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Estimating Ground water Balance in the Presence of Climate Change Impact: A Case Study of Semi-Arid Area

Mohammed Nanekely[1], Furat Al-Faraj[1,2,*], and Miklas Scholz[3,4]

[1]Civil Engineering Research Group, School of Science, Engineering and Environment, The University of Salford, UK
The University of Salford, Newton Building, Salford M5 4WT, UK;m.a.a.nanekely@edu.salford.ac.uk

[2] School of Engineering, The University of Bolton;
The University of Bolton, Bolton BL35AB, UK; f.al-faraj@bolton.ac.uk

[3]Division of Water Resources Engineering, Faculty of Engineering, Lund University;
Department of Civil Engineering Science, School of Civil Engineering and the Built Environment, University of Johannesburg
[4]Lund University, P.O. Box 118, Lund 221 00, Sweden;
Kingsway Campus, PO Box 524, Aukland Park 2006, Johannesburg, South Africa
m.scholz@salford.ac.uk

*Correspondence: f.al-faraj@bolton.ac.uk; f.a.m.al-faraj1@salford.ac.uk

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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. 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 the Erbil province of the Iraqi Kurdistan Region as a representative case study for semi-arid climate areas where current practices of groundwater resource utilization 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 concerning groundwater storage have been evaluated 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imbalance between the input (groundwater recharge) to the Erbil province aquifers and corresponding output (groundwater withdrawn).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*

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1 INTRODUCTION

Proper management of groundwater resources requires thorough knowledge and detailed information on aquifer characteristics, long-term behaviour of the aquifer, and groundwater quality and quantity. Additionally, groundwater management requires investigations on population growth coupled with urban development, the land-use change and practices, and climate alteration and variability have considerably contributed to over-exploitation of groundwater resources, to meet ever-increasing demands for public water supply and irrigation, especially in arid and semi-arid regions where low precipitation and high evapotranspiration rates are the main concerns (Okello, Tomasello, Greggio, Wambiji, & Antonellini, 2015).

Assessment of groundwater storage can be performed by applying the water balance method, which accounts for the inflow-to and the outflow-from the aquifer (Hiscock & Bense, 2014). The groundwater balance method is useful to quantify the amount of groundwater that could be safely withdrawn. Groundwater balance is imperative to measure the safe yield of the aquifer system and to set its sustainable management and rational abstraction (Voudouris, Diamantopoulou, Giannatos, & Zannis, 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).

Kumar (2012) indicated that the effects of climate change on surface water resources are widely recognized but not much is known about its effects on groundwater. The reasons are seen to be; it requires long historical time series that is not always available, also, the driving factors that cause such changes are yet unclear. Moreover, (Earman & Dettinger, 2011)have seen that the responses of groundwater systems to climate by adopting sustained and frequent monitoring is seen as more decisive, recognising the impacts of climate change on groundwater would help groundwater decision-makers to seek adaptative 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, Scholz, & Al-Faraj, 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, besides, maintained groundwater management in semiarid conditions requires a solid framework development that to be built upon sustainability notions (M. Nanekely, Scholz, & Qarani Aziz, 2017).

Erbil province like other semiarid regions has been going under intensive groundwater depletion so far, as revealed that the groundwater depletion has become a global water security threat(Famiglietti, 2014). This research deals with the estimation of groundwater balance in Erbil province in Iraq towards establishing a regulatory sustainable strategic framework of rational use and management of groundwater, which could potentially be adopted in arid and semi-arid climate regions.

2 MATERIALS AND METHODS

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 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 (1).

$$I - O = \pm\Delta S \qquad (1)$$

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 (Stevanovic & Iurkiewicz, 2009):

$$P + Sf = R + E + Q + A \pm GWR \qquad (2)$$

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.

2.1 Study area

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 agricultural production (KRG, 2019; KSRO, 2019).

According to the Köppen–Geiger climate classification, the northern part of Erbil province is of the Mediterraneansemi-arid (CSa) climate class (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006; Peel, Finlayson, & McMahon, 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 semiarid (Hot Steppe) climate (Rasul, Balzter, & Smith, 2015). The district is almost influenced by hot-summer Mediterranean climates, that is with long, extremely hot, sweltering summers, 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.

Erbil Province that covers an area of 15,089 km^2 (3.5% of Iraq) has been chosen as an example case study. The study area encounters: (a) Groundwater over-exploitation(Issa, 2018); (b) increasing in temperature and potential evapotranspiration rates and reduction in precipitation due to climate change (Fadhil, 2011; Lück, Farahat, & Hannouna, 2014; Stevanovic & Iurkiewicz, 2009); (c) lacking of solid and consistent application of groundwater artificial recharge systems (UNDP, 2011); (d) lacking integrated land-use planning and rapid urban growth (Hameed, Faqe, Qurtas, & Hashemi, 2015); (e) Absence or weakness of law of drilling of wells and enforcement of groundwater development regulations; and (f) shortage of financial provisions needed to implement and or rehabilitate relevant infrastructure (Erbil Governorate, 2018; MoAWR-KRG, 2016; MOP-KRG, 2011; UNDP, 2011).

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 (Table 1). The study areas' elevations vary in ranging from less than 200masl from the far south of the province to approximately 3613masl in the far north (BirdLife International, 2019)(Figure1 and Table 1). The agricultural land is estimated to be 41% 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).

2.2 Meteorological data and time series analysis

Daily data of seventeen meteorological stations (MS) were downloaded and analysed for 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) and Climate Forecast System Reanalysis (spatial resolution = 0.5° × 0.5°). Table 1 shows the coordinates and the altitudes of the meteorological stations and the location of these stations have been portrayed in Figure 1.

The Food and Agriculture Organization Penman-Monteith (FAO-PM) method (Allen, Pereira, Raes, & Smith, 1998)was used to determine the potential evapotranspiration (PET). This method has been commonly used worldwide in obtaining the reference crop evapotranspiration (ETo) (Bogawski & Bednorz, 2014; Debnath, Adamala, & Raghuwanshi, 2015; Kwon & Choi, 2011; Sharifi & Dinpashoh, 2014; Tabari & Talaee, 2011; Vangelis, Tigkas, & Tsakiris, 2013). The FAO tool version 3.2 (FAO, 2012)was applied to obtain the PET. The Penman-Monteith (FAO-PM) method is given in Equation 3.

$$ET_o = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{T + 273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \quad (3)$$

where ETo is the reference evapotranspiration (mm/day); Rn is the net radiation at the crop surface ($MJ/m^2/day$);G is the soil heat flux density ($MJ/m^2/day$); T is the mean daily air temperature at 2 m height (°C); u_2 is the wind speed at 2m height (m/s); e_s is the saturation vapour pressure (kPa);

e_a is the actual vapour pressure (kPa); (e_s-e_a) 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 calculated long-term minimum, maximum, and mean annual precipitation, temperature, and potential evapotranspiration are shown in Table 1. Figure 2 displays the long-term mean monthly precipitation (P), long-term mean monthly potential evapotranspiration (PET), and the long-term mean monthly deficit and surplus for the seventeen meteorological stations (MS). The northern and the mid parts (mountainous and plateaus lands) of the study area where (MS1 to MS13) are located, which are 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.

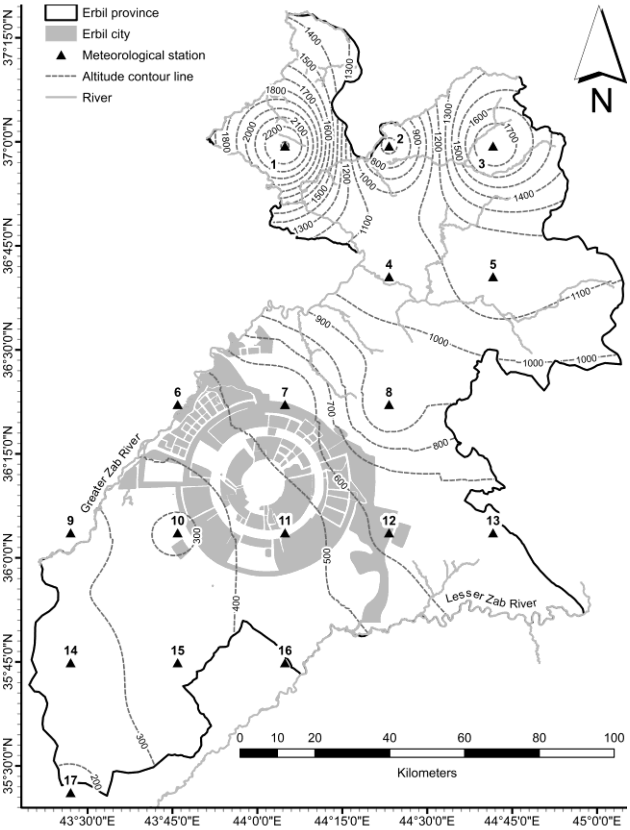

Figure 1: The study area

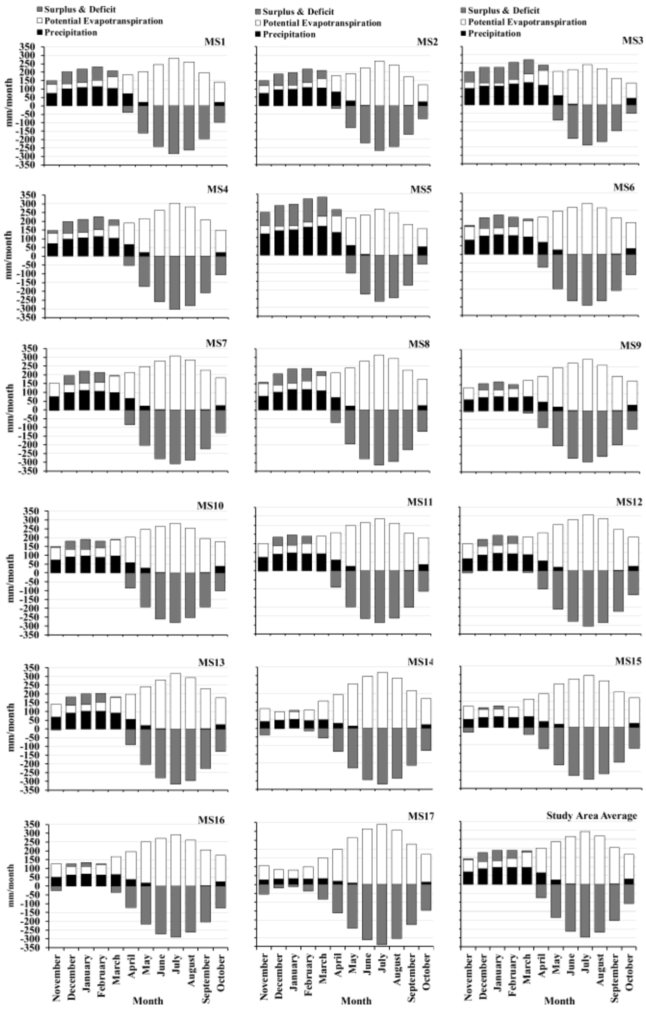

Figure 2: Box plot of long-term mean monthly precipitation and potential evapotranspiration over the period (1980-2014) for the 17stations.

Table 2 and Figure 3 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 was 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 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 December, January, and February. Whereas Figure 5 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 2: Long TermMean monthly precipitation, mean monthly potential evapotranspiration, and water status for the period (1980-2014).

Month	P (mm)	PET (mm)	Difference (PET-P) (mm)	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	

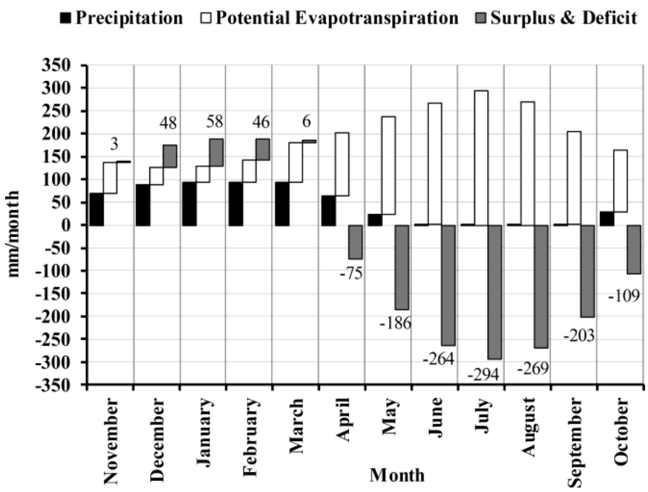

Figure 3: The average areal panned PET of the 17 stations: long-term mean monthly precipitation and potential evapotranspiration for the period (1980-2014).

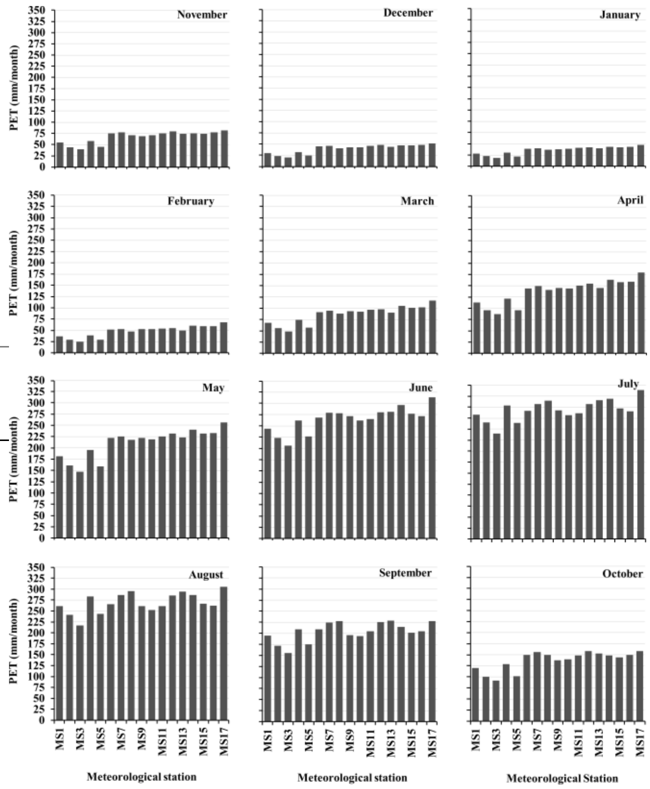

Figure 4: Long Term Mean Monthly Potential Evapotranspiration (LTMMPET) of 17 stations

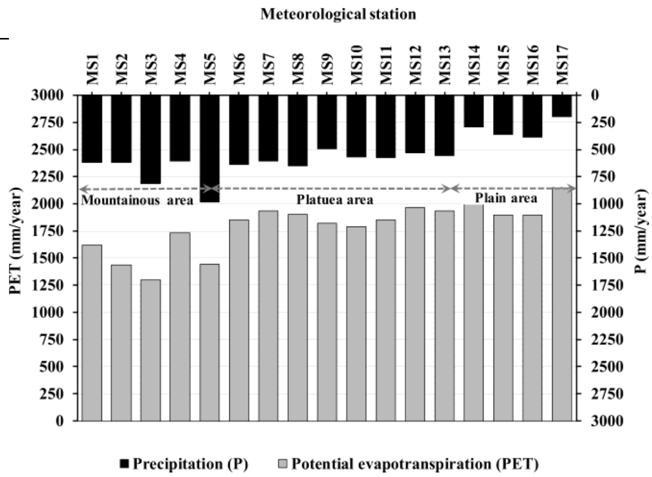

Figure5: Long Term Mean Annual Potential Evapotranspiration (LTMAPET) and Mean Annual Precipitation (LTMAP) of 17 stations

Figure 6 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 show a notable decline in PET values from 1995mm to 1818mm. A 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.

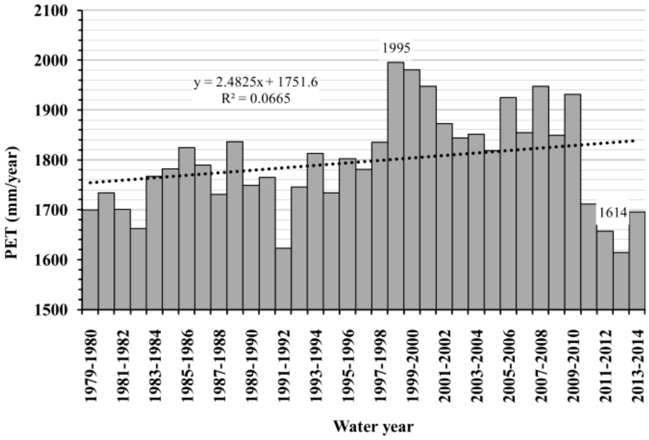

Figure 6: Average of the annual PET (APET) over the study area with trend line (1980-2014)

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[1], UNEP[2], and UNCCD[3], 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):

$$AI = \frac{P}{PET} \quad (4)$$

[1]Food and Agriculture Organization (http://www.fao.org/).
[2]United Nations Environment Programme (http://www.unep.org/).
[3] 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, 1992), 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:

Table 3: Climate zone classification

Zone	Precipitation/ Evapotranspiration (P/ET)
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 Table 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 in such semiarid region, as a consequence, it reflects drought crisis that affecting negatively on the recharge of groundwater.

2.3 Assessing aquifer status using effective infiltration analysis

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 is considered as one of the techniques by which groundwater storage can be assessed and quantified. 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 have been undertaken before (Hameed, 2013; Stevanovic & Iurkiewicz, 2009), and the data that have been taken from official government departments (MoAWR-KRG, 2016), additionally, primary data were prepared represented as daily precipitation, and air temperature (NCEP, 2015) that have been relied on by other studies (Dile & Srinivasan, 2014; Fuka et al., 2014), to find out mean monthly potential evapotranspiration for 17 stations across the area. Hydrological years defined over twelve consecutive months from 1st November of any year to 31st October 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 the dry season is from May to October that mostly the monthly precipitations were not exceeded 100mm (Murray-Tortarolo, Jaramillo, Maass, Friedlingstein, & Sitch, 2017).

In this case, the effective infiltration (I_{eff}) has 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}) coefficient is between 0 and 1. It is defined by the following analytical equations (5)(Bonacci, 2001):

$$I_{eff} = \frac{P_{eff}}{P_g} \times 100 \quad (5)$$

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

It is worth mentioning, 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 (6) has been employed to minimise errors.

Equation (6) has been used to estimate the values of long-term mean seasonal effective precipitation for the whole studied area along 35 hydrologic years.

$$I_{eff} = \frac{\sum_{i=1}^{6} P_{eff}}{\sum_{i=1}^{6} P_g} \quad (6)$$

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 7 and Figure 8), considering the annual character of the outcomes, all values are in 10^6 m^3/year (MCM/year).

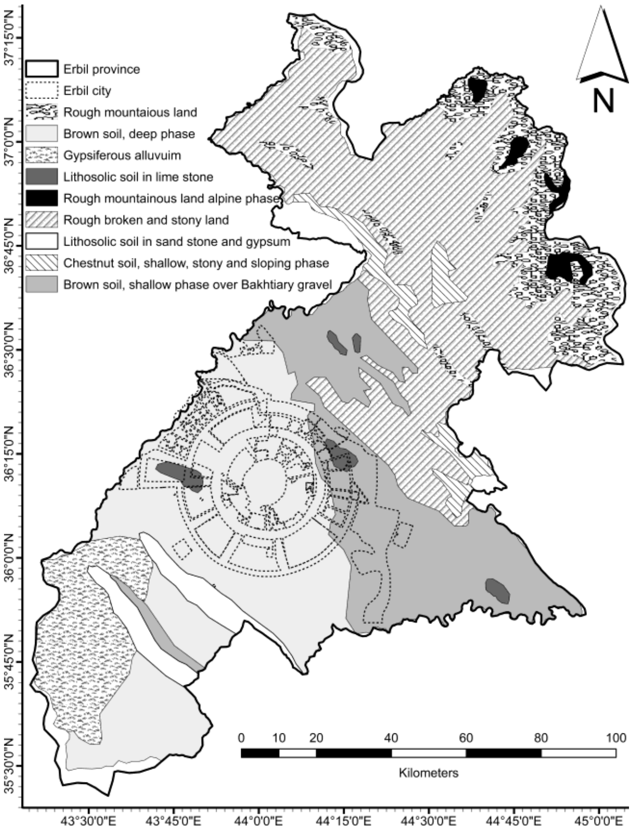

Figure 7: Soil cover types across the case study area

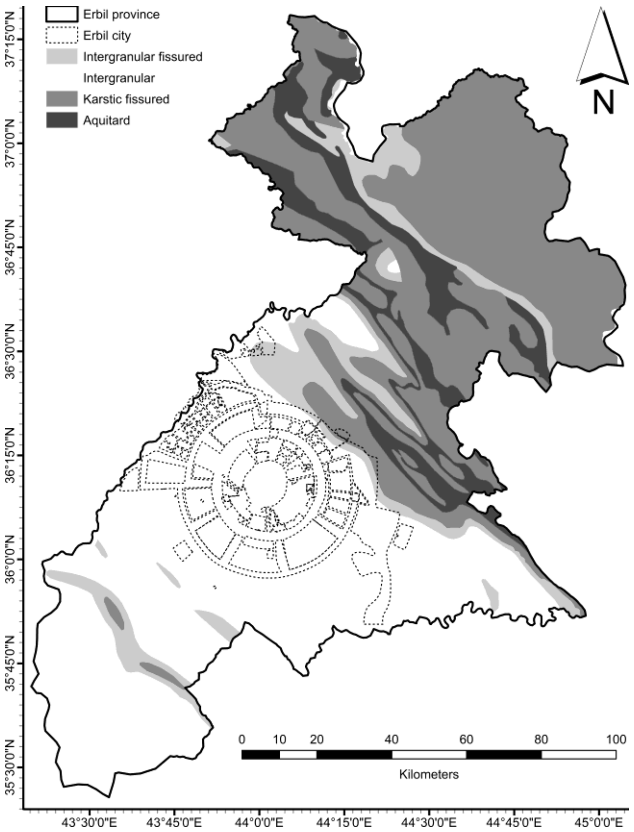

Figure 8: Aquifers types across the case study area

To grasp aquifers' status over the studied area and for the targeted period, the groundwater recharge rates, volumes, and the permissible deemed times for water extraction from wells have been calculated, see Table (5), 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 a table (5), 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 Equation (3) have been tabulated and compiled in a number of spreadsheets. The monthly precipitation and potential evapotranspiration for each year and every particular meteorological station (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 (5 and 6).

The aquifer formations and aquifer productivity maps helped to identify the corresponding soil classes to them (Figure 7, 8, and 9). First, the productivity of every aquifer has been set (Johnson, 1967; Lewis, Cheney, & O Dochartaigh, 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 the condition that seasonal effective precipitation (P_{eff}) to be greater or equal than the seasonal evapotranspiration.

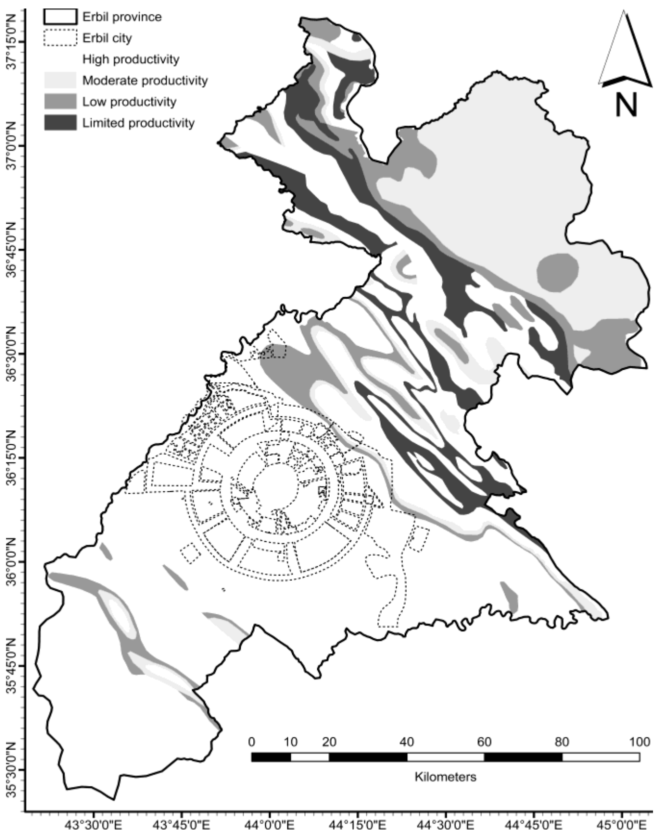

Figure 9:Productivity of aquifers across the case study area

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 meteorologic stations that cover the certain soil area. In the beginning, the average (MAP) was determined. Then, the effective precipitation (P_{eff}) for soil classes has been determined using Equation (6). 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 (10).

2.4 Assessing aquifer status using Mass-Curve analysis

Stevanovic and Iurkiewicz (2009) have critically claimed that the application of a 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 Table (6) have been set, the same procedures have been followed as in table 5 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.

2.4.1 Groundwater storage change and extraction

To estimate the safe yield and aquifers' storage capacity, there a need to find annual storage volumes. The change of annual groundwater storage is determined by the following equation and Figure (11):

$$\Delta S_i = R_i - D_i - PET_i - Q_i \qquad (7)$$

$i = 1, 2, 3, ..., N = 35$ 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 mentioning 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 relies on the actual flux(Heath, 2004; Loáiciga, 2017).

The actual operated well numbers and the average 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 (8) below:

$$Q = \frac{\sum_{i=1}^{N} Q_i}{N} \qquad (8)$$

Since lakes, wetlands and seas are not existing in this semiarid 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 (Figure. 1), and that has not been considered because of unavailable quantitative data, but even so, the groundwater balance assessment has been carried out based on the other available data.

2.4.2 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 9, and (S_o)denotes the initial groundwater storage:

$$V_n = \sum_{i=1}^{n} \Delta S_i = S_n - S_o = \sum_{i=1}^{n} (R_i - D_i - E_i - Q_i) \qquad (9)$$

$1 \leq n \leq N$

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 (10) and Figure (12).

$$\Delta S_i = S_i - S_{i-1} \qquad (10)$$

Storage and fluxcomponnts 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.

2.4.3 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 (13). 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:

$$CR_n = \sum_{i=1}^{35}(R_i + D_i + PET_i) \quad (11)$$

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 RESULTS AND DISCUSSION

Table 5 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 time 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 the climate conditions of the targeted time period, there was a restricted volume of groundwater reserves that should utilise as per robust water resources planning.

Figure 10portraysthe 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 de-escalating trend of effective precipitation, further, there were significant sharp drops in the hydrologic years (1989, 1998, and 2008). It is notable that there was almost four folds 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.

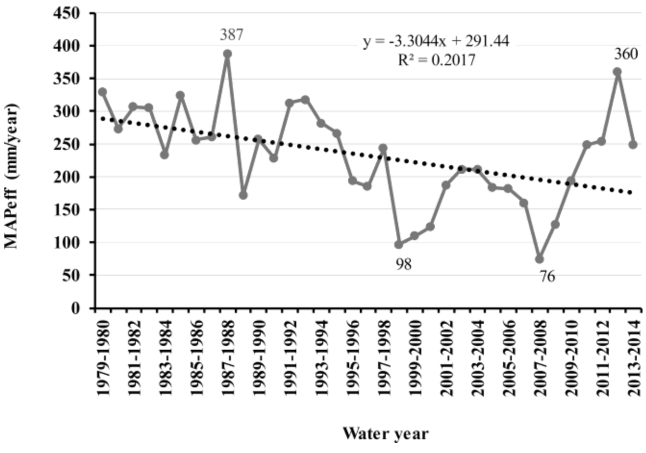

Figure 10: Long term annual effective precipitation and trendline

Table 6 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 the Figures (11, 12, and 13). As in table 5, the resulted minus values were considered zero for all calculations. As the entry data were on a monthly basis, the results have a bit different with table 5, 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 reliable results are, and the second, solid and sustainable groundwater management is needed to conserve the storage volume per year.

Figure 11 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.

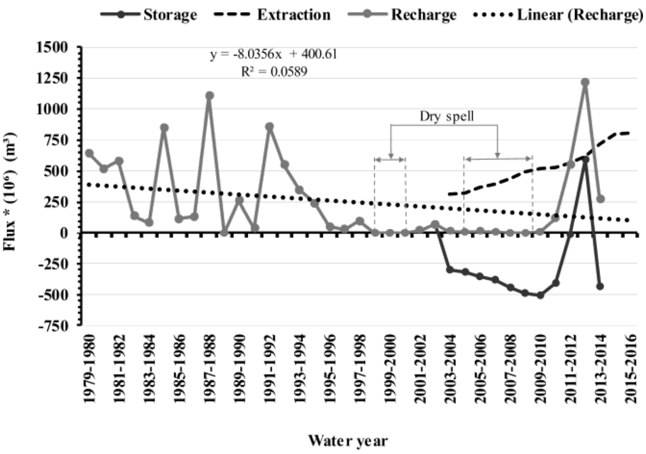

Figure 11: Line graphs of the annual fluxes along the study period

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 the 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 semiarid 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 limiting the licensed time to operate wells. Besides, there are two considerable factors that 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 12 describes the cumulative change in storage of groundwater in the study area per annum throughout the period 1980 to 2014, which was determined by Equation 9. The lower-bound assessment of the capacity of Erbil aquifer's storage can be simply found from (Figure 12), that been calculated by applying Equation 12(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.

$$C = S_{max} - S_{min} = V_{max} - V_{min} = \sum_{i=1}^{n_{max}} \Delta S_i - \sum_{i=1}^{n_{min}} \Delta S_i \quad (12)$$

Where: C is the capacity of aquifers; V is groundwater storage volume; nis 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, decades time span series might be decided as a requirement of result certainty. The longer time span period, the more result certainty is.

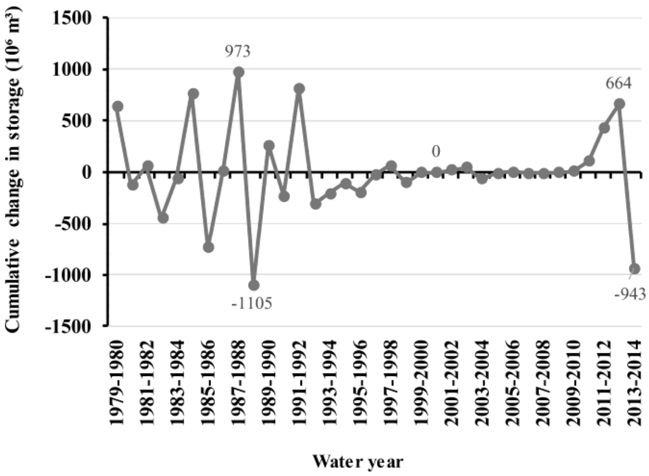

Figure 12: Cumulative change in groundwater storage for the Erbil aquifers for the period of 1980-2014

There has been dealt with the estimation of groundwater recharge for the different types of aquifers in the Erbil basin. In order to assess the safe yield of these aquifers, the net recharge volumes have been adopted on.Figure (13) shows the analysis of the mass curve for the aquifers corresponding to the studied time period.

It can be seen that 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 semiarid 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.

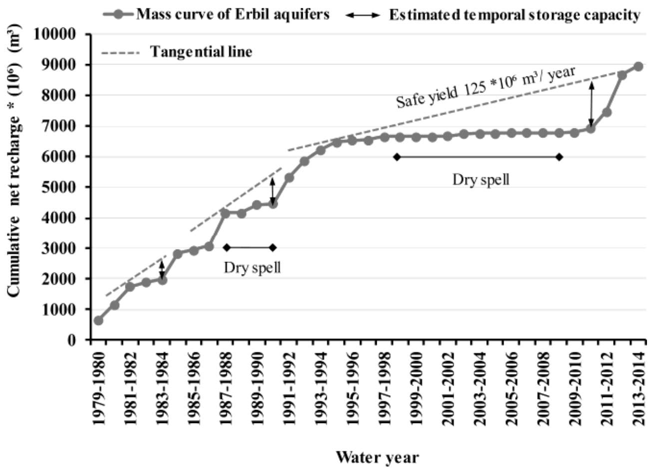

Figure 13: Mass curve of net recharge for the study area aquifers

4 Conclusion and Recommendations

Results revealed that all assessed aquifers have been impaired by over-exploitation of groundwater. The amounts of recharge during dry seasons considerably exceeded the one during the wet seasons. The abstractions exceed both recharge and safe yield of the aquifer system.

To manage groundwater in a safe and sustained manner, researchers on semiarid 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.

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 semiarid 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 semiarid 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 law-makers 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.

Water is 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 the technical framework.

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TABLE 1: LONGTERM MINIMUM, MAXIMUM AND MEAN ANNUAL PRECIPITATION, TEMPERATURE AND POTENTIAL EVAPOTRANSPIRATION

Meteorology station	**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(masl)	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1	44.0625	36.9991	2306	237.5	1372.3	621.6	11.6	15.6	13.8	1430.7	1816.6	1612.7
2	44.3750	36.9991	682	241.5	1063.2	615.7	9.4	13.6	11.7	1251.0	1587.7	1434.8
3	44.6875	36.9991	1783	313.9	1378.5	814.2	7.4	12.1	9.7	1097.8	1442.8	1295.0
4	44.3750	36.6869	1053	213.2	1150.1	607.9	13.0	17.6	15.5	1543.8	1948.3	1736.5
5	44.6875	36.6869	1154	370.4	1625.3	980.9	9.4	13.7	11.8	1238.4	1602.7	1440.2
6	43.7500	36.3747	401	191.8	1126.9	637.4	18.6	22.4	20.6	1628.9	2072.8	1850.7
7	44.0625	36.3747	507	182.9	1136.6	605.4	17.9	21.7	19.9	1582.7	2192.1	1937.2
8	44.3750	36.3747	977	189.0	1551.9	652.4	16.0	19.9	18.1	1487.8	2176.9	1905.7
9	43.4375	36.0624	261	100.8	928.8	492.6	18.9	22.6	20.9	1653.0	2017.4	1823.7
10	43.7500	36.0624	278	130.1	1070.4	570.2	18.5	22.3	20.6	1619.3	1962.0	1789.1
11	44.0625	36.0624	439	134.9	985.2	575.2	18.2	21.9	20.1	1656.3	2051.0	1851.9
12	44.3750	36.0624	605	128.0	1005.4	533.6	17.8	21.6	19.9	1573.6	2225.3	1965.1
13	44.6875	36.0624	648	145.1	1022.0	552.9	16.0	20.0	18.4	1579.5	2204.4	1936.6
14	43.4375	35.7502	252	44.5	526.5	294.4	19.6	23.2	21.6	1835.7	2200.5	1998.9
15	43.7500	35.7502	306	55.4	666.7	360.4	19.2	22.9	21.2	1747.1	2075.1	1898.3
16	44.0625	35.7502	483	63.2	720.5	389.6	19.1	22.8	21.1	1746.8	2080.9	1897.9
17	43.4375	35.4380	175	31.5	392.2	201.5	20.4	24.0	22.3	1986.1	2347.1	2145.1

TABLE 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

TABLE5: ESTIMATED RECHARGE VOLUME, AQUIFERS' STATUS,AND PERMISSIBLE WELL NUMBERS FOR THE AVERAGE LONG TERM 35 WATER YEARS

Cover soil		Estimated annual I_{eff}(%)	Precipitation					Aquifer			LTSMPET (mm)		Recharge rate ($l.sec^{-1}$)			Recharge volume x 10^6 (m^3/year)			Aquifer status	Estimated permissible well number
Soil type	Area (Km^2)		LTSMP (mm)		P_{eff}(mm)			Formation	Productivity rating	Productivity ($l.sec^{-1}$)										
			W.S.	D.S.	W.S.	D.S.	Total				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 (November-April) **D.S.**: Dry season (May-October)

A: Lithosolic soil in lime stone **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 sand stone and gypsum

H: Chestnut soil, shallow, stony and sloping phases **I**: Brown soils, medium and shallow phase over Bakhtiary gravel

TABLE 6: A SAMPLE CALCULATION TABLE FOR ESTIMATED RECHARGE VOLUME, AQUIFERS' STATUS,AND PERMISSIBLE WELL NUMBERS FOR THE WATER YEAR (2013-2014)

Cover soil		Estimated annual I_{eff}(%)	Precipitation					Aquifer			LTSMPET (mm)		Recharge rate ($l.sec^{-1}$)			Recharge volume x 10^6 (m^3/year)			Aquifer status	Estimated permissible well number
Soil type	Area (Km^2)		LTSMP (mm)		P_{eff} (mm)			Formation	Productivity rating	Productivity ($l.sec^{-1}$)										
			W.S.	D.S.	W.S.	D.S.	Total				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-moderate	2	288	1079	592	0	592	19	0	19	Safe	296
F	1276	55	779	20	428	11	439	karstic fissured	Low-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**			**274**		**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(November-April) **D.S.**: Dry season(May-October)

A: Lithosolic soil in lime stone **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 sand stone and gypsum

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