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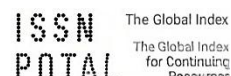
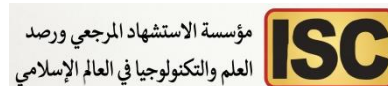
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Spatial and Temporal Variability of Groundwater Aquifer Properties in Eastern Maysan Governorate, Southern Iraq

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Abstract

This research focuses on studying the spatial and temporal variations in the hydrogeological characteristics of groundwater aquifers in eastern Maysan Governorate, including groundwater depth, saturated thickness of aquifers, well discharge, and water flow direction. This helps in understanding the behavior of groundwater aquifers and identifying the most suitable areas for groundwater exploitation. Analysis of data obtained from the archives of the General Authority for Groundwater revealed that the study area is characterized by two types of aquifers: the Quaternary aquifer, which is an unconfined aquifer and the main aquifer in the area, with a saturated thickness ranging from 23 to 47 meters; and the Tertiary aquifer, which is the secondary aquifer with a saturated thickness ranging from 19 to 27 meters. Groundwater flow in the area is from the northeast

towards the western and southwestern parts. Well discharge is high in the northeastern parts compared to the rest of the study area, with fluctuating groundwater depths, especially in the northeastern parts, due to increased extraction. Studying and identifying these characteristics provides a scientific basis for supporting the sustainable management of groundwater and protecting it from depletion.

Keywords: aquifers, wells, Saturated thickness, Characteristics, Groundwater

1. Introduction

Groundwater is essential for life on Earth, and the largest source of fresh water lies under the Earth's surface (Todd & Mays, 2004). Groundwater is also a primary source of water for irrigation, domestic uses, and industrial purposes in arid and semi-arid regions (Sahu et al., 2013). With the increase in population and demand for water resources, groundwater resources have been depleted in many countries (Graaf et al., 2019; Feng et al., 2018; Liu et al., 2001; Scanlon et al., 2012). As a

result, many problems have occurred, such as falling groundwater levels (Huang et al, 2023), land subsidence (Ghalib, 2017; Gong et al., 2018), saltwater intrusion (Sherif and Singh, 1999), and decreased food production (Tamea et al, 2016). Studying and identifying hydrogeological characteristics is crucial in groundwater exploitation due to their key role in understanding aquifer behavior (Wahab & Al-Abadi, 2025). These hydrogeological characteristics, such as saturated thickness, aquifer pumping capacity, groundwater flow direction, and groundwater depth, provide clear insights into the potential for highly efficient groundwater exploitation (Fetter, 2001).

The eastern and northeastern parts of Maysan Governorate depend entirely on groundwater and rainwater (Hashoosh et al., 2021), with the presence of two intermittent rivers, the Teeb and the Dewereg (Abdul-Razzak & Al-Neif, 2022). The data available in the records of the General Authority for Groundwater indicates that the region is characterized by the presence of two aquifers, one of which is a confined aquifer within the Tertiary deposits (Al-Maqdadi and Bay Hassan Formation), and is a secondary aquifer, and a primary aquifer within the Quaternary deposits, which is of the unconfined type, forming a high thickness in the eastern parts within the alluvial fan deposits, and which depends on local recharge from rainfall and floodwaters during the winter season (Al-Ghanimy et al, 2019; Al-Jaburi, 2005; Bashu et al., 2004).

Due to the increasing demand for groundwater resulting from the expansion of agricultural land, many wells have been drilled, which has negatively impacted groundwater levels in some areas, especially the northeastern regions. Also, under the drought conditions in Iraq, it has become possible to determine or calculate hydrogeological characteristics of groundwater aquifers to the east of Maysan Governorate to manage groundwater optimally and invest it optimally

2. The Study Area

The study area is located in east and northeastern Missan governorate, southern Iraq, between the latitudes of (32° 0'0"-32°30'0"N) and the longitudes of (46°30'0" -47°30'0"). The study area occupies an area of about 3180 km². It is bordered to the north by Wasit Governorate, to the east by the Islamic Republic of Iran, and to the west by the Tigris River fig. (1). The major parts of the study area are flat and low relief with a few isolated hills (Hamrin Hills) (Parsons, 1955). Three-quarters of the study area has a gentle slope and represents the southwestern parts of the study area. The remaining quarter is located in the eastern and northeastern parts and extends along the Iranian border, and is interspersed with low convex folds interspersed with syn-valleys (Barwary, 1993; Maarooof & Kareem, 2022). The elevation in the study area ranges from 14 to 270 meters above sea level, figure (2). The surface elevations of the study area decrease from northeast to southwest. The topographic elevation is derived from digital elevation models (DEM) obtained from the website (<https://opentopography.org>). The area is crossed by two rivers, the Teeb and the Duwairij. Both originate in Iranian territory. Surface drainage is characterized by an intermittent flow regime due to the long dry period. The discharge of the Duwairij River is high

only during the rainy season and nonexistent on other days. The discharge of the Teeb River is also high during the rainy season and low on other days, not exceeding $3\text{-}5\text{ m}^3/\text{s}$. Due to the deficiency of surface water resources, groundwater is the main resource in the study area.

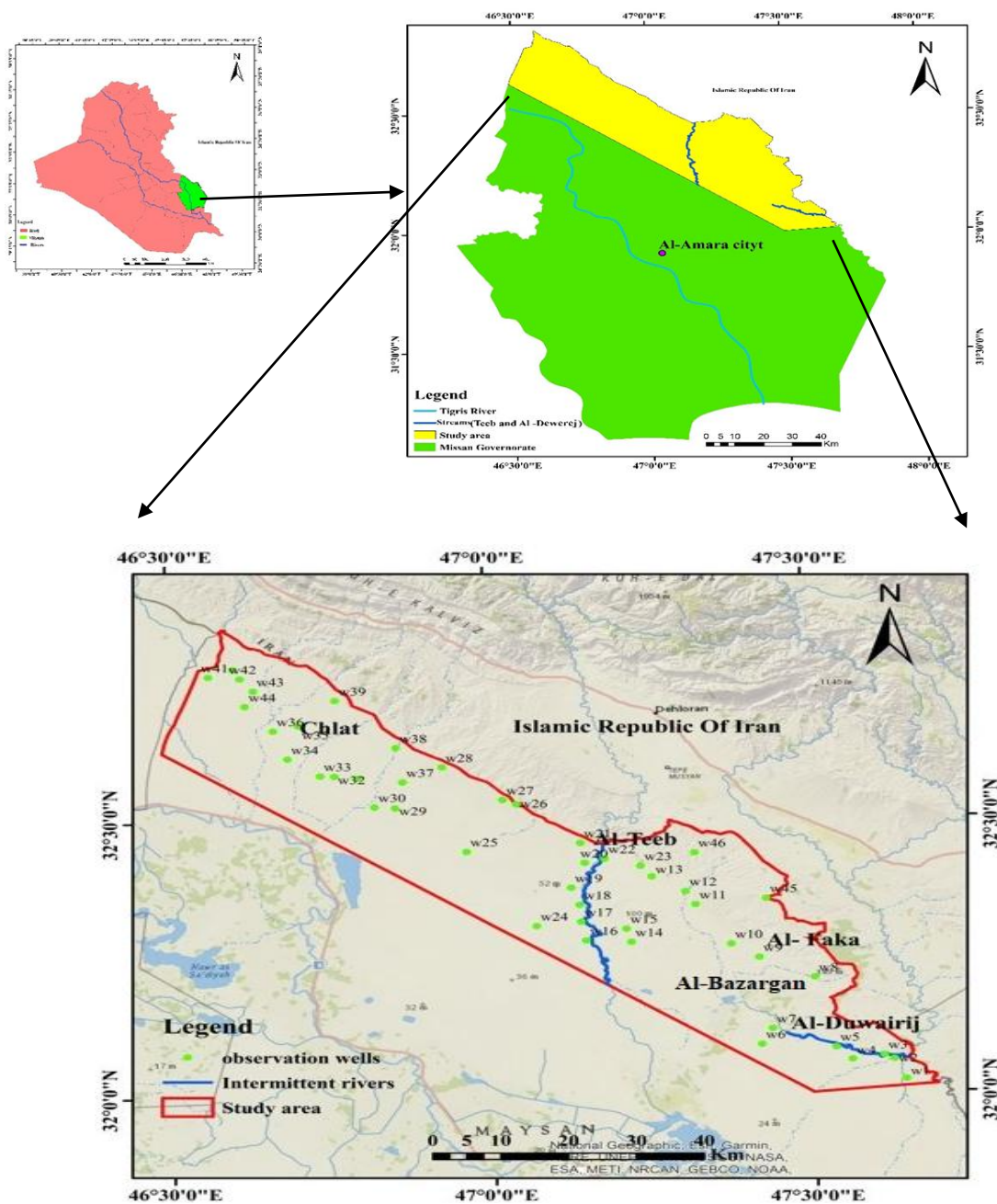


Fig. 1. Location of the study area

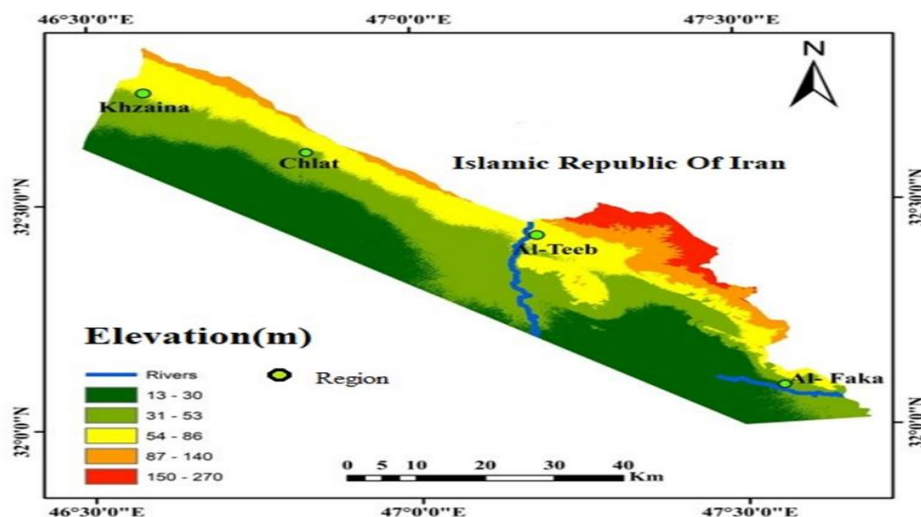


Fig. 2. Elevation of the study area.

The study area represents the eastern parts of the sedimentary plain (Abdulnaby et al., 2021) which consists of Quaternary (Holocene-Pleistocene) sediments and Tertiary rocks (Pliocene – Miocene), (Barwary, 1993; GEOSURVE, 1993; Jassim & Goff, 2006), (83%) from the northern, western and southwestern parts with a total area of 2622.15 km² covered by Quaternary sediments. (17%), which are exposed in the eastern and southeastern areas of the Al-Teeb area and with an area of 543 km² represents the deposits of the Tertiary period (Mukdadiyah and Bai Hassan formations) in the study area, (Al-Jaburi, 2005; Al-Saady et al., 2013) Fig(3)

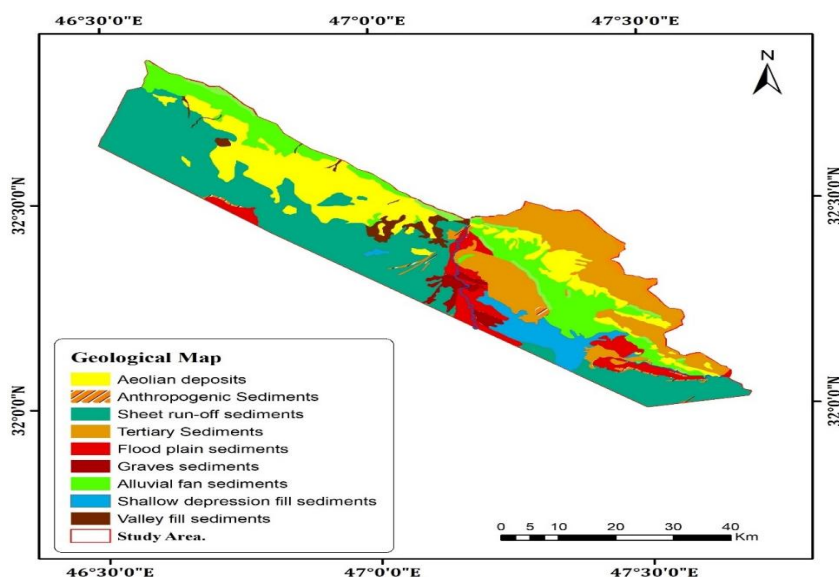


Fig. 3. Geological map of the study area

3. Methodology

3.1 Type of aquifers

To understand groundwater management, it is essential to define the aquifer. This is achieved by studying the structure of aquifers through the construction of a geological model after examining their hydraulic properties. Therefore, establishing a geological model of the aquifer is a crucial step in most hydrogeological studies. This requires subsurface information obtained from well lithological archives and geophysical data. Constructing a conceptual or geological model of the aquifer structure is beneficial for various purposes, most importantly, identifying an aquifer and building a numerical model of groundwater flow. Erosional data obtained from well drilling periods in specific or defined strata is prone to errors, including (Al-Abadi & Al-Shamma'a, 2014).

- The mixture of sediments recovered from the surface during drilling.
- The transition from one geological unit to another may be unclear.
- The poor quality of many groundwater well data points is due to insufficient training for well drillers in identifying sediment types. Despite these facts, this is the only way to develop model concepts for aquifer units in the study area, given the lack of information technologies such as geophysical data.

Based on the selected analysis method from the archives of drilled wells in the study area (12 wells), these were obtained from the records of the General Authority for Groundwater/Ministry of Water Resources and previous studies, table (1), table (2), and table (3). The study area can be practically divided into two sections: Quaternary and Tertiary deposits (Al-Muqdadiyah and Bay Hassan).

The geological records of these wells were used to design the aquifer system by drawing three cross-sections, one to link the Tertiary layers and two to link the Quaternary layers. Because these wells have a nearly complete record and an even distribution throughout the area, and according to this information, the aquifer system within the area is divided into two layers: the main (unconfined) aquifer (Quaternary aquifer), and the deep (confined) aquifer (Tertiary aquifer), (Figures 4 and 5)

Table (1) Selected wells cross-section(A-A') drawing of Tertiary layers

Well no.	Coordinate		Depth (m)
	X	Y	
W1	742342	3553693	89
W2	727236	3589877	130
W3	717921	3591690	120
W4	706149	3593216	80

Table (2) Selected wells cross-section(A-A') drawing of Quaternary layers

Well no.	Coordinate		Depth (m)
	X	Y	
W1	693197	3575981	112

W2	718899	3578041	58
W3	734465	3550598	29
W4	740851	3548865	21

Table (3) Selected wells cross-section(B-B') drawing of Quaternary

Well no.	Coordinate		Depth (m)
	X	Y	
W1	696117.26	3595338.87	82
W2	678535	3604849	75
W3	654944	3615546	34
W4	648525	3622854	46

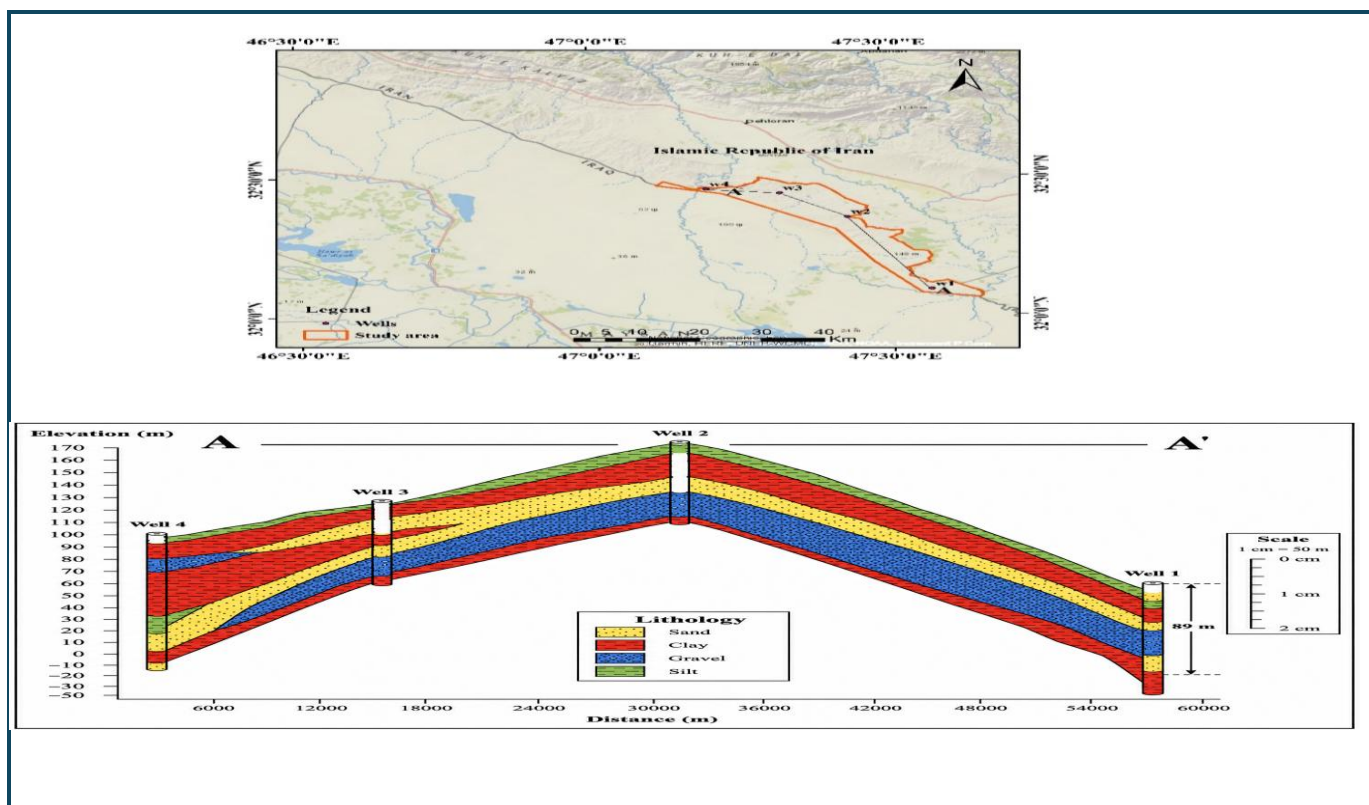


Fig. (4): Selected cross sections in the study area (Tertiary period)

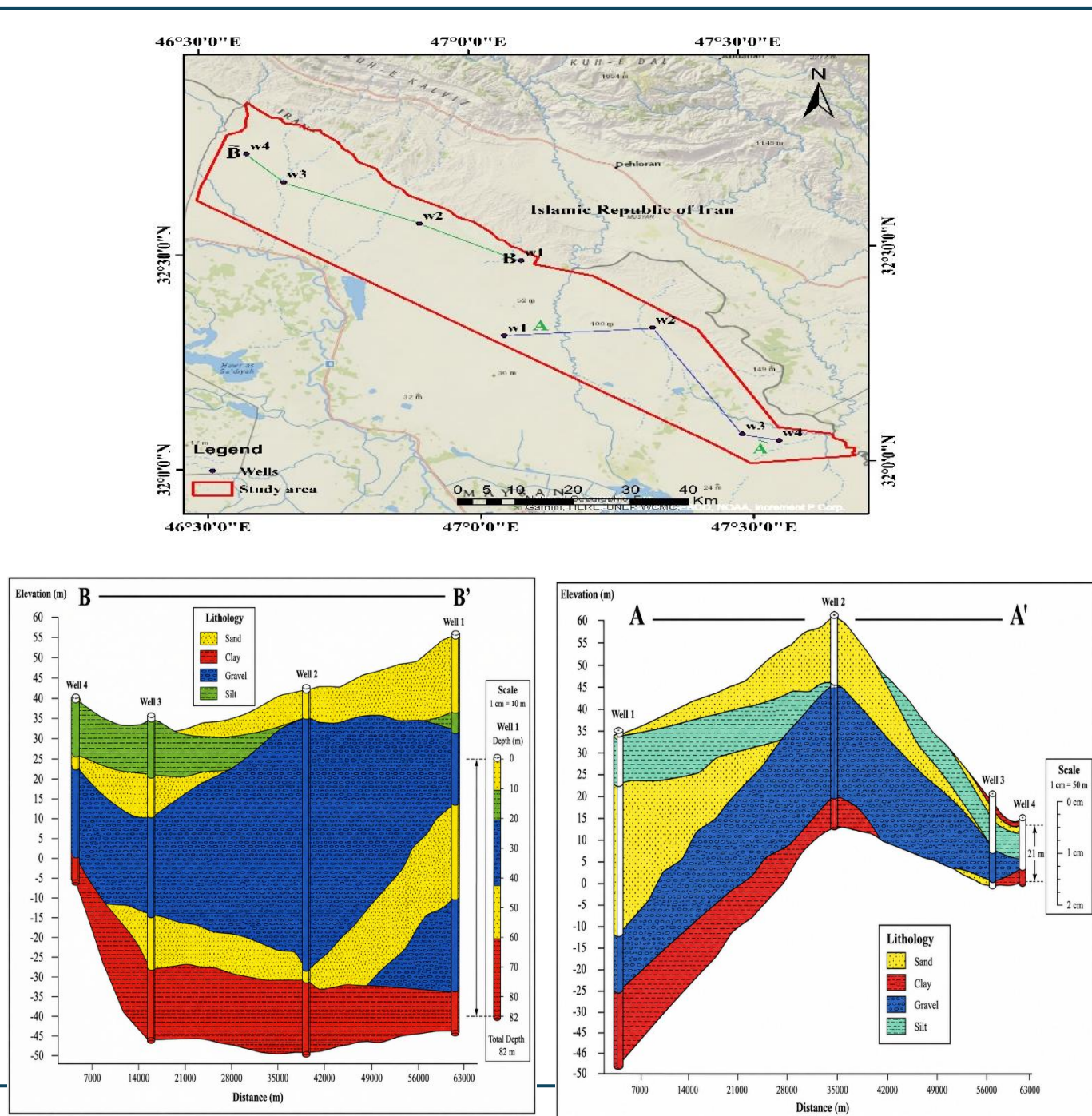


Fig. (5): Selected cross sections (A-A' and B-B') in the study area (Quaternary period)

1-Tertiary aquifer

The Tertiary aquifer extends within the Tertiary deposits of the Muqadadiyah-Bay Hassan formations, which are characterized by a varying thickness depending on the gravel, sand, and sandy gravel layers. The aquifer is of the confined type; saturated thickness ranges between 19 and 27 meters and is characterized by moderate productivity, ranging between 4 and 8 l/s, and good water quality, where the total dissolved solids (TDS) range between 400 and 1000 mg/L (Al-Kaabi, 2009). The depths of drilled groundwater wells range between 80 and 130 m (General Authority for Groundwater, Branch Maysan) unpublished data.

2-Quaternary aquifer

The quaternary aquifer extends within the quaternary deposits (sand and gravel) (Jassim and Goof, 2006), which are characterized by a varying thickness depending on the gravel and sand layers. The aquifer is of the unconfined type; saturated thickness ranges between 23 to 47 meters and is characterized by moderate productivity ranging between 12 and 26 l/s and brackish to salt water, where the total dissolved solids (TDS) range between 500 to 7000 mg/L (Al-Jaburi, 2005). The depths of drilled groundwater wells range between 40 and 85 m (General Authority for Groundwater, unpublished data) unpublished data.

4. Results and Discussion

4.1 Saturated thickness of aquifers(b)

The aquifers in the study area consist of Tertiary and Quaternary period sediments, as indicated by the wells drilled within the study area and available in the records of the General Authority for Groundwater, Maysan Branch/Ministry of Water Resources. The saturated thickness of the aquifer is calculated by determining the thickness of the coarse sedimentary layers below the static water level through lithological analysis of wells drilled in the study area.

The stratigraphic sequence of these wells shows that coarse sediments (gravel and sand) extend along the eastern and northeastern parts of the study area and gradually decrease towards the western and southern parts. Therefore, the thickness of the reservoir in the northeastern parts is higher than the rest of the study area. Through Table (4), the thickness of the aquifer during the Tertiary period (Al-Muqadadiyah and Bai Hassan formations) ranges between 19 and 27 m in the eastern and southeastern parts.

In the northern, northeastern, western, southern, and some central parts of the region, represented by Quaternary sediments, the thickness of the reservoir ranges between 23 and 47 m. The average thickness of the aquifer during this period is 35 m.

Table (4): Saturation thickness (b) in the study area.

Well no.	X	Y	b(m)	Well no.	X	Y	b(m)	Well no.	X	Y	b(m)
W1	674609	3600369	34	W19	648231	3631038	42	W37	668761	3605435	30
W2	678024	3605571	45	W20	656552	3629983	55	W38	748194	3548790	50
W3	681440	3608131	41	W21	669816	3609036	30	W39	744351	3552399	31

Well no.	X	Y	b(m)	Well no.	X	Y	b(m)	Well no.	X	Y	b(m)
W4	670412	3608162	41	W22	679496	3608740	44	W40	710405	3585678	32
W5	658312	3614885	33	W23	650220	3633027	52	W41	705011	3590065	33
W6	659750	3616528	25	W24	681495	3608665	47	W42	724268	3586427	18
W7	655819	3616826	33	W25	717074	3579481	50	W43	725633	3584005	20
W8	652098	3620644	35	W26	684734	3591406	24	W44	728977	3582062	17
W9	656255	3615484	33	W27	699210	3595837	40	W45	692030	3601021	25
W10	652182	3622805	35	W28	727260	3590041	22	W46	701464	3593238	33
W11	653446	3624753	43	W29	717674	3584128	38	W47	744450	3553651	12
W12	652519	3624942	43	W30	735692	3554241	27	W48	708404	3575751	34
W13	651277	3626127	41	W31	748134	3550212	50	W49	713404	3587430	39
W14	650191	3627361	40	W32	678024	3605571	55	W50	736075	3566378	30
W15	665187	3621907	53	W33	674609	3600369	25	W51	683894	3592525	27
W16	674214	3612390	55	W34	656255	3615484	30	W52	718299	3591352	22
W17	646613	3626442	34	W35	651277	3626127	50				
W18	648426	3622209	29	W36	661063	3616549	18				

4.2 Depth of Groundwater

The groundwater static levels time-series analysis for 46 wells (Table 5, Figure 1). during the monitoring periods from August 2024 to July 2025 shows fundamental spatial and temporal changes in groundwater behavior across the study area. Through the Table6 and Figure (6) shows that several wells show relatively stable water levels throughout the monitoring period, indicating a balance between recharge and withdrawal rates. Wells W1, W4, W6, W8, W12, W16, W18, W21, W22, W23, W24, W25, W27, W28, W30, W39, W45, and W46 show some fluctuations over time. This shows stable hydrogeological conditions and that these wells are located within confined or semi-confined aquifer zones with very low withdrawals. This reflects a balance between recharge and pumping rates.

However, some wells show gradual increases in their water levels, suggesting that groundwater withdrawal rates have increased. Wells W2, W3, W9, W11, W13, W15, W20, W26, W32, W33, W38, and W42 exhibited convergent groundwater levels. In contrast, several wells experienced moderate to sharp fluctuations in groundwater levels, characterized by significant rises and falls. This reflects local hydrogeological issues in the aquifer and increased withdrawal rates due to agricultural activities during the winter. Wells W5, W10, W14, W17, W19, W29, W34, W35, W36, W37, W40, W43, and W44 exhibited irregular groundwater behavior during the monitoring period.

Several wells also showed a decrease in groundwater levels during the monitoring period, which may indicate a reduction in groundwater extraction relative to recharge rates in some parts of the aquifer. Wells W17, W24, W35, W37, W40, and W44 recorded significant decreases in groundwater levels during their monitoring period. The spatial variation in groundwater levels in the monitored wells from W1 to W46 reflects the heterogeneous nature of the aquifer system, in terms of rock composition, aquifer thickness, hydraulic characteristics, recharge rates, and agricultural activities.

The topographical setting of the area (elevation above sea level and slope) a significant impact on groundwater movement. Therefore, groundwater flows from areas with high hydraulic head to areas with low hydraulic head, resulting in groundwater movement from the northeastern and eastern parts towards the western and southwestern parts. Well productivity varies depending on hydrogeological factors such as the thickness of the aquifer and annual recharge rates; therefore, it is higher in the northeastern parts than in the rest of the parts.

Table (5): Data of observation wells in the study area

Well no.	S.W.L 2024/8	S.W.L 2024/9	SWL 2024/10	SWL 2024/11	SWL 2024/12	S.W.L 2025/1	S.W.L 2025/2	S.W.L 2025/3	S.W.L 2025/4	S.W.L 2025/5	S.W.L 2025/6	S.W.L 2025/7
1	10.48	10.41	10.50	10.51	10.53	10.54	10.56	10.54	10.52	10.53	10.54	10.55
2	10.45	10.60	10.82	10.90	10.97	11.23	11.16	11.19	11.12	11.20	11.10	11.11
3	10.70	10.57	10.66	10.66	10.72	10.84	10.96	10.88	10.88	10.86	11.80	11.88
4	8.67	8.67	8.67	8.65	8.67	8.67	8.66	8.66	8.65	8.66	8.67	8.67
5	8.67	8.45	8.50	8.54	8.55	8.56	8.52	8.53	8.53	8.54	8.53	8.55
6	4.5	4.33	4.35	4.35	4.35	4.36	4.35	4.37	4.36	4.35	4.34	4.35
7	3	3.27	3.30	3.30	3.31	3.31	3.32	3.29	3.27	3.26	3.26	2.27
8	8.90	9.11	9.15	9	9	9	9	9	9.05	9.02	9	9
9	5.27	5.29	5.32	5.30	5.30	5.33	5.35	5.36	5.36	5.37	5.36	5.38
10	4.42	4.53	4.60	4.62	4	4.80	4.73	5.22	5.36	4	4.03	4.10
11	15.92	15.94	16	16.03	16.04	16.16	16.11	16.31	16.44	16.51	16.48	16.49
12	14.66	14.70	14.72	14.70	14.70	14.72	14.70	14.70	14.71	14.70	14.70	14.75
13	20.39	20.42	20.42	20.45	20.67	20.70	20.72	20.73	20.73	20.73	20.71	20.74
14	4.92	5.7	5.12	5.11	5.14	5.6	5.6	5.5	5.4	5.4	5.28	5.30
15	3.30	3.30	3.30	3.40	3.44	3.45	3.44	3.69	3.52	3.67	3.60	3.62
16	11.42	11.44	11.45	11.29	11.40	11.43	11.42	11.42	11.40	11.41	11.41	11.46
17	9.27	9.30	9.32	9.28	9.23	9.14	9.11	8.99	8.97	8.95	9.10	9.12
18	6.70	6.80	6.83	6.36	6.88	6.76	6.76	6.66	6.58	6.55	6.67	6.69
19	4.50	4.66	4.70	4.74	4.74	4.64	4.64	4.53	4.52	4.50	4.69	4.51
20	6.19	6.35	6.40	6.52	6.45	6.38	6.40	6.31	6.18	6.14	6.57	6.59
21	11.75	11.90	11.93	12.05	12.07	12.11	12.13	12.13	12	11.99	12.11	12.12
22	10.70	10.73	10.93	11	11	11.10	11.11	11	11.2	11	11	11.05
23	27.50	27.60	27.57	27.40	27.57	27.58	27.59	27.57	27.55	27.54	27.63	27.66
24	4.87	4.68	4.70	4.72	4.73	4.66	4.67	4.53	4.50	4.52	4.52	4.53
25	1.20	1.22	1.24	1.20	1.22	1.23	1.26	1.24	1.22	1.20	1.21	1.22
26	57.70	57.08	57.17	57.38	57.40	57.60	57.62	57.60	58.18	58.12	58	58.03
27	50.30	50.45	50.47	50.50	50.50	50.55	50.59	50.57	50.52	50.50	50.49	50.51
28	48	47.80	48	48.04	48.03	48.06	48.10	48.07	48.40	48.42	48.44	48.48
29	5.70	5.40	5.86	5.87	5.88	6.17	6.16	9.10	8.58	6.14	6	6.02
30	3.92	4	3.93	3.95	3.90	3.94	4.02	4.03	4.09	4.04	4	4.03
31	4.95	4.85	5.78	5	4.95	4.96	5.03	5.04	5.03	5.04	5.10	5.12
32	5.30	5.35	5.23	5.27	5.17	5.34	5.69	5.52	5.61	5.45	5.47	5.49
33	3.25	3.31	3.48	3.50	3.45	3.46	3.95	3.82	4.15	3.74	3.81	3.83
34	4.43	4.43	4.45	4.72	8.17	11.85	11.87	8.18	6.15	5.73	5.75	5.77
35	23.85	25.70	24.29	25.26	26.11	26.13	26.15	25.84	22.35	20	20.06	20.07
36	12.45	12.38	12.22	13.55	14	14.15	23.97	23.30	23.15	16.46	16.49	16.52

37	12.25	12.22	12.20	14.16	16.22	18.34	18.40	18.19	17.10	16.11	13.20	13.22
38	17.15	17.20	17.40	17.56	18.10	20.11	20.12	20.71	20.3	18.88	18.48	18.55
39	27.30	27.32	27.37	27.42	27.50	27.50	27.48	27.47	27.39	27.35	27.43	27.37
40	15.4	15.6	15.30	17.88	18.89	18.91	18.86	18.88	18.49	17.44	16.09	16.14
41	13	13.10	13.9	13.22	13.26	13.48	13.44	13.47	13.81	13.66	13.21	13.24
42	17.50	17.57	17.61	18.10	21.22	22.6	23.11	24.28	23.36	19.11	19.10	19.12
43	18.25	18.24	18.20	19.7	19.91	21.28	22.5	23.11	22.5	20.17	19.16	19.18
44	14.43	14.44	14.39	16.19	19.16	22.36	22.87	23.16	21.84	21.92	20.75	19.21
45	64.48	64.47	64.49	64.50	64.48	64.51	64.51	64.51	64.53	64.59	65.58	64.53
46	20.70	20.72	20.70	20.80	20.80	20.77	20.77	20.72	20.78	20.70	20.75	20.75

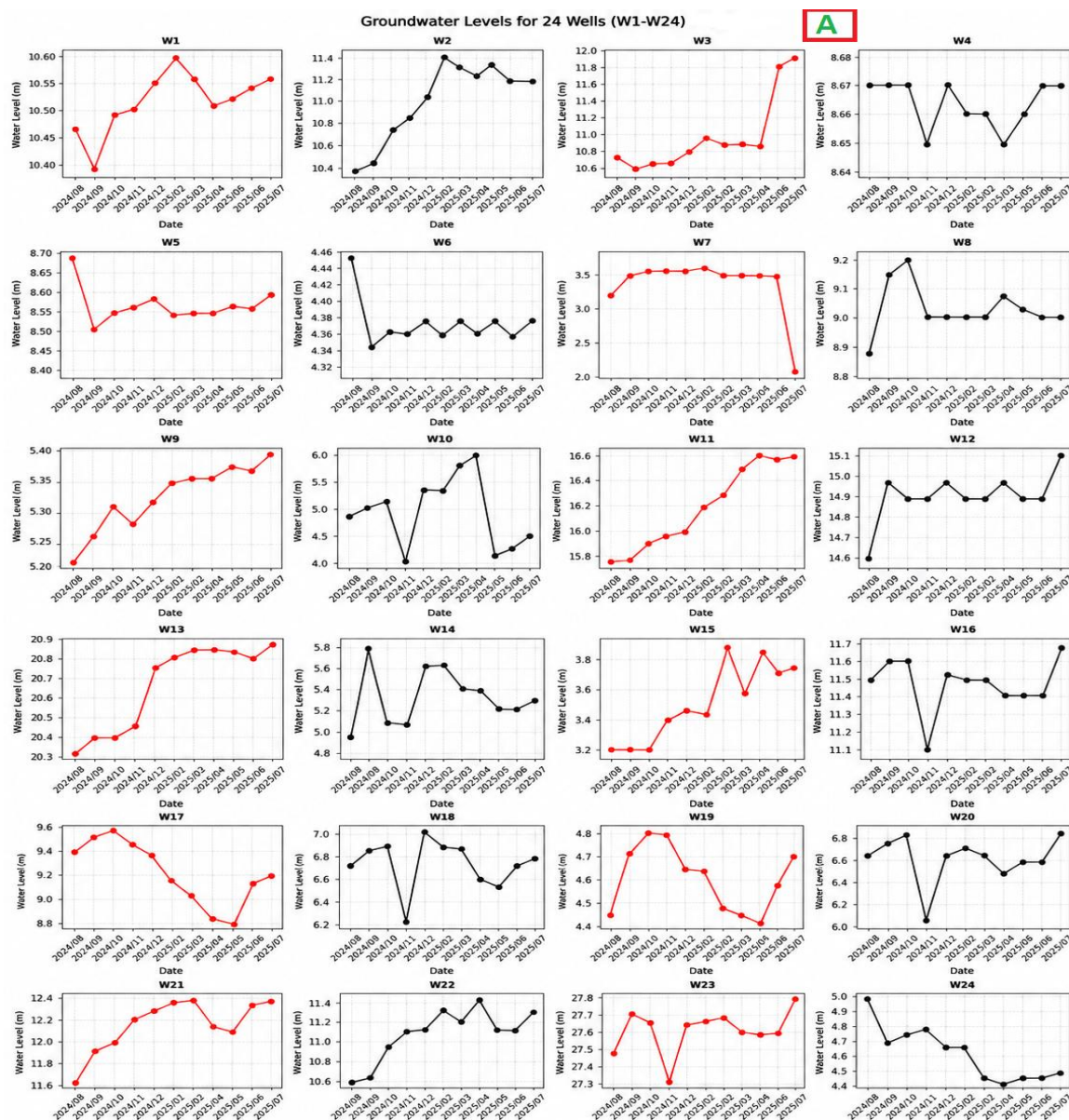


Figure (6): (A)Groundwater levels in the study area, wells (w1 -w24)

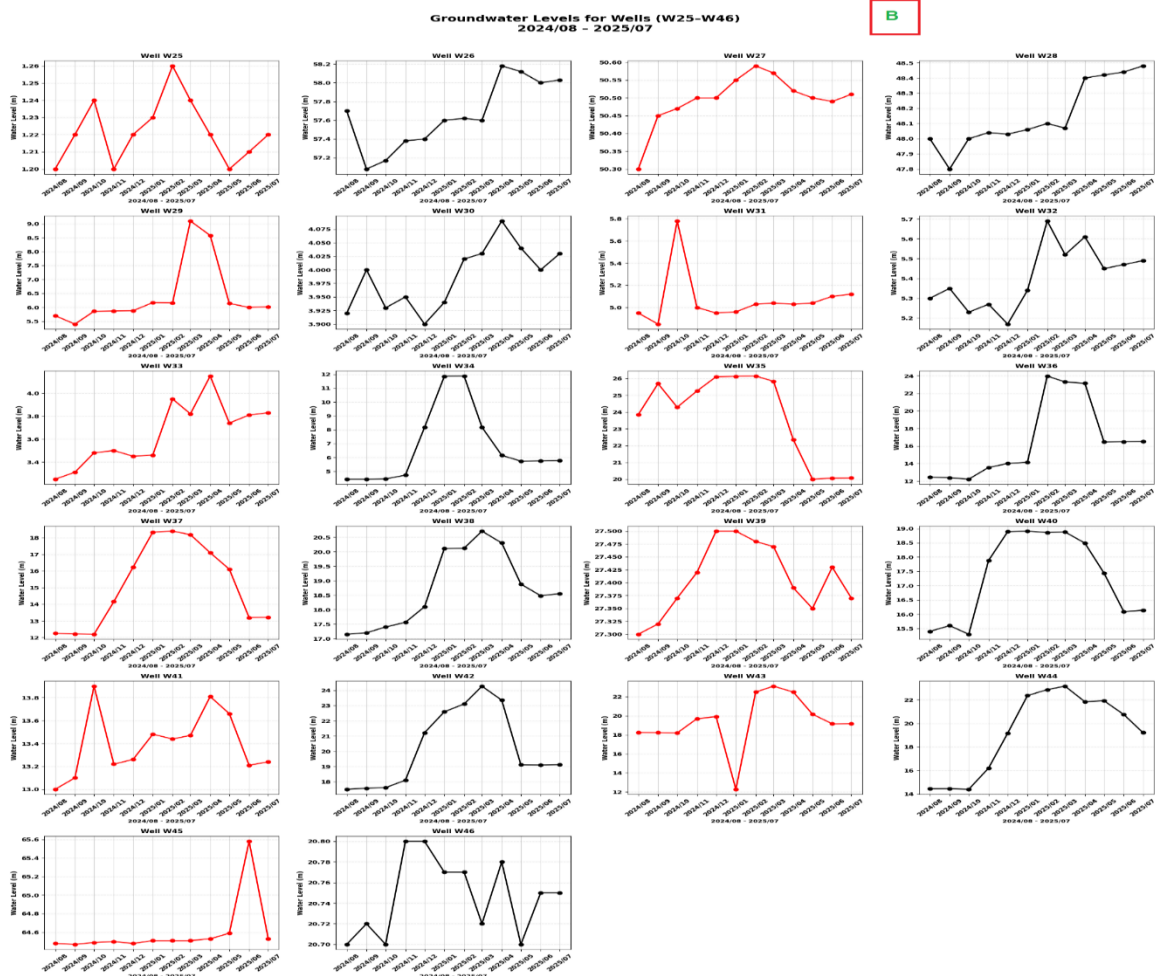


Figure (6): (B)continue...., wells(w25-w46)

Table (6): Statistical Analysis of Temporal Variations in Static Water Levels (SWL)

Well	Initial SWL (m)	Final SWL (m)	Absolute Change (m)	Relative Change (%)	Interpretation
W1	10.48	10.55	0.07	0.67	Stable
W2	10.45	11.11	0.66	6.32	Moderate groundwater level decline
W3	10.7	11.88	1.18	11.03	High groundwater level decline
W4	8.67	8.67	0	0	Stable
W5	8.67	8.55	-0.12	-1.38	Stable
W6	4.5	4.35	-0.15	-3.33	Slight groundwater level recovery
W7	3	2.27	-0.73	-24.33	Groundwater level recovery
W8	8.9	9	0.1	1.12	Stable
W9	5.27	5.38	0.11	2.09	Slight groundwater level decline
W10	4.42	4.1	-0.32	-7.24	Groundwater level recovery

Well	Initial SWL (m)	Final SWL (m)	Absolute Change (m)	Relative Change (%)	Interpretation
W11	15.92	16.49	0.57	3.58	Slight groundwater level decline
W12	14.66	14.75	0.09	0.61	Stable
W13	20.39	20.74	0.35	1.72	Stable
W14	4.92	5.3	0.38	7.72	Moderate groundwater level decline
W15	3.3	3.62	0.32	9.7	Moderate groundwater level decline
W16	11.42	11.46	0.04	0.35	Stable
W17	9.27	9.12	-0.15	-1.62	Stable
W18	6.7	6.69	-0.01	-0.15	Stable
W19	4.5	4.51	0.01	0.22	Stable
W20	6.19	6.59	0.4	6.46	Moderate groundwater level decline
W21	11.75	12.12	0.37	3.15	Slight groundwater level decline
W22	10.7	11.05	0.35	3.27	Slight groundwater level decline
W23	27.5	27.66	0.16	0.58	Stable
W24	4.87	4.53	-0.34	-6.98	Groundwater level recovery
W25	1.2	1.22	0.02	1.67	Stable
W26	57.7	58.03	0.33	0.57	Stable
W27	50.3	50.51	0.21	0.42	Stable
W28	48	48.48	0.48	1	Stable
W29	5.7	6.02	0.32	5.61	Moderate groundwater level decline
W30	3.92	4.03	0.11	2.81	Slight groundwater level decline
W31	4.95	5.12	0.17	3.43	Slight groundwater level decline
W32	5.3	5.49	0.19	3.58	Slight groundwater level decline
W33	3.25	3.83	0.58	17.85	High groundwater level decline
W34	4.43	5.77	1.34	30.25	High groundwater level decline
W35	23.85	20.07	-3.78	-15.85	Groundwater level recovery
W36	12.45	16.52	4.07	32.69	High groundwater level decline
W37	12.25	13.22	0.97	7.92	Moderate groundwater level decline
W38	17.15	18.55	1.4	8.16	Moderate groundwater level decline
W39	27.3	27.37	0.07	0.26	Stable
W40	15.4	16.14	0.74	4.81	Slight groundwater level decline
W41	13	13.24	0.24	1.85	Stable
W42	17.5	19.12	1.62	9.26	Moderate groundwater level decline
W43	18.25	19.18	0.93	5.1	Moderate groundwater level decline
W44	14.43	19.21	4.78	33.13	High groundwater level decline
W45	64.48	64.53	0.05	0.08	Stable
W46	20.7	20.75	0.05	0.24	Stable

4.3 Groundwater head or Hydraulic head (h)

Hydraulic head (h) is a fundamental physical quantity in groundwater hydrology. It represents the total mechanical energy per unit weight of water at a specific location within an aquifer or groundwater system. The hydraulic head determines the direction and rate of groundwater flow—water moves from regions of high head to low head. Measurement and analysis of hydraulic head are essential for effective groundwater management (Freeze & Cherry, 1979).

The hydraulic head is calculated in monitoring wells or piezometers by subtracting the measured depth to the water level from the surveyed elevation of the top of casing. According to the formula:

$H = \text{Elevation of top of casing} - \text{depth to water in the well (S.W.L)}$

Based on the values of Table 7, a map of the groundwater hydraulic head for the study area was drawn after detaining the hydraulic head figure (7b). Table (6) shows that the hydraulic head increases in the study area in the eastern part along the Hamrin Hills and decreases in the southern and western parts. The minimum value of groundwater depths in the study area reached 12 meters, while the maximum value reached 117 meters.

Table (7): Values of hydraulic head in the study area.

Well no.	H(m)	Well no.	H(m)	Well no.	H(m)	Well no.	H(m)
1	25	13	48	25	29	37	32
2	30	14	38	26	44	38	48
3	22	15	36	27	46	39	60
4	23	16	28	28	46	40	44
5	19	17	34	29	19	41	45
6	12	18	39	30	22	42	42
7	24	19	42	31	30	43	42
8	52	20	50	32	23	44	32
9	28	21	49	33	19	45	86
10	31	22	48	34	20	46	117
11	46	23	38	35	24		
12	55	24	31	36	25		

4.4 Groundwater flow system

The water in groundwater systems is always in motion. Groundwater flows from recharge areas (areas of high hydraulic heads) to discharge areas (areas of low hydraulic heads), (Tóth, 1963). Movement of groundwater takes place whenever a difference in total head exists between two points. Thus, water moves from the location of high total head to locations of low total head. Water in confined aquifers can move from low-pressure areas to high -pressure areas (Sterrett, 2007).

Through the data of the hydraulic head values in Table 6 for drawing a contour map in the ArcGIS program, the movement of groundwater in the study area is north and northeast towards the west and southwest of the area, and figure (7b).

4.5 Wells discharge rate

49 wells were selected; Table 8 and the discharge of these wells was determined. The productivity of these wells ranged between (4-26 l/s), the northern and northeastern parts of the study area, and some of the central parts (Um- Seil area), and part of the Al-Faka area are characterized by high productivity, as these areas represent alluvial fan deposits (Quaternary period), (Bashu, 2004). Figure (7c) shows the discharge of wells in the study area.

Table (8): The values of wells discharge (l/s) in the study area.

Well no.	X	Y	Q	Well no.	X	Y	Q	Well no.	X	Y	Q
W1	699210	3595837	5	W18	736526	3556157	13	W35	681440	3608131	13
W2	727260	3590041	5	W19	732189	3549930	8	W36	674265	3612292	13
W3	717674	3584128	13	W20	728297	3552828	8	W37	666958	3612706	13
W4	717074	3579481	26	W21	736075	3566378	5	W38	664895	3617822	19
W5	735692	3554241	8	W22	723739	3573013	19	W39	653236	3623637	26
W6	748134	3550212	26	W23	709048	3573333	5	W40	648280	3630934	26
W7	678024	3605571	26	W24	710807	3570968	8	W41	658333	3609968	26
W8	674609	3600369	5	W25	708404	3575751	8	W42	673723	3608318	26
W9	656255	3615484	19	W26	702381	3573604	8	W43	681666	3601991	26
W10	651277	3626127	26	W27	710405	3585678	13	W44	701821	3577811	8
W11	661063	3616549	13	W28	713404	3587430	19	W45	701418	3580764	8
W12	668761	3605435	8	W29	718299	3591352	5	W46	702769	3582628	5
W13	748861	3546497	8	W30	705011	3590065	13	W47	705204	3585375	19
W14	744351	3552399	13	W31	689809	3598290	19	W48	706692	3589142	13
W15	744425	3550602	19	W32	701464	3593238	5	W49	709525	3589367	8
W16	744450	3553651	4	W33	692030	3601021	5				
W17	740737	3551306	13	W34	684734	3591406	8				

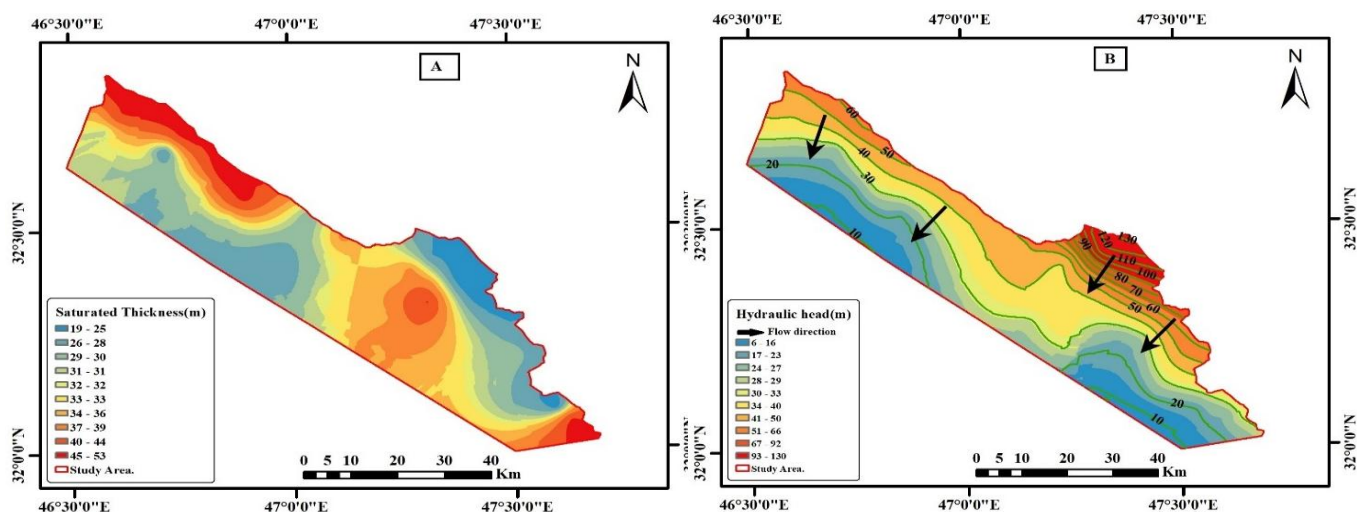


Figure (7): (a)Saturated thickness, (b)Hydraulic head with Flow direction in the study area

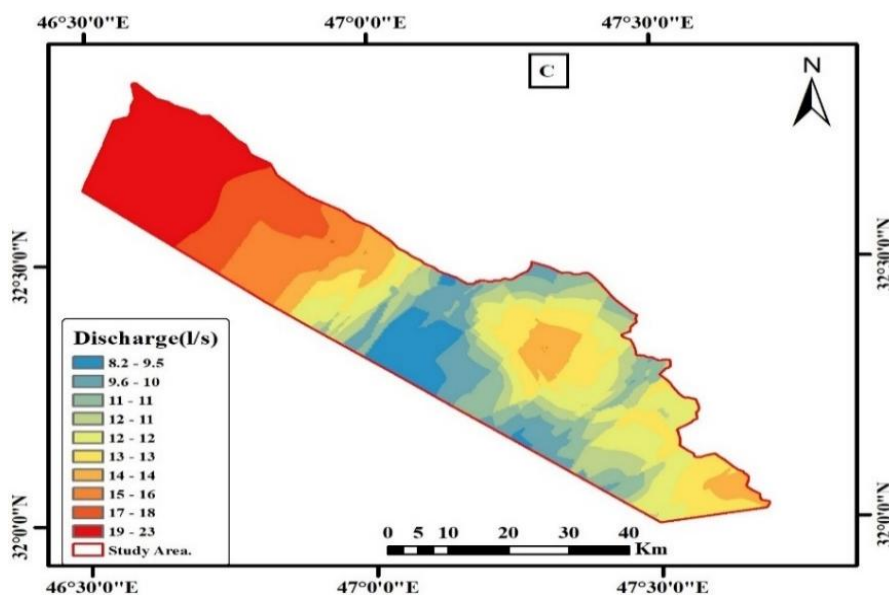


Figure (7): continue.....(c)Discharge of wells in the study area

The saturated thickness of the groundwater aquifers in eastern Maysan is controlled by geological processes, specifically the prevailing depositional conditions. The Tertiary aquifer exhibits a variable thickness depending on the thickness of the saturated water layer, which consists of gravel and coarse sand deposits in the Al-Muqdadiyah and Bai Hassan formations within continental fluvial environments, with an average thickness of 23 meters. The saturated

thickness of the Quaternary aquifer depends on the thickness of the coarse sediments within alluvial fan deposits, with an average thickness of 35 meters. Generally, the Quaternary aquifer is thicker than the Tertiary aquifer, being higher in the northeastern parts and lower in the remaining areas fig(7a).

5. Conclusions

Based on the analysis of hydrogeological data obtained from monitoring the static water levels of 46 wells between August 2024 and July 2025, in addition to the well log archives available from the General Authority for Groundwater, the following conclusions were reached:

1. The study area is characterized by two aquifer systems: a confined Tertiary aquifer within the Al-Muqdadiah and Bay Hassan formations, with a saturated thickness ranging from 19 to 27 meters and an average productivity ranging from 4 to 8 liters/second; and an unconfined Quaternary aquifer within alluvial fan deposits, with a saturated thickness ranging from 23 to 47 meters, which represents the main aquifer system in the study area.
2. The spatial distribution of coarse alluvial deposits controls the thickness of the aquifers in the study area. In the Quaternary aquifer, coarse sediments are greatest in the northeastern parts and gradually decrease towards the western and southern parts, becoming finer sediments. The greatest thickness of the Tertiary aquifer is found in the far central eastern parts. Generally, the thickness of the Quaternary aquifer exceeds that of the saturated Tertiary aquifer throughout the study area.
3. Time-based analysis of stable groundwater levels in 46 monitored wells during the monitoring period revealed three scenarios regarding groundwater level behavior. The first scenario, comprising 18 wells (W1, W4, W6, W8, W12, W16, W18, W21, W22, W23, W24, W25, W27, W28, W30, W39, W45, and W46), showed relatively stable groundwater levels during monitoring, reflecting a balance between recharge and withdrawal rates. The second scenario, comprising 12 wells (W2, W3, W9, W11, W13, W15, W20, W26, W32, W33, W38, and W42), showed gradual decreases in groundwater levels, consistent with increased extraction rates. The third scenario, comprising 13 wells (W5, W10, W14, W17, W19, W29, W34, W35, W36, W37, W40, W43, and W44) exhibited irregular fluctuations in groundwater levels, characterized by sharp rises and falls. This is attributed to increased extraction rates resulting from agricultural activities, coupled with increased recharge rates during the rainy season.
4. The highest groundwater hydraulic head values are concentrated along the Hamrin Hills in the eastern part of the study area, gradually decreasing towards the southern and western parts. This gradient determines the direction of groundwater flow from the northeastern and eastern recharge zones towards the western and southwestern discharge zones, corresponding to the slope.
6. The highest well discharge rates are concentrated in the northern, northeastern, and parts of the central study area, where the saturated thickness is highest. Productivity decreases towards the western, southern, and southeastern parts of the study area, where fine sediments in the Quaternary aquifer layers are predominant.

8. The results of this study provide a scientific basis for developing a strategy for the sustainable management of groundwater in the eastern part of Maysan Governorate. And to invest it optimally, away from depletion and irregular well drilling.

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Declaration of Conflict of Interest

The researcher declares that they have no known conflicts of interest or personal relationships that could have influenced the work presented in this work.

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