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Ground Water Formation Simulation and Systematic Analysis In Erbil, Iraq

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ABSTRACT

A region's groundwater is regarded as a significant water resource that may support surface water for a variety of demands. The conductivity of the soil, the available recharges, and other characteristics all have an impact on how groundwater moves. The management of that water supply can be improved with greater use by comprehending its production and flow as well as by creating an effective map of the groundwater table over a specific area. The Euphrates and Tigris Rivers, as well as the rivers that are connected to the Tigris River, are two of the main sources of groundwater in north Iraq. The streams of the Upper Zab and the Lesser Zab surround Erbil City. The study examined the groundwater stream to determine the direction and velocity of the streams that emerge from the two rivers as well as the impact of the city's location on the creation of aquifers over the city's and its surrounding territory. The study was based on 50 wells that were built over a sizable area inside the three main Erbil zone basins (the north, the middle, and the south basin). The average annual static heads that the Iraqi Ministry of Water Resources recorded were gathered and positioned with numbers on the appropriate latitude and longitude magnitudes. The Darcy law was applied to determine the groundwater's flow directions into and out of the Erbil city region. In order to provide clearer information about the formation of the groundwater, the directional velocities, and the effects of each well on the nearby wells, the study supported the analysis by employing the MODFLOW program as a simulator workbench. The study demonstrated that the Lesser Zab Stream and water buildup in the high elevation zone in the east and north-east of the city are the sources of the main groundwater streams in the three basins. The streams follow the Tigris River's main stream as they meander toward the west. A fraction of the groundwater streams in the north basin discharge into the Upper Zab during the recharge cycle.

Keywords: Groundwater, Upper Zab, Lesser Zab, MODFLOW, Tigris River.

Introduction

To assist individuals in need during a drought, groundwater can be used as a source of fresh water storage[1]. The water quality is good due to natural purifying processes, and it is simple to develop and treat this water to be a low-cost supply of drinking water [2]. Groundwater reservoirs are significantly impacted by climate change, especially in regions that are highly vulnerable to hydrological circumstances. Increased rainfall results in more groundwater, which in turn affects metrological factors including humidity, wind speed, and temperature [3].The surface water recharge that feeds the water storage in the fissures that occur under the surface is responsible for the aquifer's inflow [4]. The structure of the soils around an aquifer has an impact on the difficult process of an aquifer's outflow [5]. The hydraulic conductivity of the soil matrix and the flow direction affect the rate of water seepage. The soil layer's porous nature has a big impact on flow velocity [6].

In a study by Aksever F. et al. (2015), the water level in Turkey's Sandkl basin was used as a proxy for the state of groundwater variability [7]. To determine the amount and balance of groundwater in the specified basin, the method of calculating water budget was used. Investigated were the effects of precipitation, surface runoff, and evaporation on the research region[8]. The research that determined the water balance in the basin for the years 2007 to 2010 using physical ideas. The average amount of water in the basin was calculated as a consequence [9]. .

The study by Lee C., et al. (2006) looked at groundwater recharge. The aquifers allotted in the nation of Taiwan served as the study area[10][11]. For the estimating and analysis process, a water-balance approach using steady base flow data was used. By calculating the size of the product of the mean annual long-term runoff and the index of base-flow, the mean annual groundwater recharge was calculated (BFI) [12]. .

1. Hydrological Characteristics Of Erbil City

The Kurdistan region of Iraq is considered one of the areas where groundwater extraction is increasing at an unsustainable rate for many agricultural purposes, confirming that natural recharge of groundwater reservoirs is less than withdrawals[16] [17]. Because traditional irrigation systems are ineffective, the need for more water increases, and excessive groundwater extraction has a negative impact because insufficient rainfall in the region affects agriculture. The majority of industries rely heavily on groundwater in their operations[18] [19]. Underground water areas were created where possible by assigning importance to each parameter and mapping the data using various techniques such as resampling. In many research, many methodologies of accuracy are used in interpolation again for purpose of estimation to determine the quality of water and soil [20].

2. Methodology

MODFLOW Flex

Many of the water sources in the province of Erbil feed into large amounts of groundwater, which is dependent on the sedimentation process and reflects many of the water content inputs[14] [15]. On the other hand, regular transpiration which is also a result of water content leads to evaporative cooling. The climatic water balancing process is used to determine the water surplus accompanied by periods of water scarcity because various climatic variables, including such excess water amount and water scarcity, play a significant and crucial part in the life of this crop in this place. Groundwater plays the most significant role in reducing water scarcity in these situations because prospective evaporation is the quantity of water that can be evaporated under normal conditions with the help of moisture to meet the needs of vegetation cover.

By simulating groundwater flow using a mathematical model that is implicitly solved using dominating equations and equations that describe the head or flow over the model's borders, the physical processes in the scheme are carried out. The most used groundwater flow simulation program is MODFLOW Flex, and it is the only one that can generate precise sensitivities for both simple and complex flow systems. For complex boundary conditions, the direct technique of MODFLOW modeling construction is less evident. As a result, a grid or a conceptual model trend can both be used to generate a model. In order to identify the wellhead protection area, the groundwater passes through the region under steady-state flow circumstances, producing hydraulic head, calculating speed distributions, and analyzing travel time and patterns. The city of Erbil contains three basins.

A. Northern sub-basin (Kapran) : This sub-basin has a 915 km2 area. The Bakhtiary Formation makes up the topmost portion of this subbasin, which lies close to the Zagros Mountains' foothill region. The Upper Bakhtiary Formation is covered by alluvial deposits in the basin's bottom portion. Alluvial deposits can sometimes be up to 50 to 60 meters thick. There are no aquitards or aquicludes between the inter-granular Bakhtiary and alluvium aquifers, which both function as groundwater-bearing units (aquifers). The Bakhtiary aquifers are lithologically constituted of gravel, sand, silt, conglomerate, and clay beds, according to records from several deep wells, whereas alluvium aquifers are composed of interbedded sand, silt, clay, and gravel. Deep wells will eventually be artesian under normal circumstances [6].

B. Middle sub-basin: This sub-basin has a 1400 km2 surface area. This subbasin contains alluvium as well as the Upper and Lower Bakhtiary Formations. Gravel, sand, clay, and conglomerate strata make up the upper portion of the Bakhtiary Formation. On the other hand, some deep wells in the lower Bakhtiary Formation have thin layers of gravel, sand, or conglomerate. Similar to the Bakhtiary Formation, alluvium aquifers contain silt, but instead of silt in the form of several clay layers, it is present in the spaces between the layers.

C. Southern sub-basin (Bashtapa): The Upper Bakhtiary Formation predominates in the 885 km2 Bashtapa sub-basin, which is located in the southern part of the basin. This sub-basin is characterized by two distinct aquifer system types: unconfined and semi-confined. While the unconfined aquifers mostly consist of interbedded clay beds with some silt or silty clay, the semi-confined aquifers in this sub-basin involve silty substances (silty clay, sandy clay) that are interbedded with thin, fine-grained sandstone strata, amalgamated with clay layers.

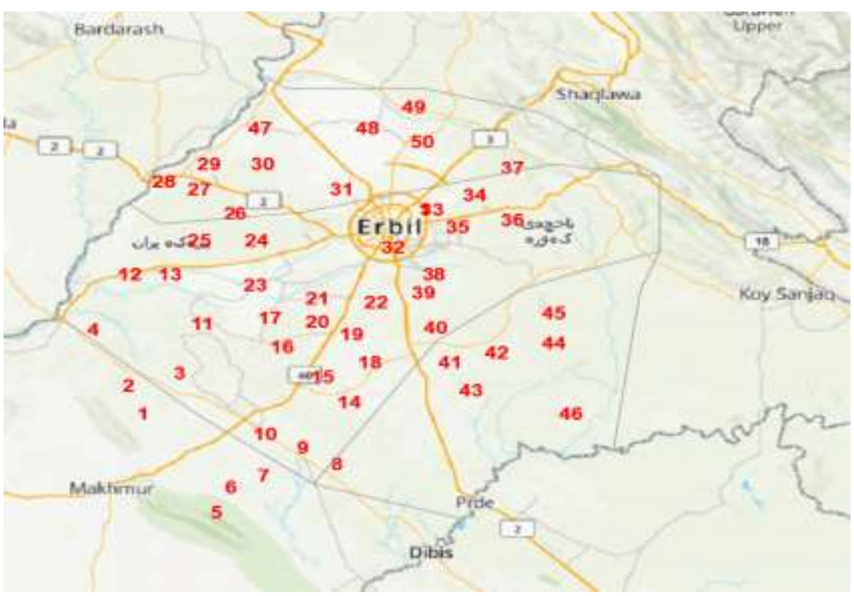


Figure 1. Positions of constructed wells Erbil region [8]

Table 1. Observation wells in study area (No. 1 to 25)

Well No.	Longitude	Latitude	Water Table Elevation (m a.s.l.)
1	43.75396	35.94672	192
2	43.73524	35.97555	134
3	43.78675	36.00437	135.9
4	43.7	36.06987	98.2
5	43.83166	35.8	245.7
6	43.84799	35.83144	194.9
7	43.88045	35.85764	169.3
8	43.96521	35.87336	245.7
9	43.91834	35.89432	223.5
10	43.89487	35.89432	214.9
11	43.82448	36.07773	141.9
12	43.75398	36.15633	200.3
13	43.77745	36.15633	203.4
14	43.96994	35.96769	252.3
15	43.94647	36.00961	286.1
16	43.89719	36.04891	235.7
17	43.89011	36.09083	200.6
18	43.99577	36.01747	295
19	43.97938	36.05939	285.4
20	43.93003	36.08297	296.2
21	43.93705	36.12227	293.9
22	43.99578	36.11179	299.3
23	43.86192	36.14323	295.7
24	43.86664	36.20087	296.3
25	43.81504	36.19825	302.4

2.2 Theoretical Analysis

Darcy's law, which is as follows, can be used to assess the origin of groundwater volumes as well as the spatial mobility along various soil segments.

$$\frac{Q}{A} = V = -k\,\frac{\Delta h}{\Delta l}$$

Where:
Q =flowrate of groundwater
A= cross area of flow
V= velocity of groundwater movement
Δh = difference of water table head between two observation wells
Δl = distance between two observation wells
K = hydraulic conductivity of the soil
The formula based on the distance between the longitudes and the latitudes for each two wells as:

$$\text{distance in (km)} = \sqrt{(longitude1 - longitude2)^2 + (latitude1 - latitude2)^2} * 111$$

Where the 111 is the conversion from the distance in the system of longitude and latitude to system of metric (in kilometers) on earth relating to area of study.

Table 2. Hydraulic conductivity of Erbil main basins

Basin	Hydraulic conductivity (m/day)
Northern sub-basin (Kapran)	6.82
Middle sub-basin	9.02
Southern sub-basin (Bashtapa)	8.31

2.3. MODFLOW Simulation

The simulation work was implemented by using the workbench of MODFLOW FLEX 6.1 program. The initial properties of the topographic map were fed in the program for better assigning and results of the simulation analysis. The study area inside the program panel was showed in figure 1. The vertical scale taken was 1/10000.

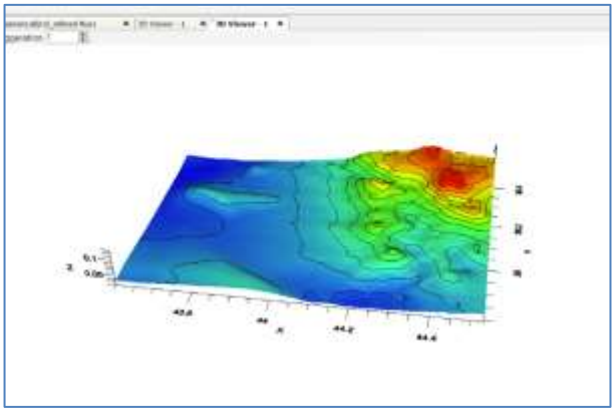


Figure 2. Topographic map of the area of study inside MODFLOW program (3D)

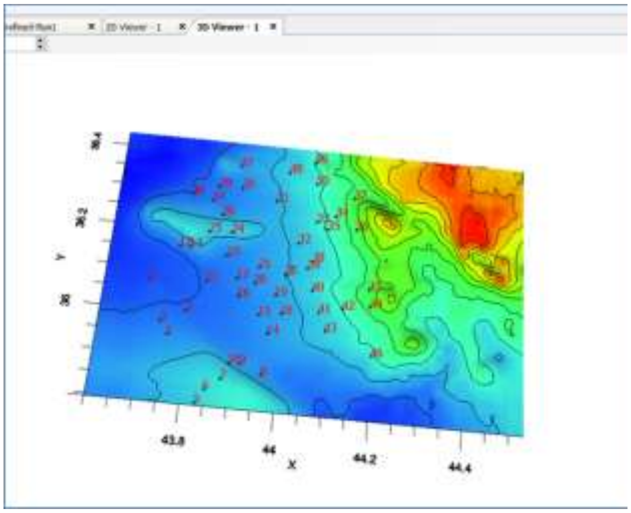


Figure 3. The observation wells and the study area inside MODFLOW program (3D)

2.4 Recharge Data

for improving the program's simulation of groundwater dynamics. Greater ZAB is 277 meters above sea level when it approaches the boundaries of the Erbil Governorate, while the Lesser ZAb River is 300 meters above sea level when it gets close to the study region (a.s.l.). The Great Zab River and the Lesser Zab River have average flows of 428 and 198 cubic meters per second, respectively. Information on the rate of evaporation and precipitation was acquired (according to Iraqi Meteorological Organization and Seismology). These numbers reflected the water needed for recharge, which might increase the amount of ground water already present.

3. Results

4. Groundwater System

By determining the distance between wells as a preliminary step, the Darcy law was used to determine the groundwater's velocity and direction depending on Erbil city. For every two of the 50 wells in the three study basins, the distances in kilometers were calculated.

Table 3. Distances (in kilometers) between wells in north basin

Well No.	Well No.										
	26	27	28	29	30	31	37	47	48	49	50
26	0.0										
27	4.9	0.0									
28	9.8	5.4	0.0								
29	8.1	4.3	7.0	0.0							
30	9.1	8.5	12.8	6.0	0.0						
31	14.3	16.5	21.6	15.3	9.6	0.0					
37	34.1	36.5	41.5	34.9	28.9	20.0	0.0				
47	14.6	12.2	14.6	8.1	6.2	13.6	30.6	0.0			
48	21.1	21.5	25.7	18.7	13.0	9.0	18.1	12.8	0.0		
49	28.2	28.7	32.8	25.8	20.2	15.1	14.4	19.3	7.2	0.0	
50	25.7	27.3	32.0	25.1	19.2	11.5	10.5	20.1	7.6	6.2	0.0

Table 4: directional velocity (in m/day) between wells in north basin

Well No.	Well No.									
	26	27	28	29	30	31	37	47	48	49
27	0.016									
28	0.022	0.026								
29	0.028	0.035	0.001							
30	0.010	0.002	-0.009	-0.022						
31	0.004	-0.002	-0.008	-0.011	-0.005					
37	-0.024	-0.025	-0.025	-0.030	-0.032	-0.043				
47	-0.045	-0.060	-0.060	-0.109	-0.121	-0.052	0.005			
48	0.000	-0.003	-0.008	-0.012	-0.007	-0.004	0.046	0.052		
49	-0.044	-0.046	-0.045	-0.057	-0.066	-0.086	-0.030	-0.031	-0.174	
50	-0.027	-0.029	-0.029	-0.037	-0.042	-0.065	0.011	-0.002	-0.094	0.088

Table 5. Distances (in kilometers) between wells in south basin

Well No.	Well No.						
	8	41	42	43	44	45	46
8	0.0						
41	21.2	0.0					
42	26.1	5.9	0.0				
43	19.0	5.0	7.3	0.0			
44	31.9	12.8	6.9	12.9	0.0		
45	34.6	14.1	8.6	15.7	4.7	0.0	
46	27.1	16.8	13.8	12.8	12.5	17.2	0.0

Table 6. directional velocity (in m/day)

between wells in middle

basin (well: 20 to 33)

Well No.	Well No.							
	20	21	22	23	24	25	32	33

21	-0.005							
22	0.003	0.008						
23	-0.001	0.002	-0.002					
24	0.000	0.002	-0.001	0.002				
25	0.003	0.005	0.001	0.008	0.010			
32	0.040	0.054	0.065	0.034	0.036	0.025		
33	0.027	0.034	0.036	0.026	0.029	0.021	-0.431	
34	-0.031	-0.035	-0.043	-0.029	-0.032	-0.028	-0.269	-0.646
35	0.032	0.038	0.044	0.029	0.031	0.023	-0.390	-0.984
36	-0.027	-0.029	-0.038	-0.024	-0.026	-0.023	-0.216	-0.323
38	0.070	0.083	0.138	0.051	0.050	0.038	-0.542	-0.299
39	-0.031	-0.034	-0.078	-0.021	-0.020	-0.018	-0.452	-0.251
40	-0.034	-0.032	-0.064	-0.021	-0.019	-0.018	-0.248	-0.175

The groundwater in the city accumulative and raised by the drain and the water sources then it move noticeably toward the lower elevation in the west and west-south region with some portion move toward the Upper Zab River.

Table 7. Maximum directional velocity (in m/day) between wells

From well no.	To well no.	Velocity (m/day)
1	2	0.142
23	3	0.082
25	4	0.096
5	6	0.115
10	7	0.093
46	8	0.064
9	7	0.084
23	11	0.165
25	12	0.113
25	13	0.144
38	14	0.067
15	11	0.084
20	16	0.105
20	17	0.192
18	11	0.067

38	19	0.091
20	17	0.192
21	17	0.134
38	22	0.138
23	11	0.166
24	11	0.097
25	13	0.144
38	26	0.045
27	47	0.06
28	47	0.06
29	47	0.109
30	47	0.121
49	31	0.086
32	39	0.114
33	34	0.291
35	34	0.384
35	36	0.213
38	39	0.663
38	40	0.2
41	43	0.177
45	42	0.178
46	43	0.191
44	42	0.171
45	42	0.178
46	43	0.191
30	47	0.121
48	49	0.174
48	50	0.094
1	2	0.142
23	3	0.082
25	4	0.096
5	6	0.115

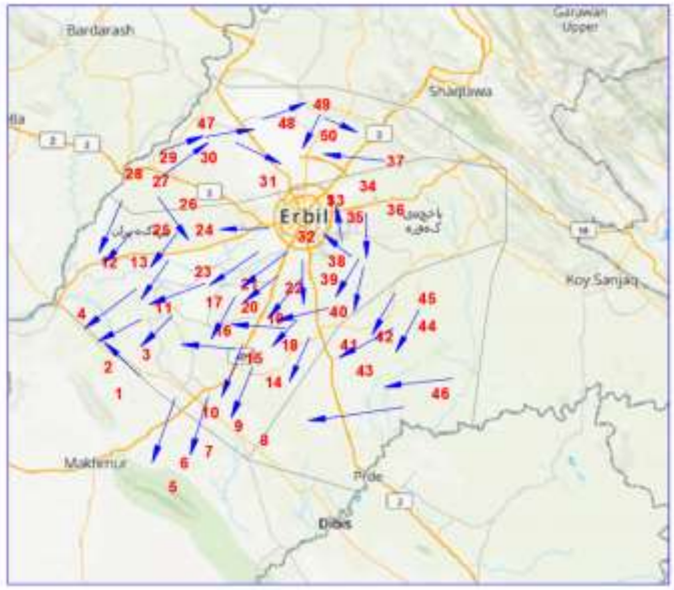


Figure 4. groundwater direction vectors in Erbil basins

5. MODFLOW Work

The MODFLOW application was utilized as a simulator tool to more precisely assign the behavior of groundwater using computerized methods. The research area's region, the earth's elevation, the locations of the wells, and the boundary conditions, which included the elevation of the water tables allotted to each well.

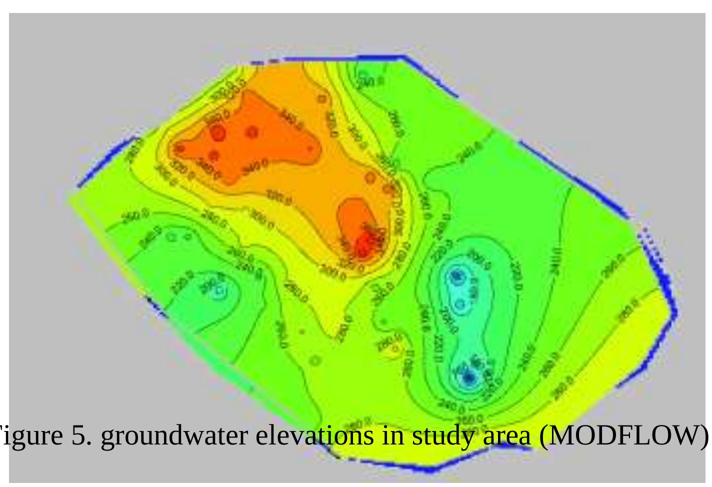


Figure 5. groundwater elevations in study area (MODFLOW)

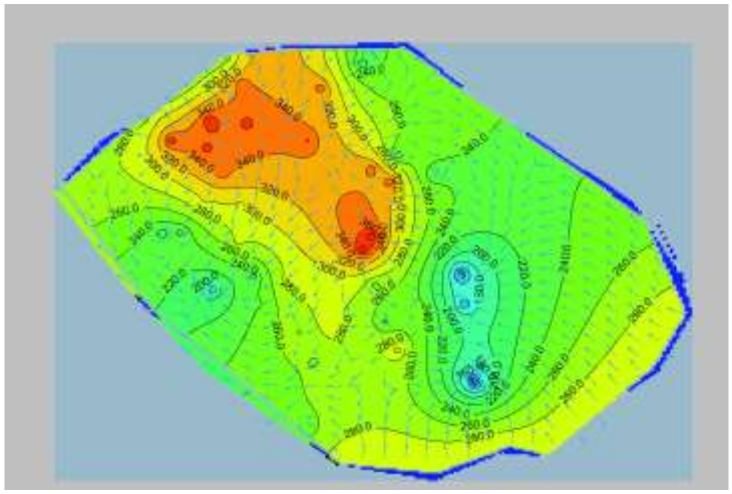
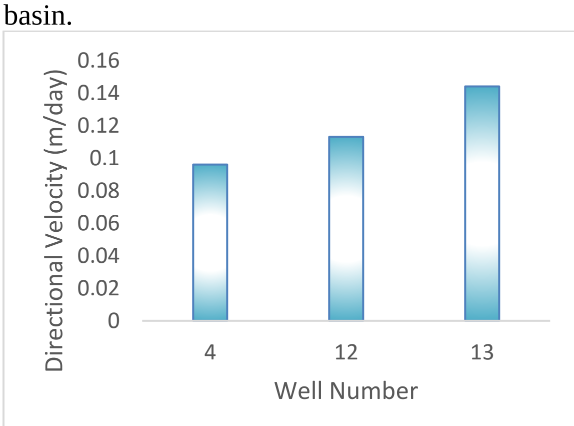


Figure 6. groundwater stream directions in Erbil basins (MODFLOW)

The buildup in the areas close to Erbil City as well as the grade of Change from the Lesser Zab River toward the City and toward the West Regions as the Downstream Zones in the Middle of Iraq. Two streams in the north basin are directed toward the west and connect to the Upper Zab stream. The primary stream in which groundwater gathers and flows into and out of the city toward the western regions is part of the middle basin. The streams from the Lesser Zab that flow toward the city and feed the streams that flow toward the west areas as the downstream region are recharged by the south basin.



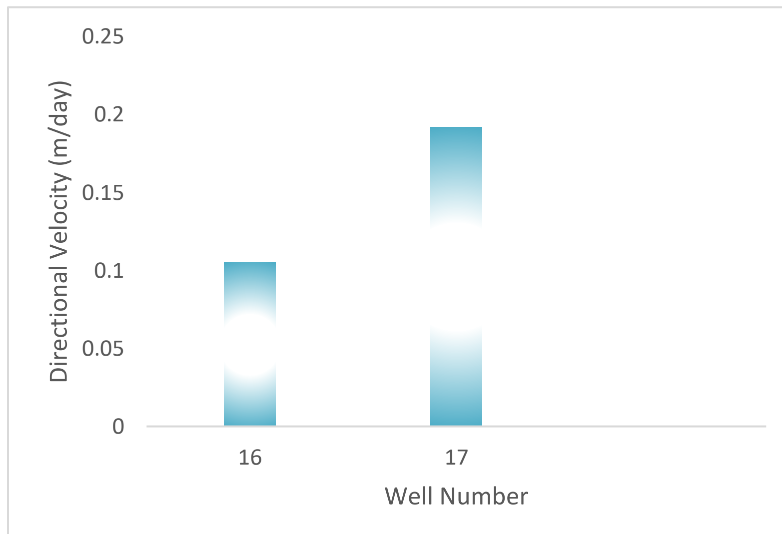


Figure 7. The groundwater velocity toward the wells from well number 25

Figure 8. The groundwater velocity toward the wells from well number 20

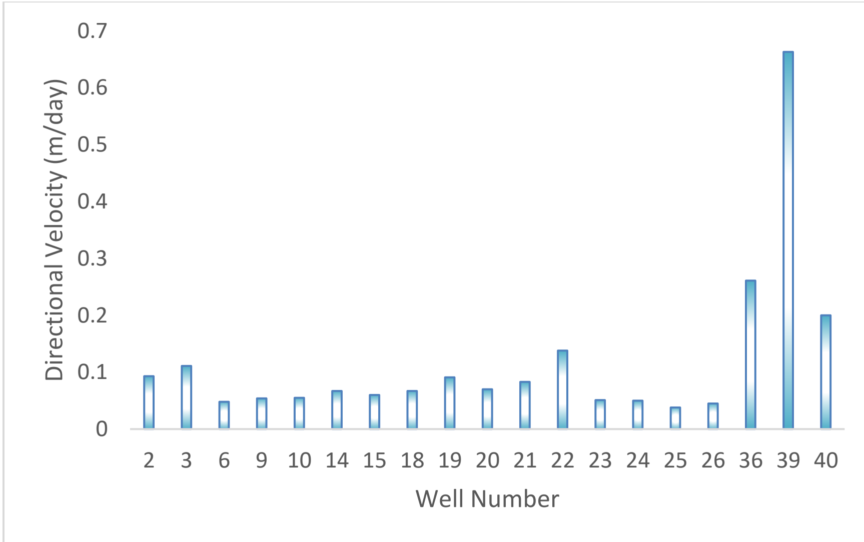


Figure 9. The groundwater velocity toward the wells from well number 38

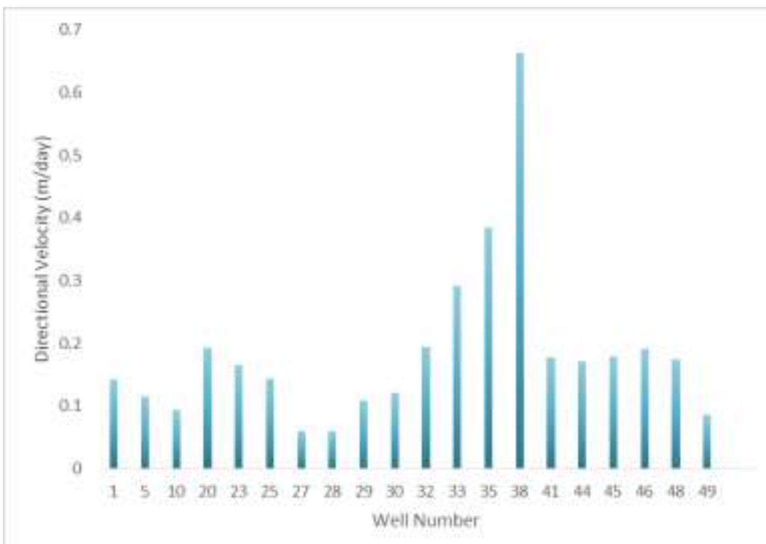


Figure 10. Maximum velocity from well.

4. Conclusion

The region around Erbil city underwent groundwater streamline analysis. The study's data source was the Iraqi Ministry of Water Resources' annual average head measurement. Over the three main basins in the study area, the velocity directions and magnitudes were assessed using the Darcy law (north basin, middle basin, and south basin). According to the study, a stream originates from the Lesser Zab and flows toward Erbil before joining another stream that travels west of the study area to the Tigris River. 50 wells were obtained by the study and were scattered over a wide region inside the study zones. One of the analytical processes included determining the distance between each pair of wells. The groundwater's evaluated flow rates ranged from a few centimeters per day to almost 0.66 meters per day, which were found in the vicinity of the city. The three basins' effects on the nearby water supply are depicted by arrows on a crucial groundwater stream map that was constructed using maximum directional velocities.

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