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The Impact of Human and Climatic Factors on Groundwater in Ain Al-Tamr District in Karbala City- Iraq

Ali Abdulrazzaq Kadhim* and Moheb Kamel Al-Rawe

Urban and Regional Planning Center for Postgraduate Studies, University of Baghdad, Iraq

*Email: Ali.Abd2100m@iurp.uobaghdad.edu.iq

Abstract:

This research focuses on groundwater in Ain Al-Tamr district in the western plateau of Iraq in Karbala Governorate, in addition to studying the characteristics of the geographical location, geological structure and the most important formations containing groundwater, in addition to mentioning the most important types of soils found in the study area, which is part of the Razzaza hydrological basin. The region depends mainly on groundwater, which is a major source for domestic, agricultural and industrial uses. With the expansion of the population and cultivated lands, especially for wheat crops, which occupy an area of 126,465 dunums of cultivated areas in 2024, noting that it did not exceed 8,000 dunums in 2014, which caused great pressure on water, especially after the increase in drilling operations to reach the number of wells to 1,514 wells after it was 350 wells in 2014. The district faces a semi-arid climate that exposes it to high temperatures that affect evaporation rates more than the rates of feeding water stored in groundwater reservoirs. The depths of the wells vary from one place to another, ranging between (40-200) m, due to the terrain of the region and the inclination of the water reservoir layers from the west to the eastern sections. The region has also witnessed a noticeable decline over the past ten years, due to pumping operations by human activities. The hydrology of the system is represented by the high salinity of the water, which ranges between 2000 and 3000 mg/L, which is unfit for human consumption, but is used for irrigation and some industries. To analyze how various natural and human factors affect the decline in water levels, the initial data was analyzed using the multiple linear regression model. It was concluded that human activity, especially agricultural activity, had a greater impact than climatic conditions. Effective methods for managing water resources in the future were proposed, such as effective and modern techniques for irrigating crops and working to activate the sustainable development of groundwater by spreading awareness among citizens, to clarify the importance of groundwater for the district, as it is the only water source for the sustainability of the district and to encourage a policy of rationalizing water use for the benefit of the current generation and the rest of the generations in the future.

Keywords: Groundwater, Climate factors, Human factors

Introduction

Groundwater is a critical resource for food producing, drinking water supply, drought control, and economic development, especially for rural society around the world (Cheo et al., 2022, p. 1). • Groundwater can play a key acting in maintaining natural ecosystem operation during droughts, especially in arid and seasonally barren climates (Marchionni et al., 2020, p. 1) Groundwater is contemplated one of our most important natural resources. Groundwater extraction has increased dramatically since the early to mid-20th century due to changes in irrigation technology (Kraft et al., 2012, p. 50) • Iraq is considered the fifth most susceptible country in the world, affected by water and food shortages and extreme temperatures (Saleh and Nehaba, 2024, p. 297). Groundwater is a large reserve of freshwater beneath the surface and is an important water resource for humans and ecosystems (Boretti and Rosa, 2019, p. 4) With the increase in human activities, the demand for groundwater is increasing rapidly. (Steinschneider et al., 2015, p. 1) Groundwater depletion occurs when groundwater production exceeds groundwater recharge for a long time and over a large area (Gleeson et al., 2010) Clime change has put additional pressure on groundwater resources and expanded the risk of groundwater recharge. Drought and climate change have negatively influenced food security, access to clean drinking water, hygiene, and public health. (Sam et al., 2018, p. 142)) Human activities cause land use changes, which affects groundwater replenishment. These activities also affect groundwater flow dynamics. This was according to a study conducted in one area of Cambodia. (Bucton et al., 2022, p. 13) A contemporary study shows that climate transformation is negatively affecting evapotranspiration, runoff and groundwater levels in Bangladesh (Kirby et al., 2016). • Land use modification and population expansion may lead to degradation of groundwater quality, requiring effective administration strategies. Although groundwater is critical in arid regions, confrontation such as overexploitation and pollution pose peril to its sustainability. Addressing these problem is essential to ensure long-term water security and environs health in barren regions. (Megahed et al., 2023, p. 1). Understanding the impact of climate and human aspect is necessary for rustic development analysis and planning. The purpose of this study is to examine the interaction between clime and human factors and their impact on rustic settlement patterns. (Fang et al., 2021, p. 13) Understanding the relation between water resources and human settlements is essential for sustainable development and water administration. (Hongtao and Ding, 2021, p. 837)

Data sources:

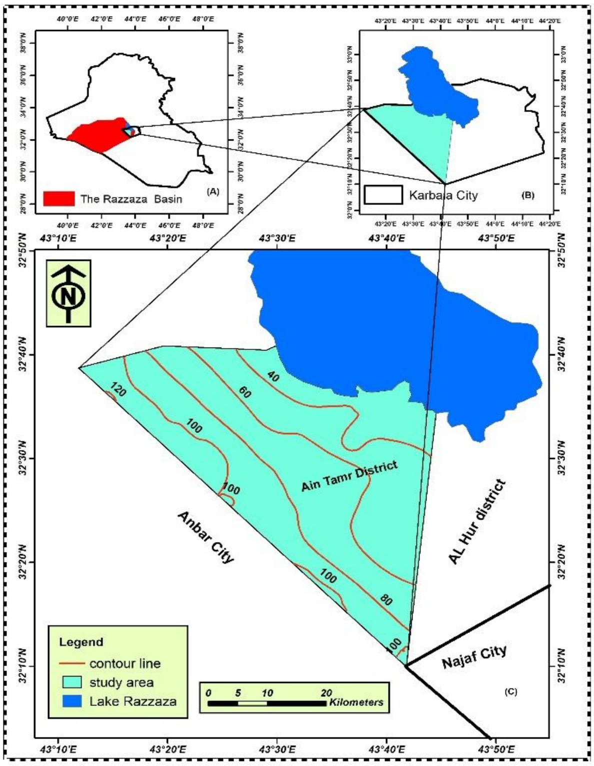
Data obtained from the Meteorological Department of the Ministry of Science and Technology, for climate data, as for well information, it was obtained from the General Authority for Groundwater, which specializes in drilling wells, where the data was collected between 2014 and 2024, in addition to population data from the Statistics Department in Karbala City and agricultural crop data from the Directorate of Agriculture in Karbala City.

Research Methodology:

The researcher relied on the descriptive and analytical approaches through collecting data and information from relevant departments and institutions about the study area, and describing the phenomenon in a scientific and accurate manner, while identifying the causes and factors that affect the existing phenomenon. The analytical approach is based on analyzing the results using some analysis methods such as GIS software through drawing maps to know the pattern of groundwater distribution in the region, its topography, the depths of wells, and interpreting the relationship between groundwater and human and climatic factors, in addition to using the statistical model such as regression. Multi-linearity, as well as evaluating the impact of climatic and human factors on the quantity and quality of water in the study area.

Study area:

Ain Al-Tamr district is located in the western plateau region of Iraq, and in the western desert part of Karbala Governorate. The district is (85) km away from the center of Karbala Governorate and is bordered to the west by Anbar Governorate and to the south by Najaf Governorate. It is bordered by Lake Razzaza from the northeastern side. As for its astronomical location, it lies between latitudes (32º 10-32º 45) north, and longitudes (43º 45-43º 12) east. It is located in the southeastern part of the Razzaza hydrological basin, where the basin area is about (60,000) km2, as the Razzaza basin represents the Euphrates River catchment area. (AL-Zubedi, 2022, pp. 91-95.



Figer1. Location of the study area and administrative boundaries of Iraq (A), Karbala Governorate (B), and Ain al-Tamr area (C).

Topographic Surface:

The topographic surface of Ain Al-Tamr district forms part of the hydrological terrain of the Razzaza area. The geological structure, including faults and cavities, affects groundwater recharge and its interaction with surface water. The slope affects surface runoff, while soil type determines infiltration rates. Natural vegetation plays an important role in retaining water, reducing erosion, and enhancing comprehensive water resources management (Fotofat et al., 2018). We notice from Figure (1) how the contour lines rise as we move from the southwest to the northeast, with elevations ranging between (40-120) meters above sea level.

This slope plays a role in feeding Lake Razzaza east of the district, in

addition to feeding the groundwater in Ain Al-Tamr district. The area is also interspersed with some depressions and elevations. In addition, the desert soil, including gravel and sand with high permeability in the west of the district, helps reduce the drainage of water through the valleys, which leads to shallow water, which helped in the emergence of seasonal ponds in the middle of this plateau. The surface of the area is divided into three sections:

1- Lake Razzaza: which is located in the far northeast of the district and occupies an area of (2000) km2. Due to the accumulated salts, it is not suitable for drinking or agricultural purposes, as its salinity has reached more than (14500) parts per million. Its height is (40) m above sea level, and the depth of the lake ranges between (30-5-) m. It can hold (26) billion m3 of water.

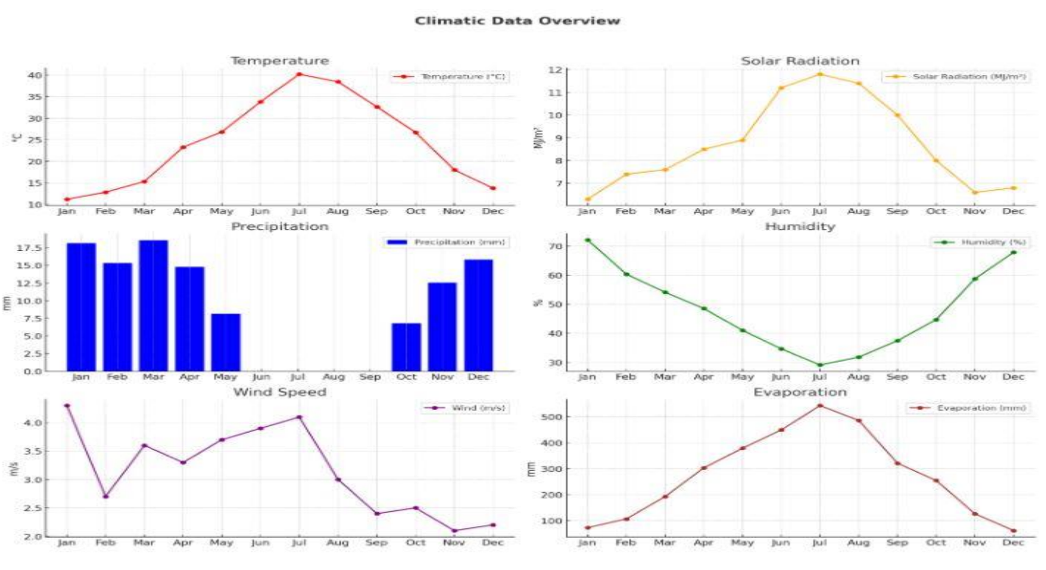
2- Valleys: Ain Al-Tamr district is crossed by a number of valleys, the most important of which are (Al-Abyad, Al-Ghadaf, Fuad, Umm Al-Rus, and Dhaleef Valleys), and all of these valleys are in Lake Razzaza. The valley that provides the district with the most beneficial water is Al-Abyad Valley.

3- The Western Plateau: It is divided into several regions, namely (Al-Hajar, Al-Hamada, Al-Dabdaba, Al-Jazeera). The district is located within the area of the discontinuous edge of the plateau, which was named thus as a result of its discontinuity within the deep valleys. The Western Plateau occupies the largest part of the district and gradually slopes from the southwest towards the northwest (Al-Nasrawi, 2023, p. 28).

Climate of the study area:

Climate change has a direct impact on the natural recharge of groundwater. This recharge occurs across the landscape either through direct rainfall (known as diffuse recharge) or through seepage from surface sources, including ephemeral streams, wetlands or lakes (i.e. concentrated recharge). The latter process is more prevalent in drylands. (Taylor, et al., 2022, p102) The climate of Ain al-Tamr district is no different from the climate of the

Figer2. Average climatic elements for the study area for the period 2014-2024



Western Plateau. Temperature played a major role in the evaporation process of water, whether surface, groundwater or rainwater, because with the rise in temperature, the evaporation process increases, which reduces the process of feeding groundwater, while feeding water increases with the decrease in temperature

rates, which is what happens in winter and spring, and most days of the summer are accompanied by drought due to the high temperatures, which prevail in the Western Desert. Through the Ain al-Tamr climate station, it is possible to identify the rates of climate elements, which are represented by temperature, rainfall rate, wind, evaporation and relative humidity for Ain al-Tamr district.

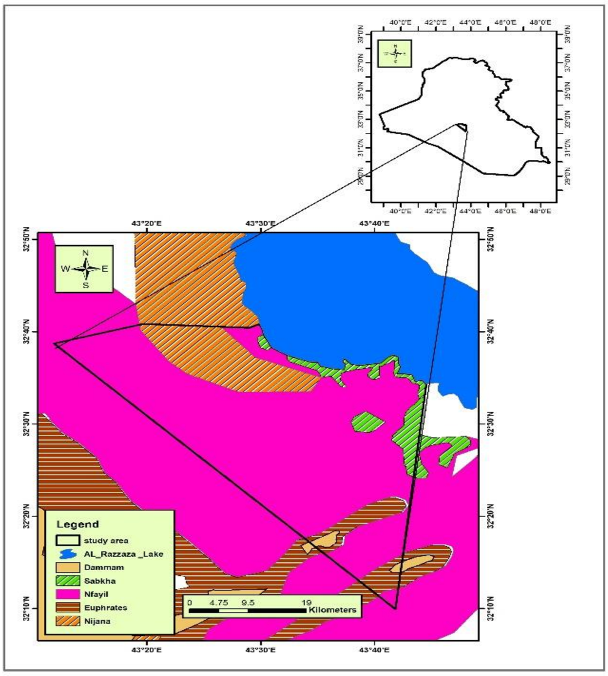
month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp.	11.23	12.86	15.32	23.27	26.83	33.81	40.2	38.45	32.65	26.71	18.04	13.78
SR	6.3	7.4	7.6	8.5	8.9	11.2	11.8	11.4	10	8	6.6	6.8
Precipitation	18.14	15.34	18.57	14.78	8.16	0	0	0	0	6.78	12.55	15.83
Humidity	72.12	60.33	54.12	48.5	41	34.62	29.08	31.77	37.43	44.69	58.75	67.87
wind	4.3	2.7	3.6	3.3	3.7	3.9	4.1	3	2.4	2.5	2.1	2.2
Evaporation	72.55	106.33	192.4	303.23	378.86	449.54	543.12	485.98	321.16	254.3	126.18	61.15

Table 1. Average climatic elements for the study area for the period 2014-2024

Geology of the study area:

The formations of the region can be divided from the oldest to the newest, represented by the Dammam Formation, which is exposed in the southeastern part of the district, and consists of altered carbonate rocks, the most important of which are (limestone and dolomite limestone with marl and evaporites), followed by the Nafael Formation, which is exposed in most parts of the district, as it covers a larger area than the rest of the formations and consists of sandy shale, dolomite and gypsum shale, then comes the Anjana Formation which appears in the

Figure3. Shows the geological structure of the study area



north of the district and consists of sandy and silty limestone rocks with a red and partially green color and lenses of sandy rocks with a lead color, and after that the Euphrates Formation, whose features appear in the south of the district and consists of (Cretaceous limestone, recrystallized limestone and bottom breccia) and finally the Sabkha deposits appear, which are one of the Quaternary

sediment deposits formed from a group of sediments and are located along the southwest of Lake Razzaza, east of Ain Al-Tamr District. (Al-Jabouri &Al-Basrawi, 2002, pp. 11-12)

Soil:

The soil of the district is mostly sandy, with a sand content of 80% and a clay and silt content of (20)%. This is due to the lack of progress in chemical decomposition processes. Thus, desert and sandy lands suffer from several problems, as the percentage of water requirement for agricultural crops increases, as well as the inability of the soil to fix nutrients and their rapid decomposition, which exposes it to erosion. Among the advantages of this type of soil is the high percentage of mineral salts that accelerate plant growth and the lack of organic matter in it due to harsh climate conditions (Al-Khafaji, 2013, p. 49).

Hydrology of the study area:

The study area is located within the hydrogeological basin known as the Razzaza Aquifer in the Western Desert, according to the classification of Hassan and Al-Kubaisi (2002). The hydrogeological production unit follows the Dammam Ristretto Formation, which is characterized by its confined groundwater-bearing layer with abundance and continuous renewal. The water of this formation is of a suitable quality for growing most crops and carrying out economic activities in the region (Ali, 2021, p. 192). The movement of groundwater in the region appears in a general direction from the west and southwest towards the east and northeast, reaching the Razzaza Lake Basin.

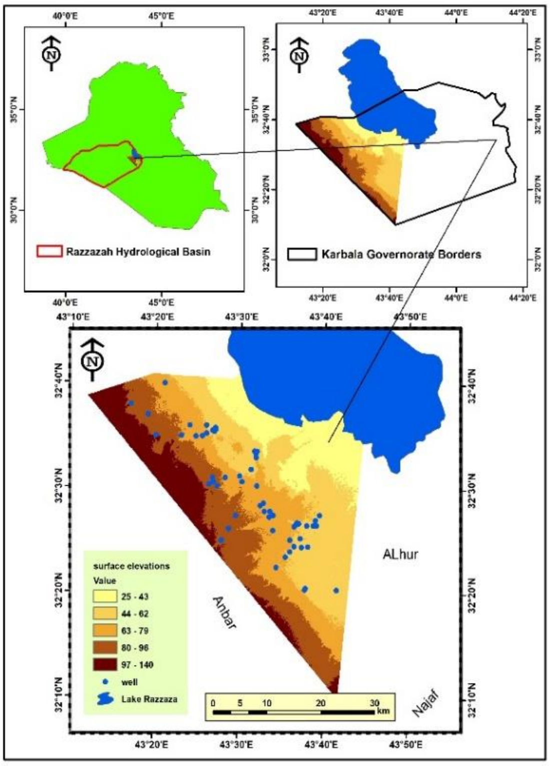


Figure 4. Well sites in the study area

The rate of groundwater movement also increases in limestone layers and in layers where soil roughness and water-retaining rock particles increase. (Knapp, 2002, p. 11-12).

Spatial distribution of wells in the study area:

The wells dug in the district are considered part of the wells of the hydrological Razzaza area, and the depths of the wells vary from one place to another, ranging between (40-200) m. This is due to the terrain of the area and the inclination of the water storage layers from the west to the eastern sections. The western region is considered a feeding area, while the eastern sections are water drainage areas until the groundwater levels are equal to the levels of Lake Razzaza. In addition to the natural factors, human factors also have an impact on the depths of the wells through the work of artificial lakes and excessive water withdrawal, which affects the decrease in groundwater levels.

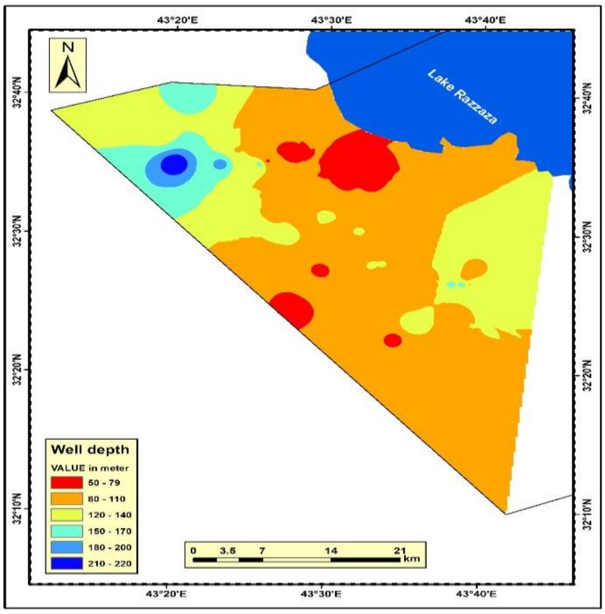


Figure 5. Shows the depths of wells in the study area

2- Human characteristics of Ain Al-Tamr district

1- Population

Population growth has a significant impact on water resources, especially groundwater, especially when the human settlement is completely dependent on groundwater, as due to domestic, agricultural and industrial use, water pumping operations increase, and this may lead to the depletion of groundwater resources, where it is necessary to manage water withdrawal operations in a sustainable manner. The district is considered one of the settlements that depend heavily on groundwater, and the population size of the district, according to estimates of the population of Karbala Governorate (2007-2023), reached (24558) people in (2007) and decreased to (24418) people (2010), after which it rose to reach (26301) people in (2015), then reached (30766) people in (2021) and finally became (33919) people in (2023).

The use of groundwater in semi-arid areas is a vital source, by providing drinking water to those areas, and it also contributes to meeting the daily need for clean water for the residents of those areas, which achieves water security for them. By studying the hydrochemical properties of the district's wells, it is clear that its water is not suitable for drinking, due to the high salinity, but it can be used for other uses such as washing, cooling, watering gardens and cleaning homes. As for drinking water, the Karbala Water Directorate has supplied the district with water from outside the district, i.e. from the (BS3) station in Karbala, 86 km away, with a capacity of (1000) m3/hour. There is also a desalination plant for the old project of the district center. As for the rural villages, they have been supplied with a number of desalination plants with a total design capacity of (62) m3/hour. After the water is extracted from the existing wells and transferred to tanks to be transported to the desalination plants, the number of these wells is (13) wells at a rate of (5 hours per day) and with a productivity of (12 liters/second).

We can calculate the domestic water consumption in the district, which includes the groundwater of the villages above.

12 liters/second = (12×3600 seconds/hour×6 hours) / 1000 = 259 m3/day.

So the groundwater consumption for domestic purposes = 259×13×365 = 1229904 m3/year

2- Industrial activities:

Many industries are spread in Ain Al-Tamr district that depend on groundwater, through drilling wells, such as crushed gravel and sand quarries, cement and gypsum factories, etc. There are about (91) wells with an operating rate of (10) hours per day, and a production capacity of (14) liters/second.

Thus, water consumption for industrial activity can be calculated as follows:

Pumping calculation for each well per day = 14 liters/second * 3600 seconds/hour * 10 hours/day = 504000 liters/day = 504 m3/day

Annual consumption calculation = 504 * (91) number of wells * 365 days = 16740360 m3/year

3- Agricultural activities:

One of the activities that consume water resources is agricultural activity, including groundwater, due to the loss of most of the water used for irrigation through evaporation from the soil or transpiration from plants. There are many agricultural crops in Ain al-Tamr district, but we will mention the crops that occupy large areas and depend on groundwater. What concerns us is calculating the water consumption of these crops. The most important of these crops are grains such as wheat, barley, corn, and horticultural crops, including palm trees and horticulture. We will take the wheat crop because its cultivation represents more than 95% of the grains in the study area, as the cultivated area is about (126465) dunums, and irrigation is done using the pivot sprinkler method, as each sprinkler covers an area ranging between (80-120) dunums, as the number of wells is (1514) wells, with a production capacity of (12) liters/second, as the irrigation season begins on November 15 of each year (the date of planting wheat) until April 15, at a rate of (15) hours. Daily, thus the water consumption of wheat can be calculated as follows:

Pumping calculation for each well per day = 12 liters/second * 3600 seconds/hour * 12 hours/day = 518400 liters/day = 518.4 m3/day

Annual consumption calculation = 518.4 * (1514) number of wells * 150 days = 117728640 m3/year

To calculate the water consumption of palm trees and fruit trees, where the number of palm trees is (270000) palm trees and the number of fruit trees is (48000) trees planted within palm groves, and according to farmers, the number of irrigations is about (80) irrigations annually, and the number of existing wells was (513) wells for an area of (11000) dunums, thus the water consumption of garden trees can be calculated as follows:

Pumping calculation for each well per day = 15 liters/second * 3600 seconds/hour * 9 hours/day = 486000 Liter/day = 486 m3/year

Annual consumption calculation = 486 * (473) number of wells * 100 days = 22987800 m3/year

Agricultural consumption = Grain consumption + Orchard trees consumption

= 117728640 + 22987800 = 140716440 m3/year

So total groundwater consumption for the study area = Domestic consumption + Industrial consumption + Agricultural consumption

= 1229904 + 16740360 + 140716440 = 158686704 m3/day

Figure 6.The relationship between water consumption and human activities and their relationship to the decline in the level.

Applying the statistical model

In order to test the research hypothesis and demonstrate the impact of natural factors represented by climate elements (heat, rain and evaporation), as well as the impact of human factors represented by agricultural, domestic and industrial activities on the decline in the groundwater level, which represents the sustainability element for human settlements that depend almost entirely on them, especially the economic aspect of the region, the researcher used the (multiple linear regression) model, to ascertain the nature of the link and the influence of each independent variable on the dependent variable.

Building the model statistically

A number of variables were chosen that the researcher believes may affect the dependent variable directly or indirectly, and the multiple linear regression equation is a mathematical

statistical equation used to model the relationship between one dependent variable (Y) and

several independent variables (X1,X2,X3,….Xn) and the regression equation is as follows:

Y=a+b1X1+b2X2+b3X3+….bnXN+ei

Where:

• Y is the dependent variable (which we want to explain or predict).

• a: The constant is the value of Y when all independent variables are zero.

• b_1, b_2, b_3,..., b_n Regression coefficients for each independent variable, which express the amount of change in Y as a result of changing one unit in each X while keeping the rest of the variables constant.

• X_1, X_2, X_3,..., X_n Independent variables, factors affecting (Y)

• ei represents the "random error" or "regression residuals". It expresses the difference between the actual value of the dependent variable (observed value) and the value expected by the regression model.

The (low water level) was considered as a dependent variable (Y) in the model as it is the main problem that the district suffers from, which is affected by a number of factors that may directly or indirectly affect it. Human factors represented by human activities (agricultural, domestic and industrial) were taken, and the total water consumption for all human activities was taken, to avoid interference between variables and improve the accuracy of the model due to the strong common relationship between them. In addition, the main goal is to know the effect of human factors in general. Climate factors represented by (temperature, evaporation, rain and humidity) were also taken, as solar radiation and wind were neglected, as solar radiation is linked to heat and evaporation and its position may be a repetition of variables, in addition to winds that are linked to evaporation, their inclusion may also be a repetition. Therefore, we limited ourselves to the elements that we see have an effect on the dependent variable and which will be entered into the statistical program (SSPS) to know the variables that most affect the dependent variable and determine the relationship between them, by applying the multiple linear regression equation.

Applying the multiple linear regression model equation

The statistical program (SPSS 26) was used to determine the relationship between the dependent variable (level decline rate) and the independent variables (human consumption - temperature - evaporation - humidity - rain) and the effect of each variable in the model. The results were as follows.

Dependent	predictors	R	R2	F	Sig.	B	t	Sig.
	constant					1.931	33.56	0.000
Low level	Temperature	0.994	0.988	79.569	0.000	0.181	0.653	0.543
	Humidity					0.022	0.227	0.829
	Rain					0.013	0.122	0.908
	Evaporation					0.144	2.333	0.067
	Human					0979	2.869	0.035

Table 2. Multiple Linear Regression Model Outputs: Coefficients and Statistical Values

Analysis of results

Table (2) of the model shows the value of (R=0.994), which represents a strong association between the decline in groundwater levels and natural and human factors in the study area, reaching more than 99%.

As for the value of the corrected coefficient of determination (R2=97.5), the independent variables explained 97% of the dependent variable, while the remaining percentage (3%) is due to other factors.

As the analysis of variance shows us that the significance value is equal to (Sig=0.000), which is a value less than the significance level $\alpha=0.05$, which indicates that the model as a whole is statistically significant, and therefore we reject the null hypothesis and accept the alternative hypothesis and say that the model has the ability to predict.

The table shows the effect of each independent variable on the dependent variable and its association with the variable. We note that human water consumption has Sig = 0.035, which is less than the significance level 0.05, so it has a significant moral effect on the decline in groundwater levels.

As for temperature, Sig = (0.54) which is greater than the significance level, so there is no effect on the decrease in water level.

While humidity, it was (0.82) which is greater than the significance level and has no significant effect, so there is no effect on the decrease in water level.

As for rainfall, Sig = 0.90 which is a large percentage, so there is no effect on the decrease in water level.

The value of Sig = 0.06 for evaporation is a percentage very close to the significance level, meaning that the effect of evaporation on groundwater is not statistically significant at the significance level of 0.05, but it can be said that the effect is close to significance, which may indicate the presence of a weak or possible effect, but it is not strong enough to be considered statistically significant.

The table also shows us that the value of b is equal to (1.931) and there is a direct relationship between the decrease in the groundwater level and the increase in water consumption (withdrawal), evaporation value, temperature and humidity, while there is an inverse relationship between the decrease in the level and the amount of rainfall, meaning that the more rainfall, the less the decrease in the level. Therefore, the multiple linear regression equation becomes: **Y=1.931+0.979X1**

That is, every time water is consumed by one degree, this leads to a decrease in the water level by (0.979) degrees. As for the value of the constant a, which is equal to (1.931), it is clear to us that in the absence of factors affecting the water level, the lowest decrease in groundwater will be (1.931).

Conclusions:

1- The salinity of the district ranges between (1500-3000) mg, which makes it unfit for drinking, but it can be used for drinking after installing desalination plants, which is what the authorities in the district did, as there are (5) desalination plants, and the local authorities are seeking to increase them in the future.

2- Groundwater is suitable for irrigating almost all crops, as well as irrigating animals and some industries, such as cement manufacturing, sand and gravel quarries, and most building materials.

3- The continuous increase in the number of residents during the past ten years indicates that there is relative stability in the district, due to the existence of the economic basis of the district, which is agricultural activity represented by wheat, barley, corn, fruit trees, palm trees and citrus fruits, and this is due to the availability of groundwater, in addition to the facilities of the local authority in receiving most crops, the most important of which is wheat, as it is a strategic crop for the region.

4- Increasing the agricultural areas of wheat crops cumulatively and at an annual rate of increase (31%), as the area in 2014 was (8000) dunums, and became (126465) dunums in 2024, which is a large increase and this creates great pressure on groundwater. The number of wells became approximately (1514) wells this year after it did not exceed (350) wells in 2014, and this is due to the purchase of the crop by the local government at good prices.

5- The increase in the areas of wheat crops did not only affect the increase in water consumption, but a decrease was observed in the areas of other grain crops, such as barley, corn and animal feed, and this causes an imbalance in the diversity of the economic basis of the region, especially since some of these crops such as animal feed and corn are considered important feed for livestock, which affects the economic system in the district.

6- Natural factors represented by climate elements as well as human factors represented by agricultural and industrial activities and others affect the depletion of groundwater, but through statistical analysis it became clear that the greatest impact is due to human factors, especially agricultural activity due to the continuous increase in agricultural areas.

Recommendations:

1- Work to activate the sustainable development of groundwater by spreading awareness among citizens through educational seminars, to clarify the importance of groundwater for the district, as it is the only water source for the stability of the district and encourage the policy of rationalizing water use.

2- Do not over-exploit the agricultural areas for the wheat crop and an annual balance must be made between the amount of rainfall and annual nutrition on the one hand and the agricultural areas on the other hand and activate water management to preserve it for the current and future generations.

3- Conduct periodic monitoring of wells in the region as well as conduct extensive hydrological studies of the settlement to assess the hydrological situation in order to identify the quality and quantities of water to identify the amount of water withdrawn to avoid depletion of the groundwater reservoir.

4- Create a balance in crop cultivation by imposing laws, so that there is no increase in one crop at the expense of another crop and this is done by developing a well-studied plan to have diversity in crops, which enhances the economic basis of the settlement.

5- Forming committees to monitor industrial activities on an ongoing basis to prevent pollution that could affect groundwater resources and conducting periodic examinations of the soil and groundwater of industrial sites to determine the extent of the environmental impact on groundwater. 6- Working to regulate irrigation water by using modern technologies such as sprinkler and drip irrigation, which have an irrigation efficiency of more than 90%. Some agricultural programs can also be relied upon to determine the crop's water needs during the growth period, such as the (CROPWAT) program prepared by the Food and Agriculture Organization of the United Nations. The program estimates the water needs of crops based on climate data, soil type, and crop type. This helps reduce water waste and direct water to optimal use.

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