RESEARCH PAPER

Comparison between different hydrological and groundwater studies in Erbil Basin

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A B S T R A C T:

Erbil Basin is one of the most important groundwater resources in the Middle East, it is located between both Greater Zab and Lesser Zab Rivers. Due to the importance of the basin locations and its major source for water supply, various researchers studied the hydrological, hydrogeological characteristics of the Erbil basin. It also divided into three sub-basins that are (Kapran, Central, and Bash-tepa). This paper struggle to present the actual conditions of the selected basin and determine the development process of the groundwater management in the area. Thus, the article evaluates and compare different hydrological and hydrogeological studies related to the Erbil basin, and shows different measurements of the basin boundary by used the researchers. As well as, summarized the characteristics and properties of the aquifer system. In addition, the paper estimated change in head using different catchment area for each basin. At the end of this study, it is concluded that the Erbil basin require more investigations and need to be managed by authorities in order to keep this vital source for future generations.

1. INTRODUCTION:

A large depletion of groundwater level has been recorded in Erbil three sub- basin (Kapran, Central, and Bash-tepa), which is the worst case of the aquifer system in the region. It is obvious that the water level decreased continuously due to overexploitation of the aquifer storages and poor groundwater management. Moreover, the sub-surface is tapped by numerous legal and illegal wells (Dizayee, 2018). The number of the recorded wells by groundwater directorate that having coordinates and can add into GIS can be estimated approximately 4000 wells and the reminder number of illegal drilled wells in Erbil basin are unknown.

In addition, the wells are operating for different purposes such as; water supply, drinking, irrigation, fire hydrants and other human activities. However, Erbil city is subjected to rapid population growth, and their requirement to water demand increase overtime. As well as, many problems faced to the water management systems that need to be solved. On the other hand, based on the data obtained from Directorate of water and sewerage of Erbil, the percentage of groundwater is about 45% of water supply system in the Erbil city and 55% for surface water (Mustafa et al. 2021) but the actual percentage of using groundwater expected to be more than the estimated value depending on the conditions of the Erbil basins. Meanwhile, monitoring of groundwater includes both groundwater level and recharge rates as quantity determination and

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(analysis of selected physical and chemical variables are as quality monitoring. However, the groundwater Monitoring is a continuous process. There are many studies on the Erbil plain, from those; the study of (Hamad, 2022) who studied the groundwater potential map using AHP techniques. And the study of (Al-Kubaisi et al., 2019) who studied on water balance in Erbil plain. (Jalal, 2022) who investigated Erbil basin groundwater. Also the study of (Mawlood, 2019) on sustainability of groundwater source and also discuss the lack in managing water resources in the same area of study. Whereas the study of (Al-Kakey et al., 2023) who studied on determining the recharge locations for Erbil basin. Moreover, the study of (Dizayee, 2018) is on effects of the illegal wells on central part of Erbil sub-basin, and presented that the lack of groundwater management. the study of (Nanakley et al. 2017 and (Nanakaly et al, 2019) which are on Erbil groundwater basin and water balance. later the study of (Shwani, 2008) on southern part of Erbil sub-basin and also studied the hydrogeological conditions of the Bashtepa area. It is clear that the hydrogeological study is conduct to understand the aquifer system and groundwater conditions in any groundwater basin, Erbil basin is selected to be study area due to the importance of the groundwater resources and it uses for various activities without any management and planning.

The purpose of selecting this paper is due to using different boundary of each parts of Erbil basin which are known as (Northern, Central and Southern) part some of the researchers named as (KAPRAN, CENTRAL, and BASHTEPA) sub-basin. The study of (Mustafa et al. 2023) who created the groundwater level map for Erbil basin using both interpolation methods of Inverse distance weight (IDW) with coincide Kriging method then compared both methods. Therefore, this article aimed to evaluate the actual conditions of the Erbil groundwater basin and compare with previous studies. At the same time, the boundary of Erbil three sub-basins is mapped by Arc Map [10.8] applications, and the area is also computed with number of wells that recorded by groundwater directorate. The previous mapped are mostly have been drawn by manually and they are not accurate as GIS applications. Thus, this study is important for the future researchers on the Erbil groundwater. From those studies that mentioned Erbil basin are: (Hassan, 1981; Hassan, 1998; Chnaraye, 2003; Bapeer 2008, Shwani, 2008; Mawlood, 2019; Mustafa et al, 2021, Hamad. 2022; Hassan, 2022) each of the researcher described Erbil area by different catchment see Table 1:

Table 1. Summarized the researcher's studies on Erbil basin area

Researcher Name	Study Title	Basin Area	Study Area
Haddad R.H., and Smoor, P.B., Basho,D.Y., Sarbaro, S.K., Al-Azawi, AL., and Damerchi, M.S., 1974	Groundwater resource of the Erbil area	Haddad et al (1975), the study confirmed that Erbil plain could be divided into three major catchment areas or watersheds. The southern catchment area drains towards the small zab river near Altun-Kupri and covers about (680 Km^2) or 27% of the area. The Kudara and Shiwasoor wadies from the largest central catchment basin extending over about (1360 Km^2) or 54% of the area and drain towards the Greater zab rivers. The northern area of the region is occupied by the Wadi Bastora catchment area that covers about (470 Km^2) or 19% of the area and drains into greater Zab river.	Erbil area
Hassan Ahmad Hassan, 1981	Hydrogeological conditions of the central part of the Erbil Basin, PhD	Total area of the basin is (3200 Km^2), which is divided into three parts; Kapran area about (915 Km^2), Central part area about (1400 Km^2), and Bash Tepa area about (885 Km^2)	Erbil Basin

Mohammed El-Sallag, 2001	UNICEF, Assessment of water resources of Erbil governorate- Northern Iraq	Erbil basin is divided into 3 hydrogeological basins as it was attended in the past, although it forms together one basin only. The extension of Erbil plain should be recognized with the help of the wells, flow direction and tectonics. These aquifers represent the total resource of groundwater Erbil plain (3500 Km^2) and it is the largest aquifer among the entire basins of northern Iraq.	Iraq
Mariwan Akram Hama Saeed Chnaray , 2003	Hydrochemical and Hydrogeological Study of Kapran Basin Erbil-NE of Iraq	Kapran sub-basin is (802 Km^2)	Kapran basin
Shwan Omer Ismail Shwani, 2008	Hydrogeological and Hydrochemistry of Bashtepa Sub-basin in Erbil Governorate Kurdistan Region-Iraq	The area of Bash-tepa sub basin estimated as (663Km^2)	Bashtepa
Galawezh Bakir Bapeer,2008	Hydrological and Geotechnical Study of Quaternary Sediments in the Middle Part of Erbil Plain-Kurdistan Region -Iraq	The central basin covers a total area of about (1,670 km²).	Central basin
HASSAN R. M., (2022).	Water budget analysis and long-term groundwater depletion in Kapran sub-basin, Erbil, Iraq	The area is (1003 Km^2)	Kapran sub-basin
Rahel Hamad, 2022	Erbil Basin Groundwater Recharge Potential Zone Determination Using Fuzzy-Analytical Hierarchy Process (AHP) in North Iraq	The area is (3,145 km^2)	Erbil Basin

2.MATERIALS AND METHODS

2.1. Study Area location

Erbil basin is located at the northern part of Iraq, which lies between Greater-Zab at north-west and Lesser-Zab Rivers at South-east. The basin divided into three sub-basins with the names of North (or KAPRAN), CENTRAL, and south (or BASHTEPA) basin. The geographical position of the region is located between longitude (E) of 44.00°, and latitude (N) of 36.19 ° with the elevation of about 420 m a.s.l. As well as, the area is classified as arid and semi-arid region. Figure 1:
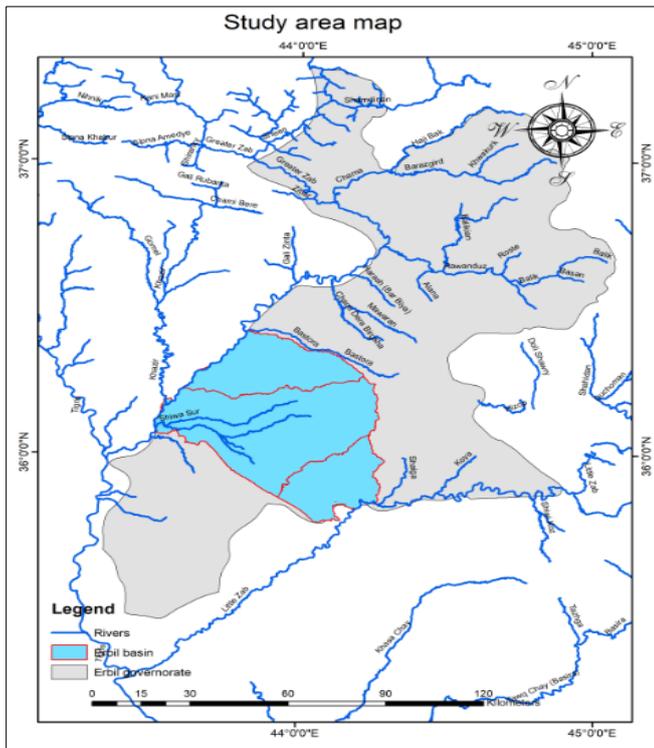
Figure 1. Study area location (Arc Map 10.8)

2.2. Hydrological Conditions of Erbil basin

2.2.1 Climate

The basin area is located in zone that has the characteristic of dry and hot in summer, humid in winter. The average annual precipitation amounts are between (250 - 600) mm. In Erbil city the climate is semi-arid that means it has cold and humid winter, hot and dry summer. The climate is determined based on the precipitation ratio and by summer temperatures of the Mediterranean Sea area (Mawlood, 2016).

2.2.2 Temperature

It is distributed according to the topographic of the study area, the maximum amount of the temperature is usually measure at the end of July or at the beginning of August. While the minimum amount is usually measure at the end of December and at the beginning of the January (Mawlood, 2016). The average monthly temperature in Erbil is in Table 2:

Table 2. The average seasonal temperature in Erbil area (Mawlood, 2016)

The average seasonal temperature in Erbil at altitude (414 m) above sea level

Winter °C	Spring °C	Summer °C	Autumn °C	Annual average °C
8.3	17.3	31.3	21.8	19.7

2.2.3. Air humidity

The study area, the relative air humidity is highest in winter and decreases until summer. The highest air humidity in the study area was recorded in December and January. The more precipitation, the highest air humidity. The average air humidity in January at the center of Erbil is (72%). There is an inversely proportional relation between temperature and air humidity, and a proportionality with the rainfall quantity. Thus, the air humidity in the June, July and August is very low. In Erbil basin the water evaporated is more than added by precipitation. The Erbil basin is supplied with fresh water from the mountains, so that it never gets to an acute water shortage. The potential evaporation increases in the study area in the direction south and south-west (Mawlood, 2016).

Rainfall in Erbil area, the maximum rainfall is approximately 576.9 mm/year and the minimum is 281 mm/year. Meanwhile, in the west direction, the precipitation amount decreases gradually. Thus, the mean annual precipitation of Erbil basin was about 467 mm during the last 20 years (2000–2020) according to the study of (Hamad, 2022).

3. GROUNDWATER CONDITION IN ERBIL BASIN

The hydrogeological conditions of the Erbil basin are described by many researchers, some of the studies refer to that Erbil basin is divided into three main sub-basins, each basin is defined by different researchers. Based on the (Stevanovic and Markovic, 2004) the study described that Erbil basin is divided into three major catchment areas:

The northern area of the region is occupied by the Wadi Bastora catchment area that covers about (470 Km^2) or 19% of the area and drains into greater Zab River. (It also named Kapran basin)

The Kudara and Shiwasor wadies from the largest central catchment basin extending over about (1,360 Km^2) or 54% of the area and drain towards the Greater Zab rivers (It also named Central basin) The southern catchment area drains towards

the lesser Zab River near Altun-Kupri and covers about (680 Km^2) or 27% of the area. (It also named Central basin). According to the referred study, the total area of Erbil catchment area is about (2,510 km^2). There are many studies and researches on Erbil basin, each researcher estimated different catchment area and aquifer characteristics, the summarized information is tabulated in Table 3:

Table 3. Different measurements of the Erbil basin area [North, Central, and South]

References	(northern) (Km^2)	(central)(Km^2)	Southern (Km^2)	Total Area (Km^2)
Haddad,1974	470	1,360	680	2,510
Hassan,1981	915	1,400	885	3,200
Chnaray, 2003	802	……	………	
Shwani, 2008	……	……	663	
Bapeer, 2008	……	1,670	……	
Kakaye, 2014	……	……	……	3,053
Hassan, 2022	1,003	……	……	
Hamad, 2022	……	…….	……	3,145
Arc Map 10.8	772	1,742	585	3,100

Estimating Erbil Basin Catchment Area

The Total Area of Erbil basin is estimated as (3,099 Km^2), which is approximately (3,100 Km^2) the area of each basin is mapped by Arc Map [10.8] applications, the boundary of each basin gives the area below:

- North (or Kapran) basin Area=772 Km^2
- Central basin Area=1,742 Km^2
- South (or Bashtepa) basin Area=585 Km^2

In addition, the number of the recorded wells increases overtime as the new wells are drilling, but it should be discussed that the actual number of both legal and illegal wells are more than the recorded wells, so that the data required to create a database for the groundwater archived files. The obtained data gives the Figure 2:
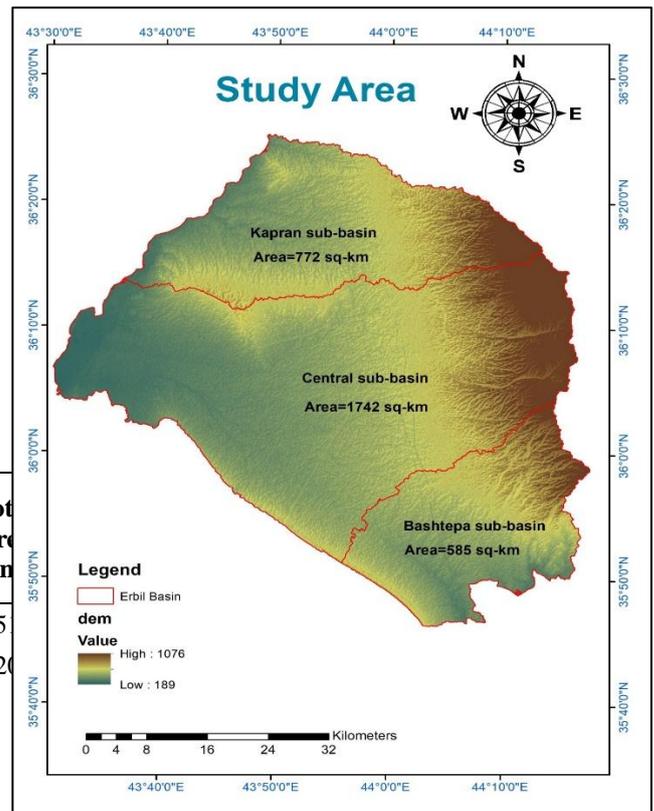

Figure 2. The boundary of Erbil three sub-basins [Arc Map 10.8]

3.2.1 Northern (KAPRAN) sub-basin

This basin is bordered from north by Bastora basin and from the south by Demir-Dagh hills, while Greater Zab River formed the west and northern west borders, where the Sharabot hills formed the eastern borders. Pliocene covering the Kapran sub basin contains Muqdadyia, Bai-Hassan formations as well as Quaternary deposits. The basin considered as medium elongated basin with semi triangle shape and high relative topographic features (Chnaray, 2003).

3.2 .2 Central sub-basin

This basin studied by (Hassan, 1981) who states that the aquifer system in this basin is Plio-Pleistocene sediments of a thickness up to (200 m), which is composed of; gravels, conglomerates and interrelations of sands, clays, and silts (Bakhtiari formation and older alluvium). The aquifer system is semi-confined and unconfined nature in its upper part, and it is regionally confined with depth.

3.2. 3 South (BASHTEPA) sub-basin

The basin studied by (Shwani, 2008) who states that the wells in the studied area penetrated Bai Hassan Formation and Quaternary Deposits and some of wells penetrated Muqdadiya Formation. The aquifer types in this basin are confined and unconfined. The hydrogeological map of Erbil basin is shown in Figure 3, and Figure 4 shows the difference between one of the previous maps that georeferenced and compared with the calculated boundary by Arc Map 10.8:
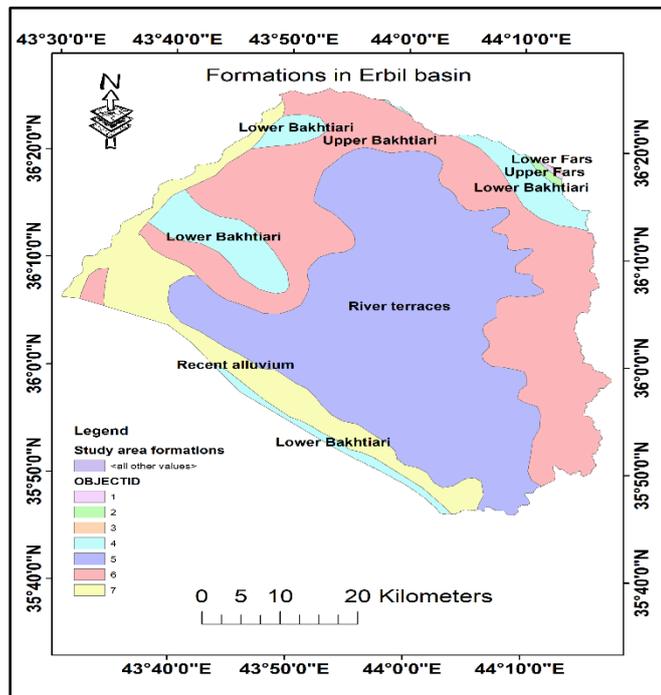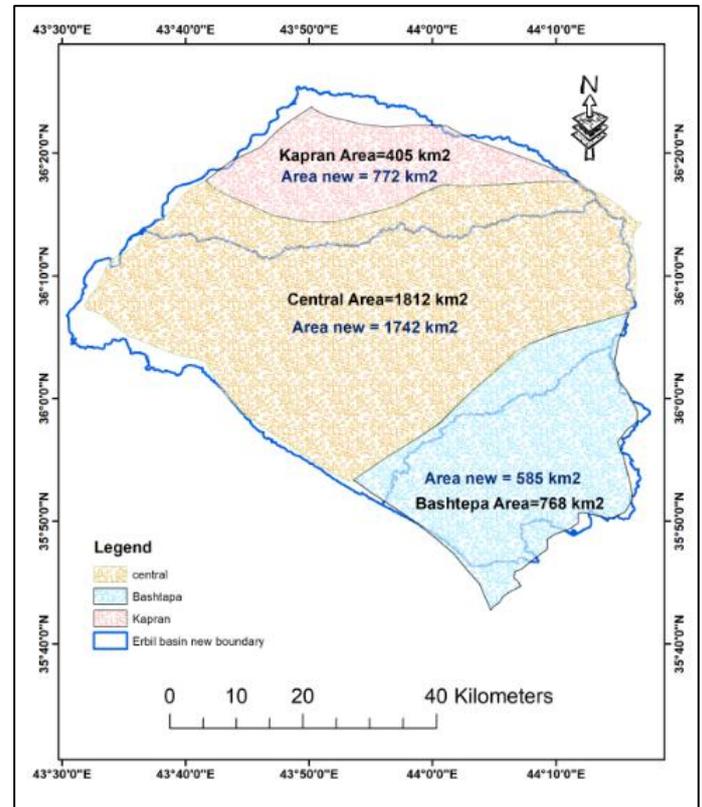

Figure 4. The calculated area of georeferenced previous map with [Arc Map 10.8] calculation results.

4. RESULTS

The study presents the characteristics and information on the Erbil basin that is summarized in Table 4:

Figure 3. The hydrogeological map of Erbil area created by [Arc Map 10.8]

Table 4. Summarized the characteristics and properties of Erbil basin

Basin name	North	Central	South	Total	Reference
	………..	………	………….	78.08×10^6	Parson,1955a
	94×10^6	199×10^6	70×10^6	363×10^6	Haddad,1974
Recharge (m³/yr)	100.01×10^6	114.38×10^6	73×10^6	288.199×10^6	Hassan,1981
	…….	187.32×10^6	………….	………….	Hassan,1998
	60.55×10^6	………….	………….	………….	Chnaray,2003
Recharge (m³)	………….	………….	38.17×10^6	………….	shwani,2008
Hydraulic conductivity m/day	………..	9	……..	……….	Hassan,1998
	0.12-80.02	………..	………..	………..	Chnaray,2003
	………..	………..	0.3-2.19	………..	Shwani,2008

	………..	676	………..	………..	Hassan,1998
Transmissivity	16.21-5601.7	………..	………..	………..	Chnaray,2003
m^2/day	………..	………..	47.44-219.37	………..	Shwani,2008
Aquifer	………..	1829	………..	………..	Hassan,1981
thickness(m)	………..	1976	………..	………..	Haddad,1974
Safe yeild (m^3/yr)	35.003 x10^6	51.471 x10^6	29.998 x10^6	115 x10^6	Hassan,1981
Effective porosity	………..	0.01	………..	………..	Hassan,1981
	………..	0.078	………..	………..	Hassan,1998

The study calculate change in head using different area for each basin to evaluate the results of change in head due to different catchment area. Hence, the change in water table Δh due to discharge calculated such as explained:

4.1. Data analysis

The specific yield (Sy) is described in (Todd and Mays, 2005) who defined as the volume of water that an aquifer releases from (or takes) into storage per unit surface area of the aquifer per unit change in head. Water recharged to, or discharged from an aquifer represents a change in the aquifer storage volume. In case of water table aquifer (unconfined) aquifer types it is expressed by the product of the volume of the aquifer lying within water table at the beginning and end of a period of time and the average specific yield of the formation.

Specific yield;

S_y = (V drain)/ (V total)……………………. (1)

Where;

A is the recharge surface area, to be taken as the aquifer's geographical area.

Δh is the change in head (water table) due to discharge

V total = A X Δh …………………………..(2)

Hence, the change in head due to discharge can be calculated

For instance, the data of Kapran sub-basin has considered as follow:

Δ h (change in head due to drain) = (V drain)/ (Area X S_y)…………………………..…(3)

Δ h= 657 X10^6 m^3/year / (470 X10^6 X 0.26)
Δ h= 5.38 m

(Change in head due to discharge water in north basin) (The amount of discharge estimated according to the study of (Mawlood, 2019). Thus, by the same procedure the changes in head for each sub-basin are calculated, see Tables 5-7:

Table 5: Change in head for Kapran sub-basin

Author name	(Northern area) x 10^6 m^2	S_y Mawlood, (2019)	Q (m^3/yr), Mawlood, (2019)	Δh (m)=Q/ S_y *A
Haddad,1974	470	0.26	657	5.38
Hassan,1981	915	0.26	657	2.76
Chnaray,2003	802	0.26	657	3.15
Hassan,2022	1,003	0.26	657	2.52

Table 6: Change in head for Central sub-basin

Author name	(central area) (x 10^6 m^2)	S_y Mawlood, (2019)	Q(m^3/yr), Mawlood, (2019)	Δh (m) =Q/ S_y *A
Haddad,1974	1,360	0.244	762.12	2.30
Hassan,1981	1,400	0.244	762.12	2.23
Bapeer,2008	1,670	0.244	762.12	1.87

Table 7: Change in head for Bashtepa sub-basin

References	(South area) (x 10^6 m^2)	S_y Mawlood, (2019)	Q(m^3/yr), Mawlood, (2019)	Δh (m)=Q/S_y*A
Haddad,1974	680	0.225	131.4	0.86
Hassan,1981	885	0.225	131.4	0.66
Shwani, 2008	663	0.225	131.4	0.88

From above results, it is clear that the change in area is directly related to change in head of groundwater basin, this will affect on the calculation of groundwater recharge and discharge amount, which are the main values of the aquifer system and also in the groundwater management process. The rapid growth in urbanization and their requirement for water supply need to proper groundwater management, Unfortunately, in Erbil basin there are a cluster of wells without any control, the map of the basin with existing of the wells are mapped using Arc Map 10.8 see Figure 5:
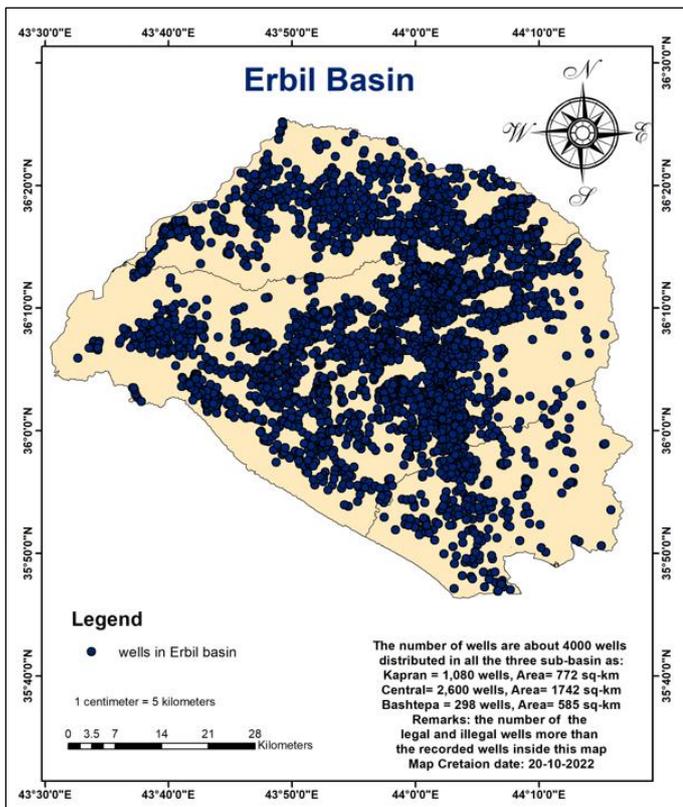
Figure 5. The calculated area and wells within Erbil basin created by [Arc Map, 10.8]

5. DISCUSSION

The results explained that different catchment area gives different change in head, see Tables 5-7, for Northern part of Erbil sub-basin which is also called KAPRAN the change in heads are (5.38, 2.76, 3.15 and 2.52)meters, in Whereas, the change in heads in central sub-basin are (2.3, 2.23 and 1.87)meters, However, in Southern part of Erbil sub-basin that is called Bashtepa sub-basin the change in heads are (0.86, 0.66 and 0.88) meters. Although, for the future investigation on the groundwater management and hydrology estimation, the boundary of Erbil basin should be accurate and unified. Thus, in this article, it is mainly concentrating on boundary determination of Erbil basin as well as, the boundary of each sub-basin at the same time. Because, for developing groundwater the main factor that has impact effect on aquifer system is Basin boundary.

The Aquifers of the Erbil basin are increasingly exposed to overexploitation. Estimates the change in head due to water abstraction. The results of the lowering head in monitoring network clearly indicate that continuous depletion is occurring in the Erbil basin, which is mainly refers to the lack in water management and also due to the absence of observation network. The area requires to have the monitoring wells only use for measuring the groundwater level, but unfortunately the recorded data are of the production wells.

6. CONCLUSIONS

The main concern in water reduction, change in water availability & decrease in groundwater level is not mainly depend on annual rainfall in the catchment area. there are many points and might to be important point is that the water availability and source which is development of the city and increasing density and population play the major role in the area and also indirect relation between density and increasing the temperature by having less green area surrounding the catchment area. on the other hand, if the number of wells increased the efficiency and drawdown are decrease and the user is increases, all those reasons lead to decline groundwater level. Also, it is clear that every 15 years the population growth is became double then, their demand to water is cause to decreases in the groundwater level in the area. The study compared and evaluated different measurements of Erbil basin boundary that used by previous researchers and compared with calculated area of each sub-basin created by Arc Map 10.8. It is necessary to establish efficient programs and applications to manage the aquifer system Also, to keep sustainable groundwater management. At the end, it is highly recommended to develop all the requirements for planning water resource management for Erbil basin. However, this point should be considered if the government and the related directorates refer to water management, they should be using the accurate the basin boundary as first step, then follow the other steps that required to develop the water resources in the area.

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