Mann-Kendall dan analisis kecerunan Sen menunjukkan trend yang negatif ($P<0.05$) pada dua buah stesen iaitu Wallan (cerun Sen = -4.72 mm/tahun) dan Al-Amir (cerun Sen = -6.11 mm/tahun). Namun trend positif berlaku di sebuah stesen iaitu AREA (cerun Sen = 50.20 mm/tahun). Jumlah recas air tanah yang menjadi input kepada sistem akuifer pinggir laut adalah sebanyak 147.53×10^6 m^3/tahun dan luahan (output) dari akuifer adalah 202.57×10^6 m^3/tahun yang menunjukkan bahawa akuifer telah dieksploitasi secara melampau. Imbangan air tanah yang negatif telah berlaku sebanyak 55.04×10^6 m^3/tahun. Penilaian kualiti air tanah yang diukur dari 60 buah

telaga di dalam lembangan Wadi Siham menunjukkan kandungan Nitrat (NO_3), Natrium (Na) dan Jumlah beban larut (TDS) yang tinggi berbanding paras piawaian World Health Organisation (WHO). Kesimpulannya, Lembangan Wadi Siham sedang menghadapi krisis kekurangan air yang kritikal yang boleh mengancam pertanian dan penggunaan air domestik. Trend hujan dan air larian yang negatif memberi impak yang negatif ke atas masalah kekurangan air di dalam lembangan ini. Kontaminasi air tanah di kawasan dataran pinggir laut Wadi Siham adalah tinggi dari berbagai sumber pencemaran. Kajian ini telah menjelaskan peri pentingnya keperluan yang mendadak perlu dilakukan segera demi memastikan pengurusan air yang lestari di dalam lembangan Wadi Siham.

ASSESSMENT OF WATER RESOURCES IN WADI SIHAM BASIN, YEMEN

ABSTRACT

Wadi Siham Basin is one of the most important agricultural areas in the country. This study aims to assess the surface water resources in Wadi Siham Basin in terms of source, quantity and spatial and temporal variation. The main focus of the study was to investigate the groundwater balance beside evaluating the rainfall and runoff trend annually and seasonally and also evaluating the quality and quantity of groundwater resources. The relationship between availability and the uses of groundwater and water balance was also evaluated. The results indicated that the total average of annual rainfall was 346.39 mm/year from 1979 to 2008, while the total volume of rainfall was 1711.26×10^6 m^3. The mean annual surface water runoff from 1990 to 2009 was 82.92×10^6 m^3 equivalent to 4.85% of the total volume of rainfall precipitated on Wadi Siham Basin. The largest amount of water loss was by evapotranspiration amounting to 1480.81×10^6 m^3 (86.53%) while only 147.53×10^6 m^3 (8.62%) lost to the ground. A total of 570 events of flood occurred from 1990 to 2009 with a mean annual flood of 53.10×10^6 m^3. The rainfall and runoff trends based on Mann-Kendall test and Sen's slope analyses results showed that the significantly negative (P<0.05) at two stations; Wallan (Sen's slope = -4.72 mm/year) and Al-Amir stations (Sen's slope = -6.11 mm/year). A positive trend, however, occurred in one station (AREA station, Sen's slope = 50.20 mm/year). A total annual groundwater recharge (input) of the coastal aquifer system was 147.53×10^6 m^3/year and the discharge (output) was 202.57×10^6 m^3/year indicating that the aquifer system was overexploited. A negative groundwater balance of 55.04×10^6 m^3/year was estimated in the aquifer system. The assessment of groundwater quality in 60 wells in the Wadi Siham showed that Nitrate (NO_3), Sodium (Na) and Total Dissolved Solids (TDS) were extremely high compared to the standard levels of World Health Organisation (WHO). In conclusion, Wadi Siham Basin is facing critical water scarcity that may threaten the agricultural activities and domestic water uses. The negative rainfall and runoff trends had a negative impact on the water scarcity problem in Wadi Siham Basin. The contamination of groundwater in the coastal plain of Wadi Siham Basin was high due to different polluting sources. The present study highlighted the necessity for an urgent and sustainable water resources management in Wadi Siham Basin.

CHAPTER 1: INTRODUCTION

1.1 Global Water Issues

During the last few decades, the deterioration in water resources has been highlighted as a crucial issue worldwide (United Nations, 2012). Water scarcity is the greatest crisis facing humanity in the 21st century and possibly beyond. Yet, there is very little awareness among most people in the world about the current global water shortage and what it implies for the future (Singh, 2008). Water scarcity is now a common phenomenon in many countries. It has been estimated that today more than 2 billion people are affected by water shortages in over 40 countries among which 1.1 billion do not have sufficient drinking water (World Water Assessment Programme, 2003). At certain times of the year, several wadis are dry before reaching the sea and this problem has emerged recently. Furthermore, groundwater is being pumped and utilised at higher levels than recharge. Thus, it leads to critical deterioration of water resource in the aquifers and rivers flow (Hoekstra et al., 2012). Therefore, various public institutions and private organisations are conscious about the unpredictable future of water availability and sustainability (World Water Assessment Programme, 2009).

The situation is particularly poor in many cities located in arid countries. Arid, semi-arid and sub-humid regions are called water-limited environments and occupy about half of the global land area (Masih et al., 2009). Several Arab countries are situated in arid and semi-arid regions and are recognised for their scarce annual rainfall and high rates of evaporation leading to deficiency in water resources. Thus, the water share per capita in such countries is as low as 10% of the global average (Al-Weshah, 2008).

Wadis basins play an important role as a source of water, particularly in the arid, semi-arid and sub-humid regions. Wadi is the Arabic word for ephemeral water courses in the arid regions, and they are a vital source of water. Catastrophic flash floods occurring in wadis are, on one hand, a threat to many communities and, on the other hand, a major groundwater recharge source after storms (Sen, 2008).

1.2 Yemen Water Issues

Currently, Yemen is encountering a critical water crisis. Although Yemen is located in the Middle East which is an arid and water-stressed region, it has its specialty in water issues as it is considered one of the world’s ten most water-scarce countries (Lichtenthaeler, 2010). Thus, Sana’a (the capital of Yemen) will probably be the first city in the world to run dry or even may run out of water supply by 2017. This complication of water issue in Yemen may affect the agricultural and industrial development in the country (Mewes, 2011; Osikena et al., 2010). Renewable water resources are limited and associated with fast growing demands. Consequently, the only available water resource is groundwater, which is essential for different activities (e.g. drinking, agriculture and industry). Agricultural production is consuming about 93% of the total water resources. The current level of groundwater abstraction greatly exceeds recharge in most of the aquifers especially in the northern areas and the intermountain plains, including Sana'a basin. Hence, a large proportion of the abstraction is being supported by depleting groundwater reserves, which is causing a noticeable decline in water levels and deterioration in water quality, undermining the sustainability of the resource base. Urban supplies and agricultural production have been under an increasing threat from unregulated and widespread use of pumped irrigation supplies by the private sector (Sauveplane, 2002; Lichtenthaeler, 2010).

According to Watkins (2006), Yemen is classified as a country facing water crisis. Unfortunately, there are no large rivers or lakes in Yemen to be considered as main water supply. Therefore, water supply in Yemen comes mainly from annual rainfall and groundwater reserves and both resources are encountering over-use. By the end of 2005, only 58% of the urban population and 37.5% of the rural population had access to safe water (Bucknall, 2007; Novak, 2007). Water scarcity is growing each year exacerbated by the continuous inequity between annual recharge and the growing water demand which has led to the critical deterioration in the groundwater levels, threatening the agricultural production and investments in some of these areas (Noman, 2007).

Based on Al-Asbahi (2005), The total renewable water resources in Yemen is estimated to be 2.5 billion cubic meters per year. However, the total demand is 3.4 billion cubic meters per year. Therefore, the abstraction of 900 million cubic meters per year is being compensated from aquifers. Consequently, the amount of water in the groundwater aquifers is dropping from 1 to 7 meters each year. In the meantime, there is a lack in the recharge because of prevalence of dryness as a result of the global climate changes. In Yemen, according to El-Habr (2007), the annual water abstraction is running at about one and a half times the rate of recharge, with even higher rates in the Sana'a Basin. Rapid population growth in the city (3.6 % a year) is outpacing new water supply schemes although Sana'a is facing severe water shortage.

Yemen has been facing the urgent problem of providing water demands for a population growing rapidly with an annual growth rate of 3%. The agriculture sector is by far the major consumer of water and will continue to be so in the future. The pressing need to increase agricultural products, people's domestic needs and industrial uses has led to the available water resources depletion (Glass, 2010).

1.2.1 Surface Water Resources in Yemen

Basically, rainfall is the main source of runoff in Yemen generating intermittent surface water flows which are called wadi in arid and semi-arid environments (Ministry of Agriculture and Irrigation and FAO, 2000). In Yemen, wadis are considered as the major and the most essential source of surface water. The wadis of Yemen flow in four primary directions (watersheds) creating the catchments areas which are located in the mountainous region of Yemen (Negenman, 1996). On the other hand, this source of water is minimally affected by dryness as well as other (geographical and natural) factors. The surface runoff is controlled mainly by the topographic patterns into two directions, the outer water basins (draining to the west in the Red Sea and to the south in Gulf of Aden and Arabian Sea) and the internal water basins draining east or west towards the Rub Al-Khali desert, the Ramlat-Sabatain and Wadi Hadramout (Al-Asbahi, 2005). Surface water in Yemen was estimated to be about 1.5 billion cubic meters /year. Yet, this quantity match to the runoff levels from major wadis and excluding the amount of the runoff produced in the smaller catchments (Frenken, 2008).

1.2.2 Groundwater Resources in Yemen

It is well known that the main water source in Yemen is the groundwater which is also very important for agricultural activities. The groundwater recharge depends essentially on spate running water and rainfall. In any catchment, runoffs and springs are considered the major groundwater recharge sources. The anticipated groundwater amount in Yemen is nearly 1000 Mm^3 (Al-Asbahi, 2005; Frenken, 2008). In some cities such as Sana'a, aquifer extraction rates in the surrounding areas can reach up to 2.5 times compared to the recharge rates (Watkins, 2006).

The decline in the groundwater aquifers is estimated to be 2-6 meters every year in many zones, especially in the highlands, with scarcity in recharge. This elevation will reflect the increase in the cost of pumping and leads to severe deterioration of groundwater quality including sea water intrusion especially in the coastal areas. Other basins are currently very dry and some agricultural production has been declining significantly due to the deterioration in the groundwater levels (Frenken, 2008).

1.3 Geographical Location of Yemen

Yemen, with a total area estimated at 555,000 km^2, is located on the south-western edge of the Arabian Peninsula (Figure 1.1). Apart from the mainland it includes many islands, the largest of which are Socotra in the Arabian Sea to the far east of the country and Kamaran in the Red Sea. The country is bordered by Saudi Arabia in the north, Oman in the east, the Arabian Sea and the Gulf of Aden in the south, and the Red Sea in the west.

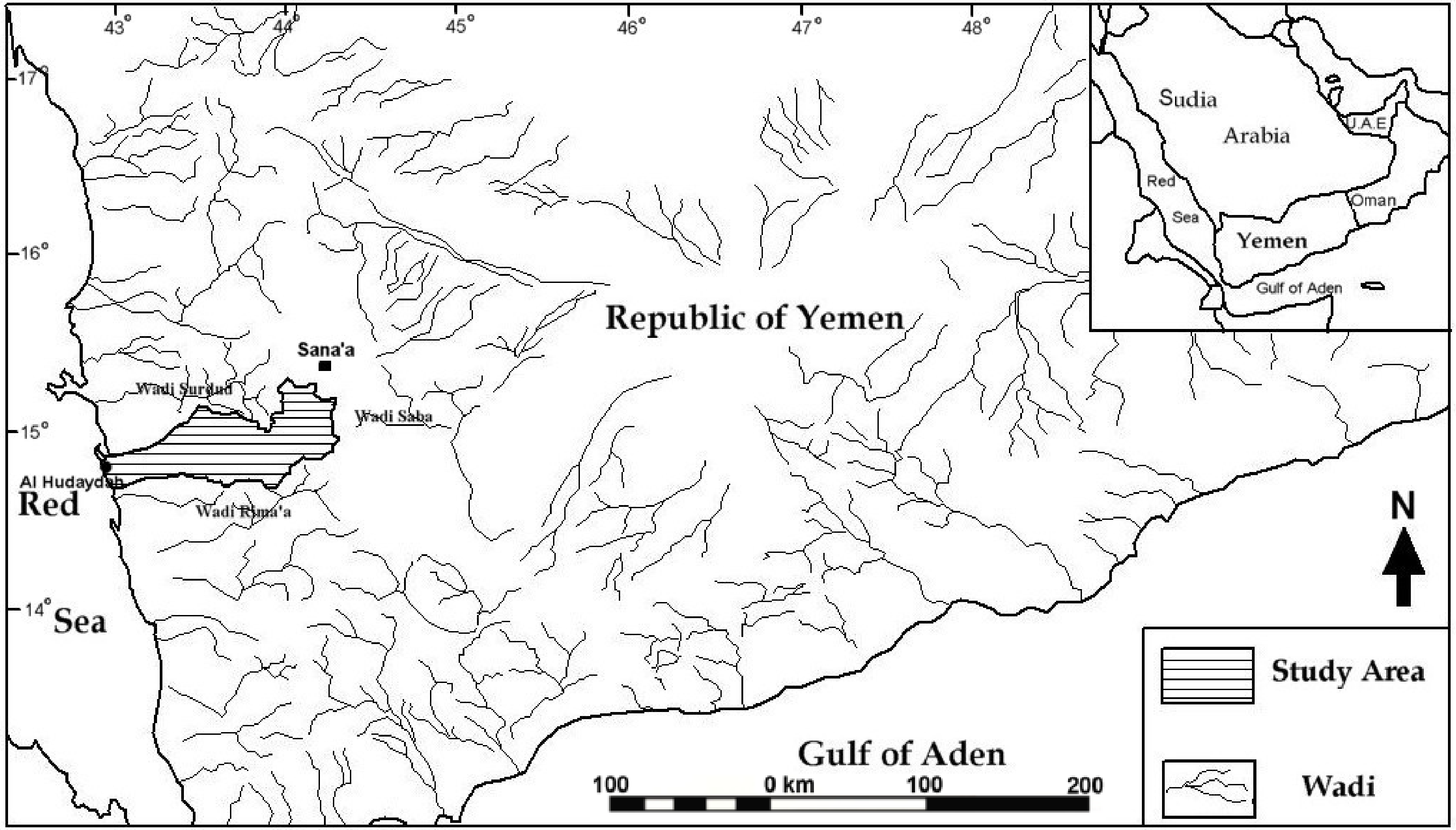

Figure 1.1: Geographical map shows the location of Yemen
Source: (Van der Gun et al., 1995)

1.4 Population Growth in Yemen

According to the population project of the Ministry of Planning and Development in Yemen, the total population is 26 million, but this is likely to double in the next 25-30 years (Ministry of Planning and Development, 2008). Yemen has one of the highest population growths in the world with an annual growth rate of 3%. In 1980, 81% of Yemen's population was rural; in 2008 it was reduced to 74% and by 2015 it is expected to be around 69%. The average population density is about 39 inhabitants/km^2, but in the western part of the country the density can reach up to 300 inhabitants/km^2 (lbb province) while in the three eastern provinces of the country the density is less than 5 inhabitants/km^2. This is closely related to the physical environment. By far the largest part of the population lives in the mountainous area in the western part of the country, where rainfall is still significant, although not high in many locations. Due to the limited amount of fresh water, these growing populations will continuously reduce the water availability per capita (Glass, 2010; FAO, 2011a).

1.5 Statement of the Problem

Wadi Siham Basin is one of the most important agricultural areas in Yemen. The agricultural activity is the major activity practiced by farmers as the main source of income. This area faces many problems regarding water supply for agricultural purposes. Water resources are insufficient because of the badly managed usage and lack of proper and sustainable plans. In addition, the rapid population growth and increase water demand added another burden to water resources. Contamination of groundwater and decline of water levels are increasing at severe rates with substantial increase in the groundwater salinity. The variation in rainfall trends, fluctuation in the total runoff (due to climate change) and the high demand for water in agricultural areas have added more burden to water resource in this basin. The lack of information about the status of the groundwater as well as other hydrological knowledge highlighted the importance for studying this area.

1.6 Research Objectives

Therefore, the current research was conducted to answer the following objectives:

1- to assess the surface water resources in Wadi Siham Basin in terms of sources, quantity and spatial and temporal discrepancy.

2- to study rainfall and runoff trends across rainfall and runoff gradient in Wadi Siham Basin.

3- to evaluate the groundwater resources in the coastal plain of Wadi Siham Basin in terms of aquifer, quality, level and quantity.

4- to understand the relationship between availability and uses of groundwater in regard to its balance.

5- to examine the current policies of water resources management and suggest policies that can overcome problems of water scarcity.

1.7 Research Questions

Based on the discussion in the previous section, the research questions of the present study are:

1- What are the sources, quantity and spatial and temporal discrepancy of the surface water resources in Wadi Siham Basin?

2- What are the trends of rainfall and runoff in Wadi Siham Basin?

3- What are the groundwater resources in the coastal plain of Wadi Siham Basin in terms of aquifer, quality, level and quantity?

4- What is the status and relationship between groundwater and groundwater uses of groundwater with regard to groundwater balance?

5- How effective are the current policies of water resources management and what policies can be suggested to overcome problems of water scarcity?

1.8 The Significance of the Study

The current study on water sources in Wadi Siham Basin has its own significance in preserving water in Yemen. The study of surface and groundwater resources in Wadi Siham Basin is one of paramount importance (Lichtenthaeler, 2010). This is because people in this area face many challenges such as water depletion and inadequate reserves for agricultural requirements and home use. These challenges are closely associated with mismanagement of the natural resources.

Yemen is suffering from an acute shortage of water (Noman, 2007). This study also has its own significance because it focuses on one of the important populated areas. Al-Hudaydah city is located within the area of Wadi Siham Basin and has its importance as being one the biggest cities in Yemen; it is an important port and densely populated (452,538 people). Thus, Wadi Siham Basin has a high rate of population growth (3.4% per year). As far as the Wadi Siham Basin is concerned, it is believed that with good and well planned use of water in this area the risk of environmental crisis will be reduced and enough water will be provided for those rural and urban communities to avoid water crisis. Taken these issues into account, the current study attempts to explore the effectiveness of recommended ideas that would enhance optimum usage of the water resources in Wadi Siham Basin.

The findings of the current study have their significance to policy makers in Yemen by providing vital information regarding the uses of water resources in Wadi Siham Basin. The information provided in these issues would help in suggesting solutions regarding the implementation of effective policies for future water management in Wadi Siham Basin and hopefully in other wadis in Yemen with similar characteristics.

Finally, the current study has its own significance as it contributes to the field of research on water resources in Yemen, especially on the major basins in the country as well as the evaluation of current uses of water resources in the popular basins in Yemen. This study also investigates the average areal (mm) and volume rainfall (Mm^3) based on Thiessen Polygons and Isohyetal maps. Another contribution is investigating the rainfall and runoff trends in Wadi Siham Basin. The study also identifies the relationship between the existing groundwater and groundwater uses through calculating water balance as one of the main contributions.

1.9 Thesis Structure

The present study consists of six chapters as follows:

Chapter 1: Introduction

This Chapter includes general introduction on the setting of the study, statement of the problem, research questions, research objectives, significance of the study and thesis structure.

Chapter 2: Literature Review

This chapter introduces the literature review of water crisis and population pressure, water scarcity in arid and semi-arid areas including hydrology and water demand issues (rainfall trends, temporal and spatial variation of rainfall, rainfall recurrence interval and probability, runoff trends, flood and water demand issues). The chapter also covers groundwater issues (groundwater uses in arid countries, groundwater quality, groundwater recharge, groundwater discharge and groundwater balance) as well as morphometric, water management and previous studies.

Chapter 3: Geographic Characteristics of the Study Area

This chapter consists of general description of study site, topography features, geology, morphometric, climate characteristics, natural vegetation and land use in the study area.

Chapter 4: Research Methodology

This chapter research methodology. The chapter concludes with the data analysis techniques. The methodology elaborates on the steps used to attain the research objectives.

Chapter 5: Results and Discussion

Data on the water resources of Wadi Siham Basin has been collected and analysed exhaustively in this chapter. Wadi Siham Basin's water resources were thoroughly studied and summarised. Annual and monthly rainfall, seasonal rainfall, areal and volume rainfall, rainfall trends, spatial and temporal rainfall variation, recurrence interval and probability, evaporation and surface water runoff were analysed statistically and provides a general discussion on several hydrological aspects of Wadi Siham Basin Moreover, hydrogeological data such as groundwater quality, groundwater level, recharge and discharge and groundwater balance were also analysed and discussed to provide complete justification and comparison of hydrological and hydrogeological aspects in Wadi Siham Basin with their counterparts in arid and semi-arid regions. This chapter also contains description about the obtained results with essential interpretation and presentation.

Chapter 6: Conclusions and Recommendations

In this chapter, the general conclusions were drawn based on the study findings. In the meantime, several recommendations and suggestions were raised for further studies and research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter introduces the literature review of water crisis and population pressure, water scarcity in arid and semi-arid areas. Hydrology and water demand issues (i.e. rainfall trends, temporal and spatial variation of rainfall, rainfall recurrence interval and probability, runoff trends, flood and water demand issues) are discussed. This chapter also covers groundwater issues (i.e. groundwater uses in arid countries, groundwater quality, groundwater recharge, groundwater discharge and groundwater balance) as well as morphometric, water management and previous studies.

2.2 Background

One third of the land surface in the world is arid and semi-arid areas (Wickens, 1998) in which the natural resources of the water are found to be in a delicate environmental balance. Unfortunately, the increasing water stress in the natural sources in the arid regions can be attributed to three factors: (1) rapid population growth and increase on water demands with limited water resources (2) civilisation and transformation in the life style and urbanisation and (3) climate change. All afore-mentioned reasons eventually lead to water scarcity and increased demands on water for various usages (agriculture, industries and the rapid growing cities) (United Nations, 2012). Therefore, arid, semi-arid and sub-humid regions are often called water-limited environments which comprise nearly 50 % of the total global land area (Masih et al., 2009).

Most of the countries in these regions (arid and semi-arid) depend either on groundwater or on desalinisation process for their water supply (Harvey et al., 1997). Furthermore, wetlands are an important for supply as they can retain water especially during dry periods, and thus enhance recharge to major aquifers (Lewis, 1995). In arid and semi-arid areas, however, the groundwater recharge usually occurs after flood events. Therefore, changes in the frequency and magnitude of rainfall events will vary according to the number of recharge events (EPA, 1996).

2.2.1 Water Crisis and Population Pressure

Water is vital and essential for all aspects of human life (food, drinking, industry, agriculture and energy). In the human body, the physiological hydration is almost 60% of the body weight, thus water is important for all physiological processes in the human body (United Nations, 2012). Recently, there has been an increasing demand on water which leads to long-standing conflicts. In different parts of the world, the insufficient distribution of the water resources leads indirectly to food issues including starvation (Ragab and Hamdy, 2004). Furthermore, deterioration in the water quality creates persistent health hazards, thus inefficient water management results in conflict and competition on the water resources (Ragab and Hamdy, 2004). With recent and steep deterioration in the freshwater resources, the water volume remains limited in association with heavy over exploitation. Consequently, the whole world may experience severe decrease in the availability of the water per person. As predicted, 3.4 billion people will face water stress or water scarcity by 2025 (Calzolaio, 2009).

It was estimated that the population of the world will be 9.1 billion by 2050 which will create great pressures on water resources (FAO, 2006; UNDESA, 2009; Bruinsma, 2009). The Arab region is characterised with rapid growth of population. In addition, migration pressures, improper urban and civil planning with significant absence of regulations and law enforcement and large fraction of the people are living close to, or at the poverty level together exacerbate the substantial difficulties in conserving the available water resources and preventing them from possible pollution (Postel et al., 1996).

Similar to other developing countries, Yemen is experiencing high rate of population growth coinciding with severe deterioration in the economic as well as prevalence of poverty and low sanitation conditions. Consequently, Yemen is having critical water issue which is elevated as the demand increases with deterioration in the level of water resources. Big cities in Yemen such as Sana'a and Taiz experience critical water scarcity. Hence, the availability of water becomes a survival issue leading to serious water conflicts. Some literature showed that 70% to 80% of rural conflicts in Yemen are because of the water access. This is influenced by high population growth in Yemen (the annual growth rate is 3%), poor management of water resources, unauthorised well drilling, absence of strong law enforcement, internal migration, misuse of the water in agriculture activities (Kasinof, 2009; Glass, 2010). Kasinof (2009) reported that Yemen is one of the most water scarce countries in the world with annual water availability of only 125 m^3 per capita compared to the global average of 2,500 m^3 per capita. It is anticipated that large cities in Yemen will run out of water by 2015.

High proportion of the water resources goes to agriculture in numerous parts of the world. Agriculture consumes almost 70% of global freshwater resources and this percentage may increase up to 90% in fast-growing and developing countries. Thus, using the water for irrigation and food production creates the greatest stress on freshwater resources (World Economic Forum, 2011). With the increasing pressure on water resources and high demand for agriculture production, the water scarcity issue is growing. Agricultural water abstraction reached up to 44% of total water withdrawal in Organisation for Economic Co-operation and Development (OECD) countries. This figure rises to more than 60% within the eight (OECD) countries which mainly depend on irrigated agriculture. In the BRIC countries (Brazil, Russian Federation, India and China), agriculture accounts for 74% of water consumption, but this ranges from a low 20% in the Russian Federation to 87% in India. However, in the Least Developed Countries (LDCs) the rate is much higher and can be up to 90% (AQUASTAT, 2011b). Based on Food and Agriculture Organization (FAO) FAO (2011c) recent estimation, there will be a 11% increase in irrigation water consumption from 2008 to 2050. A 5% increase was higher compared to the present water withdrawal for irrigation (2,740 km^3). From the first sight, the amount seems not very serious increase, but this will happen in countries which already have water scarcity (FAO, 2011b).

In the Arab region, agriculture is considered to be the major source of water pressure and accounts for 70% of the total water demand in most of the countries in this region. In some Arab countries such as Iraq, Oman, Syria and Yemen, water use for agriculture can reach up to 90% of the total water use. Furthermore, it was predicted that effects of climate change will lead to critical deterioration in 25% in agricultural productivity in most Arab countries by 2080 (Cline, 2007).

During the last decade, global warming as well as other climate change issue in relation to critical pressure on water resources have been highlighted in many conferences and scientific journals (Vorosmarty et al., 2000; Kundzewicz et al., 2007). Generally, climate change is likely to account for almost 20% of global increase of water scarcity. Thus, this issue will be more complicated especially in the countries which already have water shortages (IPCC, 2008). It is predicted that even the areas where climate change is neutral will also suffer from water scarcity (UN-Water, 2007). Basically, higher average temperatures and alteration in precipitation and temperature boundaries are anticipated to influence the level of available water resources through changes in rainfall distribution, soil moisture, glacier and ice/snow melt, and river and groundwater flows (IPCC, 2008; WWAP, 2009a).

Unpredictable changes in the climate will ultimately lead to uncertainties regarding the future of water supply and demands which, in turn, will hinder the proper management plans for conserving and protecting the available water resources. It is evident that the Arab region is mostly affected by the climate changes because it already has tremendous climate variability and water scarcity particularly the poor countries in the arid and semi-arid areas will be more vulnerable. Consequently, small changes in the patterns of climate will result in drastic ground-level impacts. Although the effects of climate change are still not fully understood, the predicted outcomes of climate change may comprise increased soil temperatures and aridity, changes in seasonal rainfall patterns (it was experienced in some rainfed agricultural areas in Syria and Tunisia), reduction in groundwater recharge rates, increase in the frequency of floods and droughts, reduction in snowfall and snow-melt in addition to increased sea levels and water salinity especially in coastal aquifers. Droughts were reported more frequent in Algeria, Morocco, Syria, Somalia and Tunisia during last 20-40 years (United Nations, 2012).

2.2.2 Water Scarcity in Arid Countries

Although, there are numerous definitions of the 'water scarcity', the simplest definition is the situation when there the cumulative impact of all beneficiaries affect both quantity and quality of water that result in inefficiency to meet all demands including the environmental and sustainability standards. Generally, water scarcity may arise at any stage of supply or demand. On the other hand, there are several causes of that most of them can be optimised or avoided. In arid and semi-arid regions, the water scarcity problem is more obvious as they are influenced by long periods of droughts and climate variability. Moreover, water scarcity issue in the arid and semi-arid areas is more complicated with profound impacts due to high population growth and fast urban development (UN-Water, 2007). In regard to the global level, there is more than enough water to go around and meet all of humanity's needs because water is like wealth, which is unequally distributed between and within countries. It does not help water-stressed countries in the Middle East that Brazil and Canada have more water than they could ever use nor does it help people in drought-prone areas of northeast Brazil that average water availability in the country is among the highest in the world (Watkins, 2006).

Meanwhile, other regions that are expected to suffer persistent drought and water scarcity in coming years include southern and northern Africa, the Mediterranean basin, large part of West Asia, and a wide band running through Central Asia and the Indian subcontinent. This distribution is similar to that of presently water-stressed regions (IPCC, 2008; Isaac and Turton, 2009). However, over 40% of countries could experience severe freshwater scarcity by 2020. This would occur mostly in low-income countries or regions in sub-Saharan Africa and Asia. It was considered more likely that unequal access to water would create new economic polarities, between 2020 and 2030. Such economic polarities would increase the dangers of political unrest and consequent conflict (Figure 2.1) (United Nations, 2012). However, high and low water-user groups are at risk of water scarcity because water endowment alone does not guarantee a sustainable water supply to support socio-economic development. Water scarcity can occur even in countries with rich renewable resources if it is not properly conserved, used and distributed among households, farms, industry and the environment (Figure 2.2) (ESCAP, 2010).

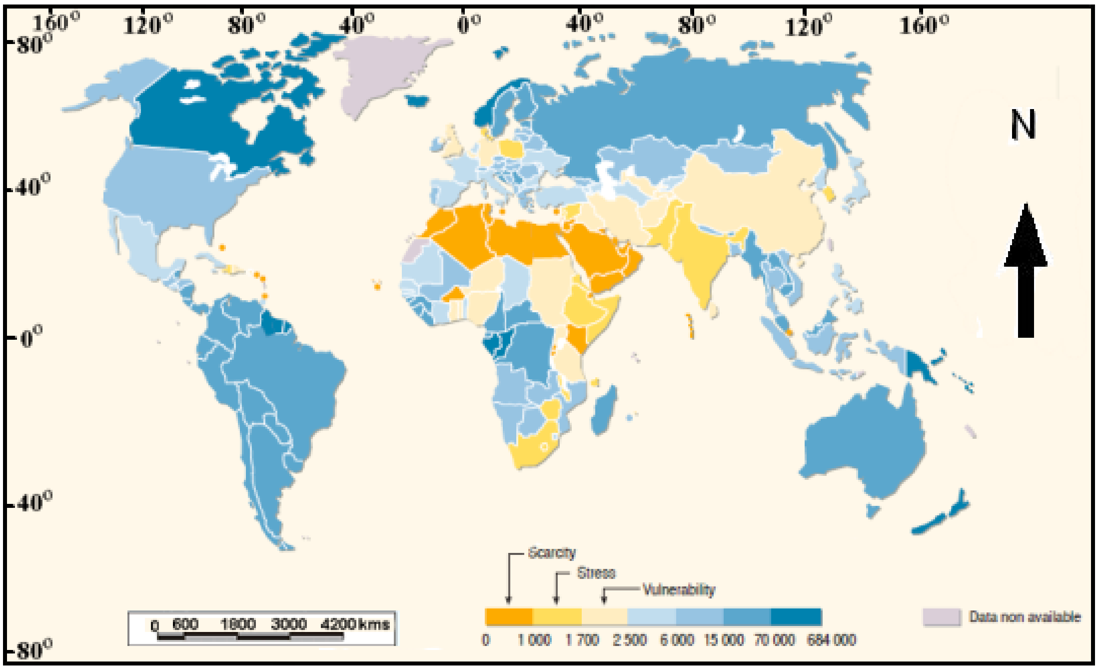

Figure 2.1: Freshwater availability (m^3 per person per year, 2007)
Source: (UNEP/GRID-Arendal, 2008)

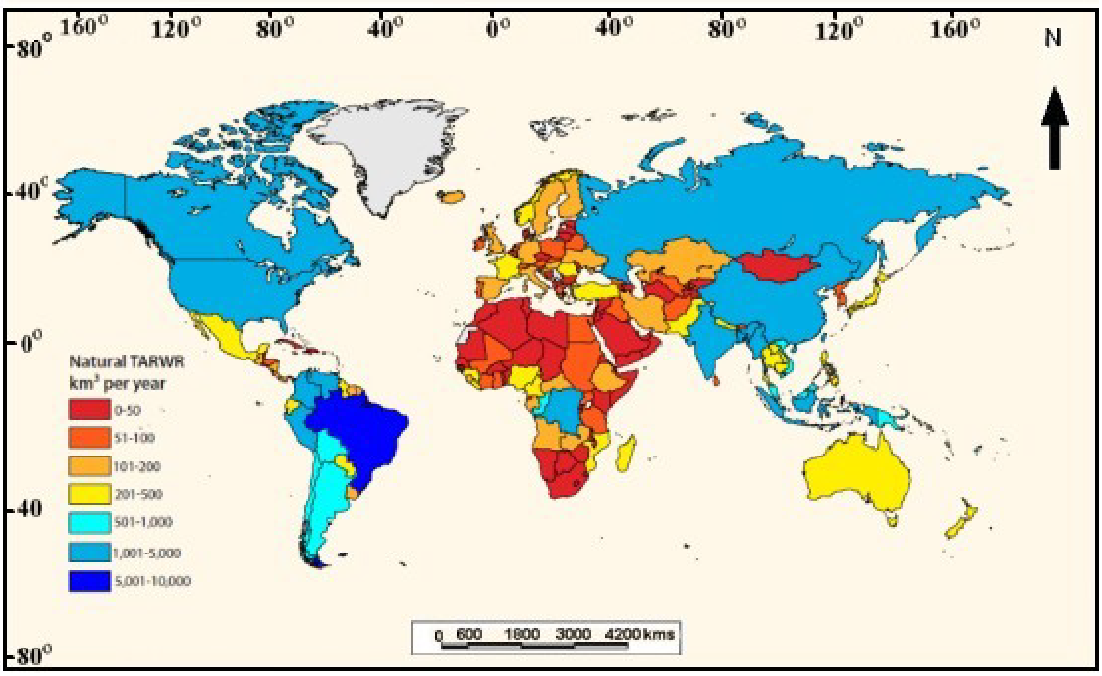

Figure 2.2: Total annual renewable water resources by country most recent estimates (1985–2010)
Source: (AQUASTAT, 2011a)

Moreover, water scarcity affects all social and economic sectors and threatens the sustainability of the natural resources base (UN-Water, 2007). For example, water scarcity may limit food production and supply, putting pressure on food prices and increasing countries' dependence on food imports. The number of countries and regions without enough water to produce their food is rising as populations increase (WWAP, 2009b). Increasing water scarcity combined with increased food demand and/or water use for irrigation as a result of higher temperatures is likely to lead to enhanced water reuse. Areas with low sanitation coverage might be found to be practising (as a new activity or to a greater degree) uncontrolled water reuse (reuse that is performed using polluted water or even wastewater) (IPCC, 2008).

While the scarcity of freshwater is felt acutely in Africa and West Asia, water scarcity is already felt in commercial centres in Australia and the western United States. If current consumption patterns continue, two-thirds of the world's population will live in water-stressed conditions by 2025. Compounding and politicising these challenges are the reality that fully a third of the world's population lacks access to sufficient quantities of safe water to meet their basic needs (WWAP, 2009b).

Therefore, water scarcity is viewed as an increasing business risk, with industrial water supply security dependent on insufficient resources. This problem is compounded by geographic and seasonal variations, as well as water allocations and competing water needs in a given region (e.g. agriculture vs. drinking water or residential supply vs. industry), a situation that may be beyond the control of industry (United Nations, 2012).

Currently, more than 700 million people in 43 countries suffer from water stress as they live under the water-stress threshold. Although the Middle East region is considered as one of the most stressed areas with only 1,200 cubic metres of water available as average per year, few countries such as Iraq, Iran, Lebanon and Turkey have higher average available water (i.e. above water-stress threshold) (Figure 3 and 4).

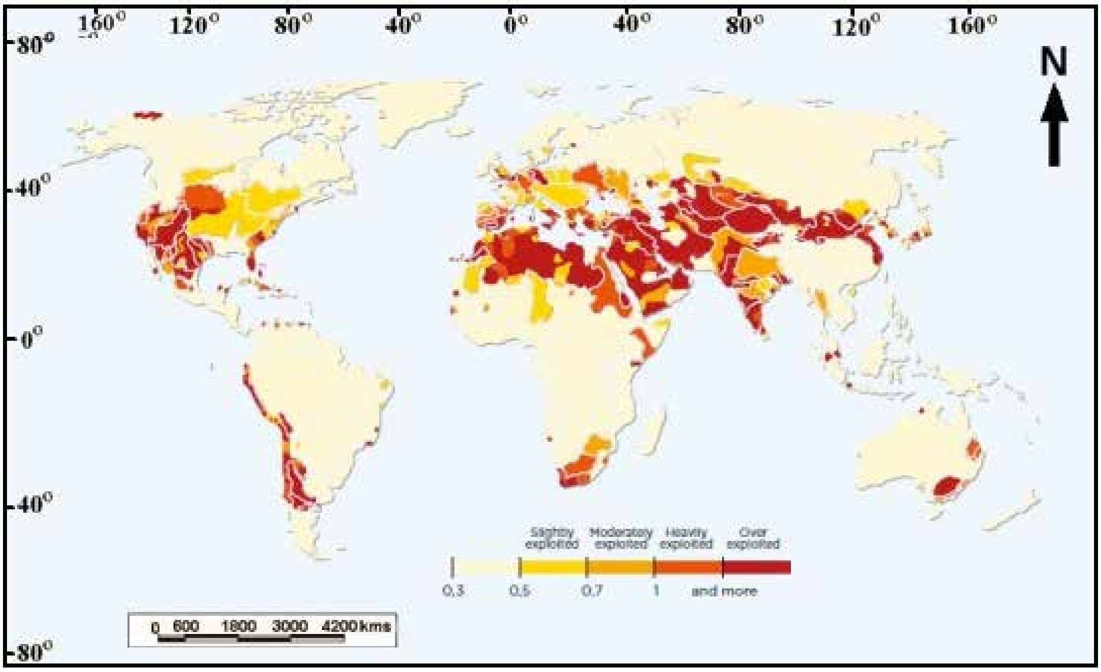

Figure 2.3: Global Water Stress Indicator in major basins
Source: (UNEP/GRID-Arendal, 2008)

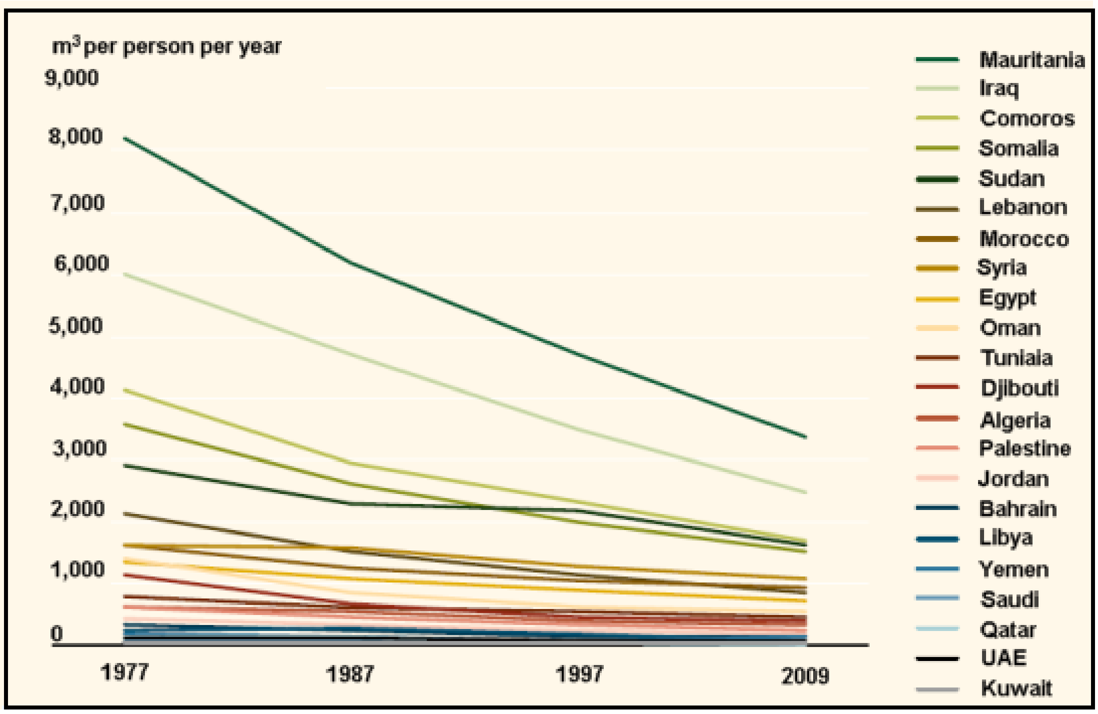

Figure 2.4: Decline in renewable water resources in the Arab region per capita
Source: (UNEP/GRID-Arendal, 2008)

In number of water-stressed countries, the Sub-Saharan African region has the highest number of countries compared to other regions of the world. Strikingly, approximately 25% of the Sub-Saharan Africa's population are living under water-stress conditions and probably this proportion is increasing gradually. As a result, it was estimated that 3 billion people will live in water-stressed countries by 2025. In addition, it is also anticipated that 14 countries will drop from water stress to water scarcity level (Watkins, 2006).

It has been observed that arid and semi-arid regions face additional challenge of absolute water scarcity. Projected increases in scarcity will be focused on rapidly expanding cities. Much of the world's population growth over the next few decades will occur in urban areas, which are projected to double in size to near 5 billion between 1995 to 2025 and face major challenges in coping with increased water pollution and incidence of waterborne disease (Vorosmarty et al., 2000).

As United Nations (2012) stated, nearly all Arab countries suffer from water scarcity, with water consumption in the Arab region significantly exceeding total renewable water supplies. Nearly all Arab countries can be characterised as water-scarce, meanwhile those with rich water resources have seen their total annual per capita share of renewable water resources drop by half over the past four decades as their populations increased. This declining trend presents the most significant challenge to the water sector in the Arab region. Egypt, Iraq, Jordan, Lebanon and Sudan derive 70% of their freshwater from perennial rivers. Surface water is the primary source in Oman, Saudi Arabia, the Syrian Arab Republic, the United Arab Emirates (UAE) and Yemen. These countries also have intermittent rivers (wadis) whose seasonal floods might be used to recharge aquifers. Baroudy et al. (2005) reported that farmers' resistance has been reduced by an awareness campaign, and the scarcity of other water supplies has led some farmers to begin using wastewater, primarily for tree plantations. In Jordan, many farmers are using mixed water from the King Talal reservoir containing at least 80% treated effluent from the As-Samra treatment plant. These farmers have seen a sharp drop in their yields because of the salinity of the water. Farmers are willing to use treated wastewater when they no longer can get freshwater, or when freshwater costs them more. In Morocco, people are often reluctant to use treated wastewater because they see it as unclean, while at the same time there are farmers who are using raw sewage.

Growing water scarcity, increasing population, degradation of shared freshwater ecosystems and competing demands for shrinking natural resources distributed over such a huge area involving so many countries have the potential for creating bilateral and multilateral conflicts (IPCC, 2008). Indicators of water scarcity include severe