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Integrated Hydrogeological Approach for an Aquifer System and Groundwater Flow, Nukhaib-Km160 Area, Western Iraq

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Abstract. The hydraulic characteristics and the hydrogeological conditions of the hydrogeological system at Nukhaib-Km160 were studied within the water-bearing horizons, highlighting the flow system and its effects on the groundwater velocities and its balance (hydraulic gradients and permeability) taking into account the regional situations of structural. Several hydrogeological areas have been selected for future exploitation and development. 3D models and maps of spatial distribution are utilized for interpretation, it is supported by points of hydrogeological controls such as transmissivity and storage coefficients, depth of groundwater, lateral extensions, aquifers thickness, specific capacity, and well productivity. Prediction applications on specific capacities and transmissivity of aquifer and Kimball's statistical method were used to calculate the ratio of groundwater mixing and recharge from aquifers of Umm Er Dhuma and/or Tayarat Fn. to production wells. The hydrogeological system of the Nukhaib- Km160 region has been categorized into eight major aquifers which include the Mulussa, Mulussa-Ubaid, Muhaywir-Ubaid, Hartha, Muhaywir-Najma, Umm Er Dhuma, Tayarat, and Tayarat- Umm Er Dhuma aquifers. Changes in hydraulic parameters for all aquifers have been examined in order to determine the spatial-hydrologic facts of aquifers, where the traditional TDS distribution, in addition to the hydraulic interpretation, shows the same phenomenon of interconnection and the source of groundwater. According to facts of the hydrogeological, the aquifers of Umm Er Dhuma and Tayrat are important and preferred for the plan of the future of water supply in the Western Desert of Iraq, especially for the increased demand for water resources and the sustainability of the assessment.

1. Introduction

Identification of aquifer systems and resources of groundwater are major requirements in various studies of hydrogeology. Important information on structural, stratigraphic, geological boundaries and hydrodynamics are used to calculate the aquifer characteristics [1]; [2] and [3]. This integrated subsurface hydrogeological technique clearly explains the aquifer's hydrogeological model and the occurrence of groundwater. Characterization of hydrodynamic is used to determine the balance of groundwater and groundwater flow behaviors [4]; [5]; [6]; [7]; [8] and [9].

The hydrogeologic parameters (permeability, transmissivity, storage coefficients, and pressure heads of waters), the geometry of aquifers system in horizontal extensions (rep-resented by spatial distribution analysis), and vertical extensions (represented by hydro-geologic models), lead to the study and use of the structural, boundaries of hydrogeologic, and stratigraphic in the interpretation of phenomena hydrogeological throughout calculation of groundwater recharge and flow, groundwater velocity, the productivity of wells, the specific capacity of wells and ratios of feeding on horizons of bearing mixed water [10], [11], [12], [13], [14] and [15].

The study aimed to evaluate aquifer systems by identifying hydrogeological facts such as maps of two-dimensional hydrogeological and models of three-dimensional hydro stratigraphic, in addition to determining the relationship between groundwater recharge with groundwater flow direction and hydraulic parameters.

Physio graphically, the location of the study area at the Western Desert of Iraq, crossed by the High way which joins Ramadi and Rutba cities and Nukhaib-km160 road that run North-South from Km160 junction. It is bordered by longitudes of 41°02′00″ to 42°30′15″ and latitudes of 31°14′00″ to 33°32′00″ with a total area of 45,000 km^2 at an altitude of 150 - 590 m a.s.l. (Fig. 1).

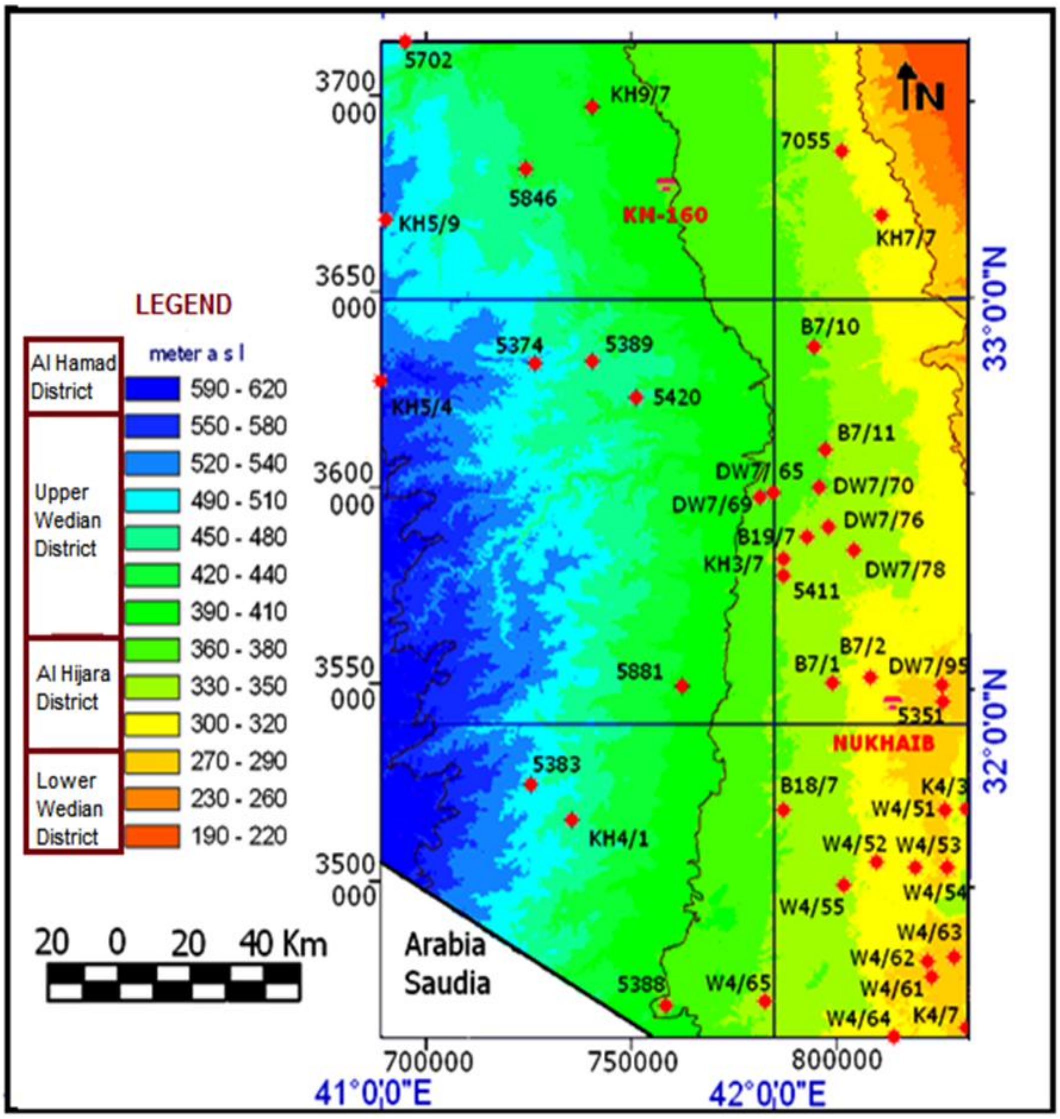

Fig. 1. Location map of wells in the studied area

The morphological phenomena were affected by the periods of rain that occurred in the Pleistocene represented by many drainage patterns of the hydrologic valley basins such as (Amij, Ubayidh, and

Ghadaf) [16]. The surface of the land is characterized by a plateau with undulating reliefs, it rises gradually from the eastern part, which is an elevation of 280 m a.s.l towards the western part which is the elevation of 540 m a.s.l (Fig. 1). The land surface has a mean slope of 2.1 m/ km towards the eastern part ranges between 0.50 m / km to 11 m / km [17]. The study depends on the climatic records in the two meteorological stations of (Km-160 and Nukhaib) for the period 1941-2010 (Table 1).

Table 1 Rainfall, Relative humidity, Temperature, Evapotranspiration, and Wind speed of two stations within the study area.

Period 1941- 2010	Annual mean				
	Rainfall (mm/y)	Relative Humidity (%)	Temperature (°C)	Evapotranspiration (mm/y)	Wind speed (m/sec)
Km-160	96.4	46	19.25	1800	4.3
Nukhaib	54	39.19	20.4	2148	3.71

The study area was designated with an extremely arid climate (zone of hyper-arid), and it has negative effects on the amount of groundwater recharge, which causes a drought condition for the area [18].

2. Materials and Methods

The study of hydraulic parameters, aquifers properties, and groundwater flow is examined by using database comprised TDS measurements in boreholes and hydrogeologic information obtaining hydraulic collected data measured in February 2009 from boreholes (Fig. 1) achieved by the center of desert studies and geologic data from eleven key boreholes [19], [20], [21] and [22].

The Groundwater Flow Model that Relies on hydraulic information is used to assess the recharge of groundwater and groundwater mixing within aquifers for exploitation plans and groundwater management [23]. This would facilitate the influence of geo-structural change and hydro-stratigraphy on the flow system. Static (fixed with time) and dynamic (variable over time) water levels with discharges of water as mentioned in previous studies are measured in water wells using the time-volume method for application of discharge and a sounder device that is electrical for levels based on the procedures related to the variables that are monitored in this study such as [13]; [24]; [25]; [26]; [27]; [28]; [29]; [30]; [31]; and [32]. Two dimensions' spatial flow of groundwater maps are shown by the Rockware-14 Software program, and other maps used ArcGIS V.9.3 program.

Water stratigraphic boundaries are utilized in conjunction with the setting of structural to build an adequate model of the hydrogeological flow regime, 3D hydrogeological models offer important advantages when carrying out assessments of groundwater resources that lead to enhanced and improved resource management results. Based on available litho-logs of eleven key boreholes, using the Rockware program, a three-dimension model of hydrogeology is performed, and it shows the hydrogeological system with its spatial distribution and the hosted geological formations (Hydrogeological units are in extension in the directions of X, Y, and Z). A statistical method was used to study the transmissivity of aquifers and the specific capacity of productive wells in order to obtain a high-level accuracy.

3. Results and Discussion

3.1. Structural and Geomorphologic boundaries

In the study area, the plateaus are present on multiple levels of elevations, with the extension of north-south direction within the Iraqi Desert. The western plateau where Amij, Ubayidh, and Ghadaf valleys are initiated and formed occurred on a level of (550-590) m asl.

The plateau is covered by calcareous soils and rocks fragments of (Umm Er Dhuma, Tayarat, Hartha, Ms'ad, Amij, and Hussayniyat) Formations. The middle plateau of a level ranges between 450 - 485 m a.s.l., incised by various drainage systems of Horan, Amij, Hazimi, Ghadaf, Tubal, Ubayidh, Hamer

Valleys, which divide the main plateau into sub plateau of minor scale and/or Mesas, forming badland texture. The eastern plateau ranges between 380 and 415 m a.s.l, crossed by Amij, Ghadaf, Ubayidh valleys. The plateau is of low relief in the exposure area of Euphrates, Zahra, and Habbariyia Gravel Formations.

In the study area, valleys are morphologic with obvious features (Fig. 2), such as Amij, Mohemidi, Ghadaf, Hazimi, and Ubayidh with its tributaries (Tubal, Abu Ghar, Mdaycece, Shabwan, Safawyet el-sheik, and Ubaydat, Hamer, and Arar), which are considered as important hydrologic basins that recharge aquifers (Fig. 2).

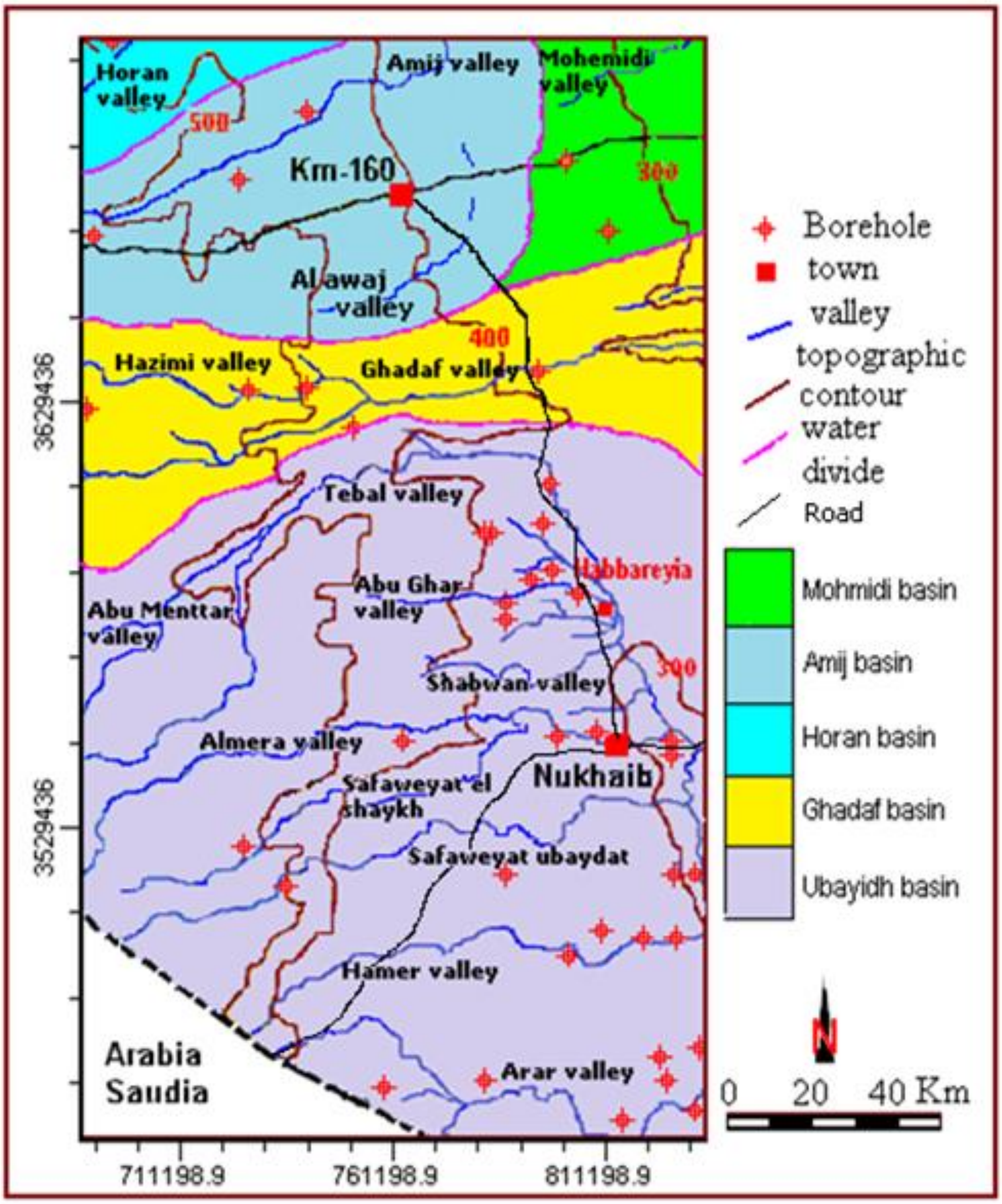

Fig. 2. Map of valleys and hydrologic basins.

These basins vary in shape and area, the drainage patterns are paralleled and dendritic for the main valleys with high stream order in badland area of elevation more than 510-meter a.s.l characterized by the presence of strata exposures of Hartha, Tayarat, and Erdhuma Formations. Systems of blind valleys exist in Alshwaweek dendritic valleys within the Amij basin whose end is plain to fill with friable sediments. The valley and depression fill sediments are considered as significant landforms; these lands are classified as the area that can be used for agricultural activities. The dissolution of carbonate rocks caused the creation of these depressions, especially if they were fractured and affected by the structural setting of beds. The depressions are filled by surface runoff and active winds by deposits of clay, sand, and silt.

In the study area, the largest depressions are Amij depression originated to the faulting in the direction of north-south and north west-south east parallel to Al-Qaseer Fault. Tlayha depression is filled with clay and silty clay deposits classified as karst topography and formed by the impact of the dissolution process on carbonates of the Maudod Formation. Shwaweek Al-Sagar depression is a part of the desert plain resulting from the dissolution process on the carbonate rocks of the Hartha Formation. Habbariyia depression is a large geomorphic feature with a north-south trend. Tectonically, the study area within a stable shelf belonging to the plate of Arabic-African, specifically is part of the Rutba Subzone [33].

A Rockware program (RW - V.14) is utilized in the completion of the Hydro structure model based on information of geological as in sections of lithologic wells (Fig. 3). The results obtained from the model Figure 4 show horizons that bearing of the water in Nukhaib and kilo-160 areas influenced by Horan fold (southern limb) with strata dipping between 1.00° and 2.00° in a direction of E S E. The results obtained from the model also explain the vertical and horizontal stretch of the geologic formations within the general geostructure setting of the region. There are many strike-slip faults extended in a direction of NW-SE including Al-Qaseer, Srayser, and Sagar fault confirmed by geological studies of [34] and [35] while [36] explanation of these faults within the normal faults accompanied by horizontal displacement.

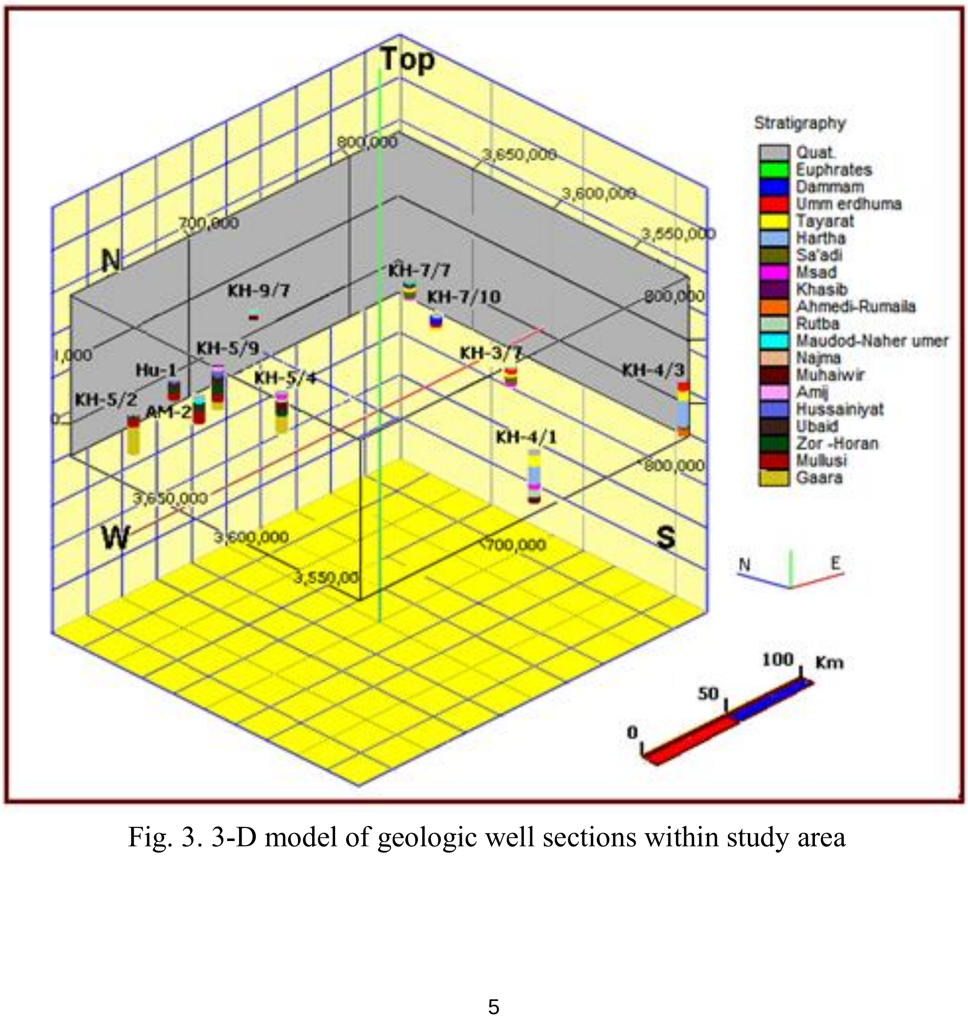

Fig. 3. 3-D model of geologic well sections within study area

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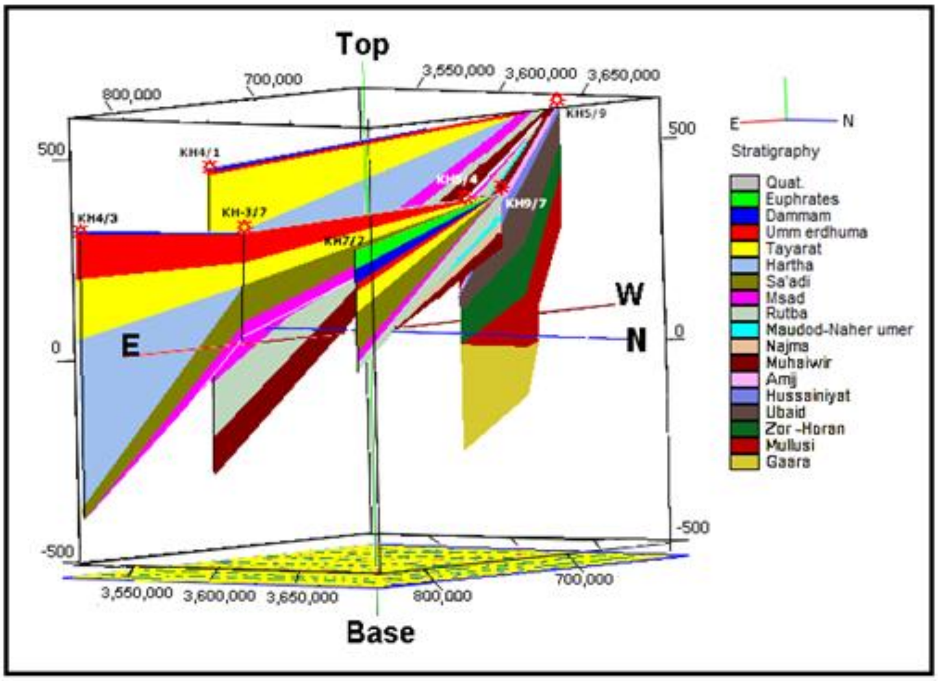

Fig. 4. 3D geological section within the study area

As for the southern part, the impact of alpine orogeny initiated in the Cretaceous period reflects vertical uplift accompanied by horizontal shifting causing forms of plateau and depressions like Al Habbariyia to fold with axes trend of (SSE-NNW) parallel to Al Habbariyia depression in addition to Maayna syncline which extends to the southern part of the study area. Another anticline fold extends to the east designated by shaped plateau associated with the mass movement in the basement and this fold may occur on the extension of Safawi block faulting (branch of Hail regional arc) [33]. The axis of the fold forms the groundwater divides which causes the deviation of groundwater towards the Nukhaib depression by controlling the movement of groundwater. Al-Ubayidh fault of east-west direction which extends from the north of Nukhaib towards Saudi Arabia borders controls the zone of groundwater recharge. Also, the hydrogeologic regime is influenced by (NE-SW) faults system in the area of Hamer Valley. The lineaments phenomena from compiled structure map (Fig. 5), [33] confirm the direct impact of the Rutbah uplift (Horan subsurface fold) on the morphologic features and extension of geologic formation which influence the recharge of groundwater through exposure and contact with rocks. The distribution map of the lineament's phenomena (Fig. 5), indicates that the ratio of lineaments repetition in a direction of WNW (orthogonal on strike lines) is dominant with lengths ranging between 10 and 150 km and has a ratio of 48% from the total lineaments. The majority is located in the northern part including areas surrounding Km-160, Muhaywir, and Tulaha. The second dominant lineaments are of NE direction in a percent of 28% conform to the direction of main valleys in the southern part (Kasra, Nukhaib, and Arar), with lengths ranging between (5-120) km. As for the linear phenomena in a direction of north-south, its lengths ranged (25-180) km corresponding with the direction of plateau edges in a repetition ratio of 17%.

These lineaments present as geomorphic cliffs (viz, Alzor slope) in conjugate direction to the valleys courses which help waters retention for long period, and allow more water to penetrate and invade through Quaternary sediments and carbonates rocks. Lineament's percent of east-west direction is 7% conformed with the direction of the main valleys created as a result of differential weathering which means the lineaments may be originated to the stratigraphic settings and topographic features.

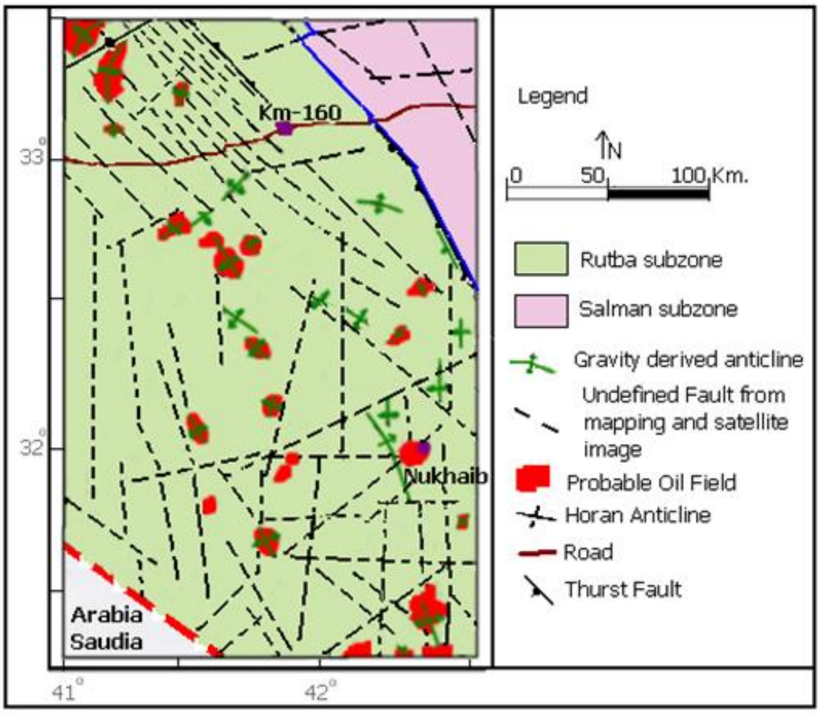

Fig. 5. Lineaments of the study area

3.2. Hydrogeologic and Geologic boundaries

According to the geologic studies of [37], [38], [39] and [40], a representative geologic section was created (Fig. 6), where the deposits of study area represented by Quaternary sediments, Zahra (Late Miocene-Pliocene), Euphrates (Burdigalian), Dammam (Lutetian), Erdhuma (Danian), Tayarat (Late Maestrichtian), Hartha (Late Campanian - Early Maestrichtian), Ms'ad (Cenomanian-Turonian), Rutba (Cenomanian), Maudod- Naher Umer (Albian-Cenomanian), Najma (Late Jurassic), Muhaywir (Bathonian), Amij (Lias), Hussayniyat (Lias), Ubaid (Lias), ZorHoran (Rhaetic), Mullusi (Carnian-Nornian) and Ga'ara (Early-late Permian) formations.

The extensions of vertical and horizontal for the geologic formations are shown in a map of surface geologic (2D) and geologic model (3D) Figs. (7 and 8). Depending on the presence of groundwater in horizons geological formation that is water bearing, determined 8 hydrogeologic regions are included (Fig. 9):

- First regions (Hussayniyat): The district exists in the northwest part of the study area. The groundwater occurred in Mullusa Formation.

The unsaturated (aeration) zone in this district is represented by layers of Ubaid and ZorHoran Formations.

- Second regions (Tlayha): found in the east and south part of the first regions. The groundwater present in Ubaid and Mullusi horizons. The zone of unsaturation comprises stratigraphic beds of Hussayniyat, Amij, Maudod, Rutba, and Msad Formations.

- Third regions (Hazimi): located in the south part of the second regions.

The groundwater exists in the Muhaywier and Ubaid Formations. The unsaturated zone in this region is represented by Hussayniyat, Amij, Maudod, Rutbah, and Ms'ad Formations.

- Fourth regions (Km-160): This district is in the site east of the 2nd and the 3rd districts. The groundwater exists in Najma and Muhaywir horizons. The aeration zone includes stratigraphic layers of Maudod, Rutba, and Msad Formations.

- Fifth region (Al Mera-Abu Menttar): located at the southwest part of the study area towards borders of the Saudi Arabia. The groundwater exists in Hartha horizons. The aeration zone contained Tayarat and Erdhuma Formations.
- Sixth regions (Arar-Ghadaf): situated to the east of the third, fourth and fifth districts. The groundwater exists in Tayarat horizons. The unsaturated zone in this district is represented by layers of Erdhuma, Dammam, Zahra, and Habbariyia Gravel Formations.
- Seventh regions (Habbariyia-Nukhaib): The district is situated to the east of the sixth region. The groundwater exists in Erdhuma water-bearing horizons. The unsaturation zone comprises stratigraphic layers of Dammam, Zahra, and Habbariyia Gravel Formations.
- Eighth regions (Habbariyia-Beret): Habbariyia-Beret district is located in the eastern and southern part of the study area. The groundwater exists in Erdhuma-Tayarat horizons. The aeration zone obtains stratigraphic layers of Dammam, Zahra, and Habbariyia Gravel Formations.

Era	Period	Age	Formation	Geologic Column	Explanation
Cenozoic	Quaternary	Holocene.	Recent deposits.		Alluvial sediments, valley and depression fills ,etc.
		Pleistocene	Huran, Habbarriya Sandy gravel .		Sandy gravel ,Conglomerate
	Tertiary	L.Miocene-Pliocene	Zahra Fn.		Limestone, sandy , Limestone
		Burdigalian	Euphrates Fn.		Fossiliferous , chalky , limestone ,dolomitic
		Lutetian	Dammam Fn.		Dolomite, dolomitic Limestone, Limestone.
		Danian	Erdhuma Fn.		Phosphatic Limestone, Dolostone.
Mesozoic	Cretaceous	L. Campanian-L. Maestrichtian	Hartha-Tayarat Fns.		Dolomitic limestone, silty clay Sandstone and Limestone.
		Cenomanian-Turonian	Rutba-Msad Fns.		Sandstones- Dolomite.
		Albian-Cenomanian	Naher Umer-Maudod Fns.		Silt, Marl, dolostone , Limestone.
	Jurassic	L. Jurassic	Najma Fn.		Sandstone, Limestone, Marl, Marly limestone.
		Bathonian	Muhaywir Fn.		Marl , Sandstones , Dolomitic limestone
		Lias	Amij-Hussayniyat Fns.		Claystones, Sandstones , Iron Ore and Dolomite
		Lias	Ubaid Fn.		Dolomite, Gypsious, Marl, Dolomitic Limestone
		Rhaetic	ZorHoran Fn.		Marl , Marly limestone **Dolostone,** Gypsiferous Marl
	Triassic	Carnian-Nornian	Mullusi Fn.		Limestone, dolomite limestone and Dolostone.
Paleo zoic	Early-late Permian		Ga'ra Fn.		Interbedded of Clay stones and Sandstones.

Fig. 6. The lithologic section represents geologic formations.

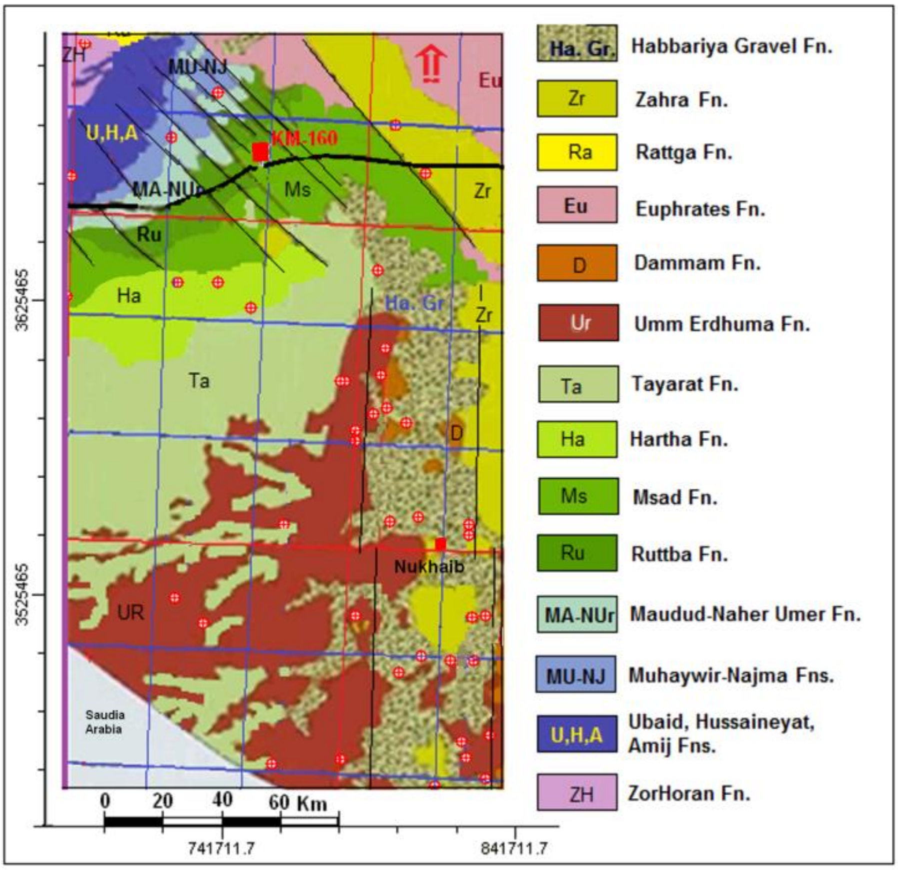

Fig. 7. Geological map of the study area.

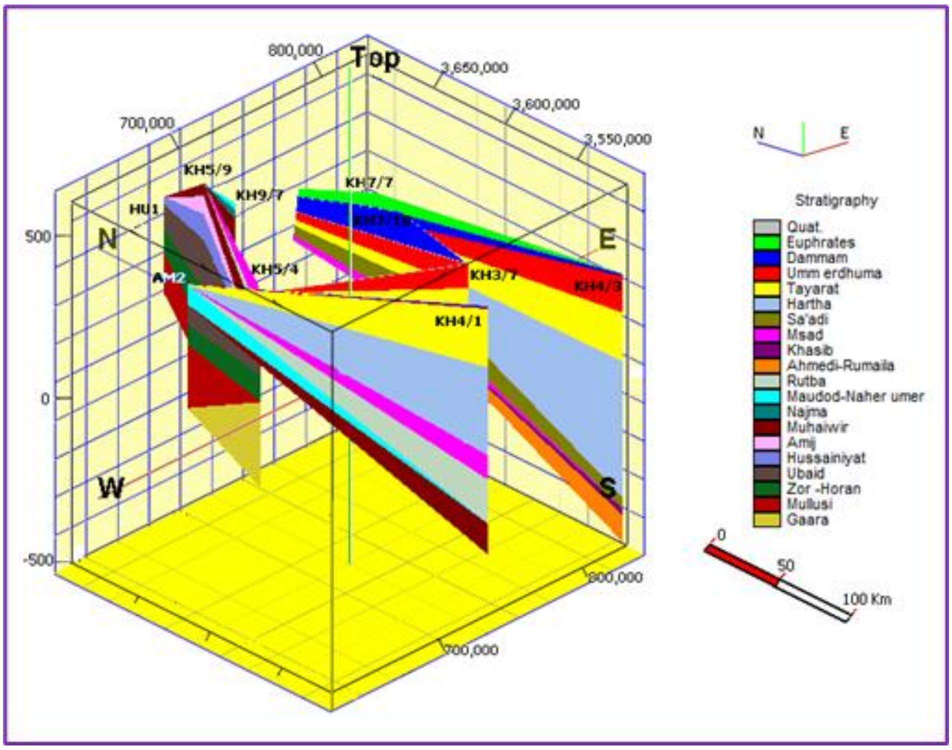

Fig. 8. 3-D geological model

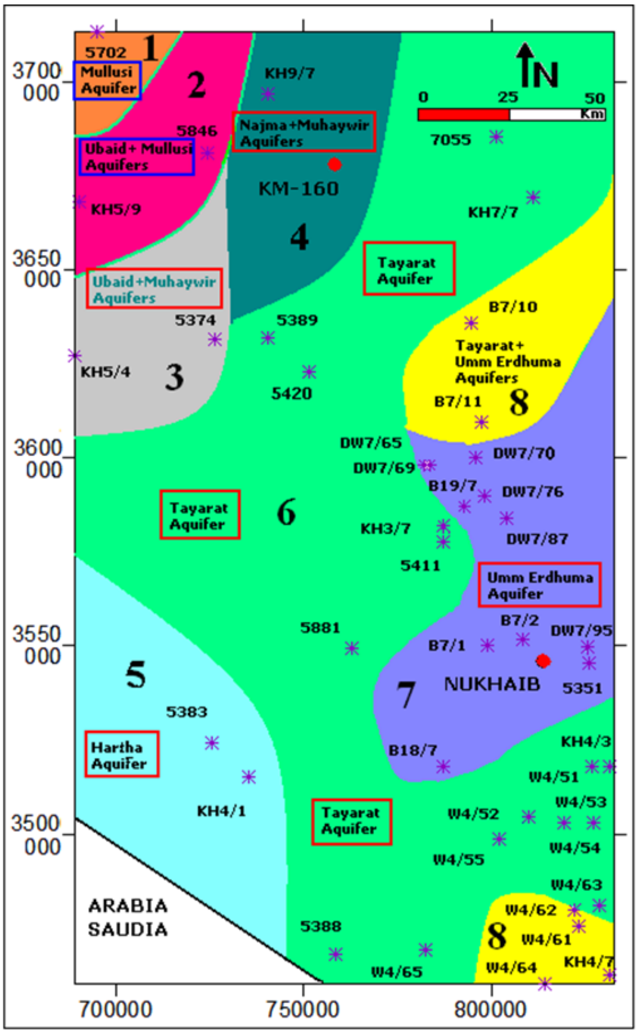

Fig. 9. Spatial distribution map of aquifers.

3.3. *Aquifers and boundary conditions*

It can be summarized the boundary conditions of aquifers based on the horizontal extensions of water-bearing layers and thickness, as follows:

1. Mulussa aquifer: It is fed from the lands of Rutbah uplift along Wadi Houran and its tributaries, which is a divide of the groundwater after water infiltration through the upper geological layers. Mulussa aquifer is considered to have conditions of semi-confined [41]. The structural setting of the region is one of the most important reasons that affect the horizons that bearing water resulting from the process of Rutba uplift, dip arises in strata surrounding uplift in a direction different. Mulussa aquifer distinguishes by extensions that are large and its thickness about 100.00 m in the part of south definitely in Abu Mennttar, 130.00 m in Amij and the part of north wedge out in Ga'ara depression at 30.00 m thick. The aquifer has a thickness in the 1st and 2nd districts (Fig. 9) are ranged between 100 and 130 meters. Fig. 8 explains the model extension of Mulussa aquifer in 3D.

2. Ubaid aquifer: It is recharged from the lands of the extension zone of Wadi Houran and Wadi Hussayeniyat in which the layers of Ubaid were exposed, arises boundaries of semi-confined to unconfined conditions [42]. The thickness of water-bearing horizons of Ubaid is affected by settings of structural, where layers of Ubaid represent part of geologic sequences in the Rutbah Uplift Zone. Ubaid Fn. is a carbonates aquifer and has thickness and extension in the 2nd and 3rd districts (Fig. 9), ranging between 44 and 80 m (Fig. 8).

3. Muhaywir Aquifer: It is fed from its exposure zone within the Ameij basin. The aquifer is characterized by unconfined storage conditions in the 3rd and 4th district (Fig. 9), which gradually changes to a semi-confined aquifer in the western parts of the study area. The thickness of the Muhaywir aquifer ranged from 40 to 95m and including sandstone and carbonates. The extensions of the aquifer in the W and NW parts are shown in (Fig. 8).

4. Najma Aquifer: The aquifer is fed by water from the Amij catchment area. The aquifer is characterized by unconfined storage conditions in the 4th district (Fig. 9), which gradually changes to a semi-confined aquifer in the eastern parts of districts. The thickness of the Najma aquifer ranged from 30 to 40m and its extensions in the northern parts are shown in (Fig. 8). The extensions of the aquifer in the W and NW parts are shown in (Fig. 8).

5. Hartha Aquifer: is recharged from the catchment area of Ghadaff and horizontal leakage of waters passing from Tayiarat aquifer in the Western parts. Hartha aquifer of confined condition which extends in 5th and 6thdistricts (Fig. 9). The thickness of the Hartha dolomitic limestone aquifer ranged between (270 - 400) m in the area SW and S of Nukhaib city, the extension of wells (KH4/3, KH4/1), (Fig. 10).

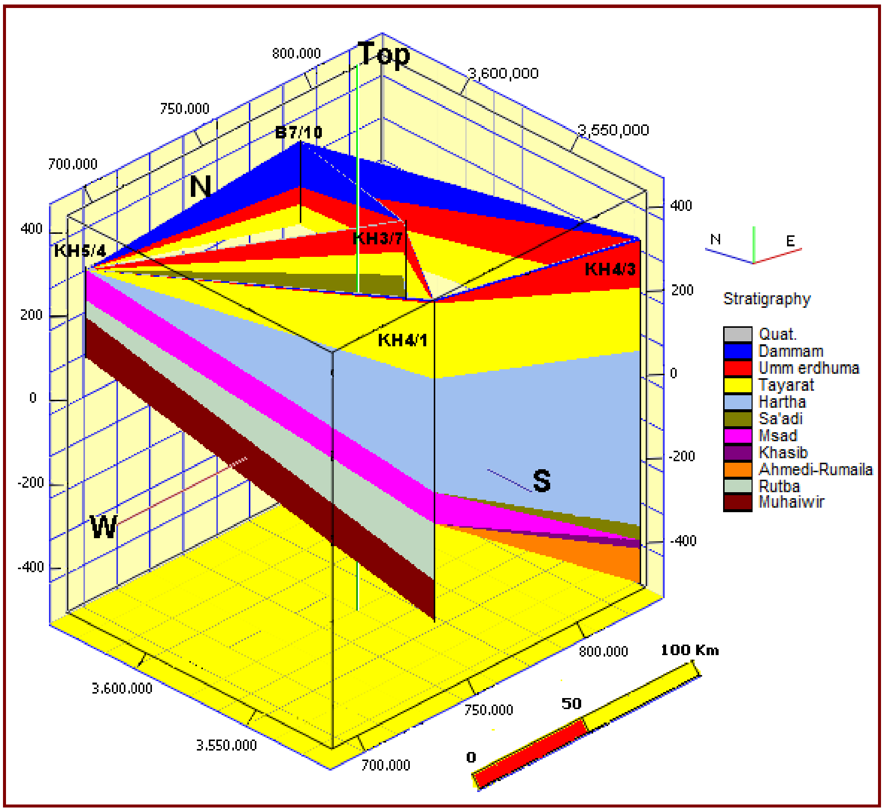

Fig. 10. 3D model of aquifers within Nukhaib.

6. Tayarat Aquifer: Tayarat's unconfined aquifer is of wide extension especially in the Arar-Ghadaf district (Fig. 9). The thickness of the Tayarat carbonate aquifer ranged between 52 and 56 m in the wells (KH7/7, KH3/7) intra-regional of Km-160 in the extensions shown in (Fig.11), increasing in SW and S of Nukhaib city in the extension of wells (KH4/3, KH4/1) (Fig. 10).

7. Umm Er dhuma Aquifer: is of unconfined storage condition in the interiors area restricted in Habbariyia-Nukhaib depression within the 7thand 8th districts, (Fig. 9). The thickness of the aquifer ranged from 10 to 112m within the Habbariyia depression (Fig. 10), and ranging between 43 to 72 meters in the area surrounding Km-160, (Fig. 11).

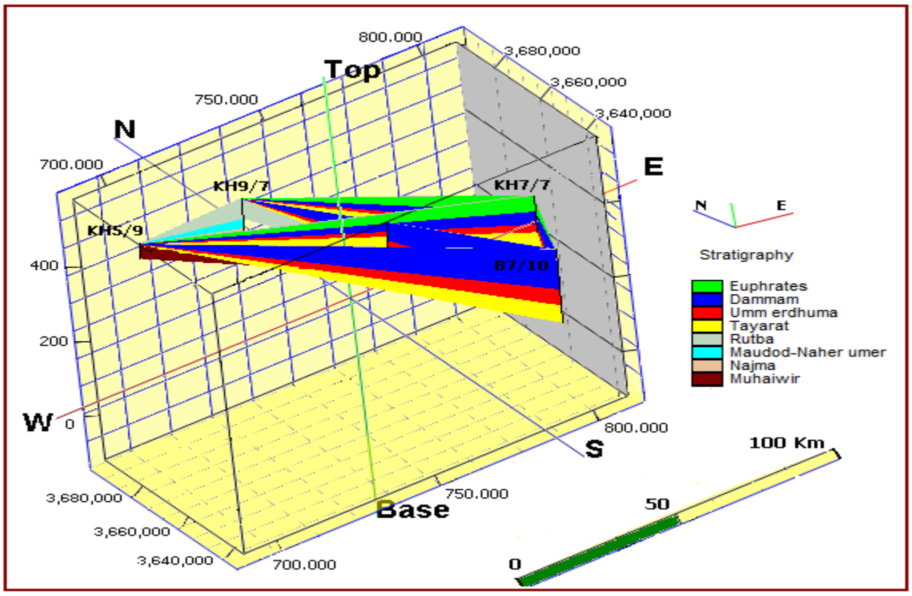

Fig. 11. Aquifer's extension model in Km-160

3.4. Infiltration rate and groundwater recharge

The recharge mainly occurs through a period of southern pluvial with the age of Late Pleistocene of precipitation dated back to 24000 - 37000 years B.P. and followed by a northern pluvial period during Early Holocene of precipitation second frequency that continued through 15000 - 22000 years BP. Then the third pluvial period (frequency of third-order) continued between 6000 - 14000 years B.P. Finally, the fourth-lowest pluvial period (period of Neolithic) is of less than 5000 years B.P. These results have been confirmed during isotopes elements analysis (^{3}H,^{14}C,^{13}C, and ^{18}O).

Al-Hammad physiographic zone is a major recharge zone of the aquifers within the region, [33], [42] and [43], just like these studies confirmed a practical occurrence of water replenishment and recharge aquifers by direct rainfall and runoff penetration during exposures rocks within the Wadies of Houran, Ghadaff, and Ubayeidh. The inflow recharge is also, done as a result of hydraulic connection between aquifers. The rate of infiltration (Rnp) in the study area to the groundwater is 4.40% from the annual mean rainfall determined from the regional study of the water balance of Iraq [44]. Accordingly, and based on the annual mean rainfall value of Nukhaib and Km-160, 54 mm/year and 96.4 mm/year respectively, therefore the rate of infiltration is 2.380 mm/year and 4.240 mm/year, respectively, using the equation of Rate Infiltrate = Rnp x PPT.

The amount of water that is infiltration in the Km-160 area north of Wadi Al-Ghadaf is determined by utilizing the following equation:

The amount of infiltration equals the rate of infiltration × area

$= 0.00424 \text{ (m/year)} \times 170.44 \text{ x } 10^{8} \text{ m}^{2}$

$=72.2 \text{ x}10^{6} \text{ m}^{3}\text{/year}$

Also, the amount of water infiltration in the area of Nukhaib south of Ghadaf valley is equal to:

$=0.00238 \text{ (m/year) } 204.56\text{x}10^{8} \text{ m}^{2}$

$= 48.7\times10^{6} \text{ m}^{3} / \text{ year.}$

3.5. Hydraulic parameters

Assessment of the properties of aquifers is calculated based on the obtainable information of hydraulic gathered from multi-previous studies of hydrogeologic. The amount of permeability for the water-bearing horizons of Muhaywir-Najma, Mullusi-Ubaid, Tayarat-Erdhuma, Erdhuma, Tayarat, Muhaywir-Ubaid, Mullusi, and Hartha aquifers are (7.7), (0.2-0.5), (0.9-1.7), (0.2-0.7), (0.3-20.7), (0.3-0.4), (1.3), (1-9.2) m/ day respectively. These aquifers are categorized as low permeability aquifers except for Tayarat and Hartha which are of middle class depending on [45], (Table 2).

Table 2 Classification of Laboutka for hydraulic parameters of aquifers.

Class	Discharge m^3/day	Specific capacity m^3/ day/ m	Transmissivity m^2/ day	Permeability m/ day
V. H. (very high)	>2160.00	> 864.00	>950.00	>864.00
H. (high)	432.00 – 2160.00	86.40 – 864.00	95.00 – 950.00	86.40 – 864.00
M. (middle)	432.00 - 43.20	8.640 - 86.40	9.50 – 95.00	8.64 - 86.40
L. (low)	< 43.20	<8.64	< 9.50	<8.64

The difference in the permeability values arises from the rock's heterogeneity forming aquifers, joints, and fractures density. The permeability as spatial distribution map (Fig. 12), shows an increase in the degree of permeability difference between 0.000002 and 0.0016 m/ day/ m distance towards Tayiarat and its lateral extensions with Erdhuma aquifer in Habbariyia depression and with Hartha aquifer in Tubal catchment area, whereas the permeability values decrease in the area SW Nukhaib and Tlayha, specifically in aquifers of Ubaid-Muhaywir and Mullusi-Ubaid. The amounts of aquifers transmissivity including Muhaywir-Najma, Mullusi-Ubaid, Tayarat-Erdhuma, Erdhuma, Tayarat, Muhaywir-Ubaid, Mullusi, and Hartha are 452, (17-41), (45-600), (15-800), (20-1000), (28-30), 20, (10-588) m^2/day, respectively. Depending on [45] (Table 2), the aquifers are classified as of middle transmissivity as spatial distribution map (Fig. 13), shows approximate and correspondence limited with the permeability distribution. There is an increase in the transmissivity ranging between 0.00007 and 0.049 m^2/ day/ m within the zone of Tayarat (Ghadaf and Mohammedi catchment area) and its extensions with Erdhuma aquifer in Habbariyia depression and with Hartha in Tubal catchment area, while the value of transmissivity decreases in Nukhaib region and Tlayha areas, specifically in Ubaid-Muhaywir and Ubaid-Mullusi aquifers.

The method of statistical is used in the differentiation of transmissivity values within Tayarat, Erdhuma, and the mixed of Tayarat-Erdhuma. [25], [46] and [47] define which aquifer has a significant impact on the water discharge of wells (productivity from mixed aquifers).

Three categories of transmissivity values for Tayarat, Umm Er dhuma, and Tayarat-Erdhuma aquifer are scheduled in (Table 3). The three groups of transmissivity values and their percent of frequency (Fs%) are drawn on the paper of probability-logarithm, (Fig. 14), where a percent of frequency is (Fs %) = $[M_0 / (N W + 1)] * 100$, M_0: Rank number, N_w: Total number of wells. The results derived from the graph paper of probability-logarithm (Fig. 14) are as follows:

1-Transmissivity values of Erdhuma aquifer within the study area are (40, 300, and 510) m^2/day, in the possibilities of 80%, 50%, and 30%, respectively.

2-Transmissivity values of Tayarat aquifer are (100, 400, and 600) m^2/day, in the possibilities of 80%, 50%, and 30%, respectively.

3-Transmissivity coefficient values of Tayarat-Erdhuma mixed aquifer are (28, 200, and 380) m^2/day, in the possibilities of 80%, 50%, and 30%, respectively.

The comparison of the three results above as clarified in (Fig. 14) shows that the transmissivity values of Tayarat – Umm Er dhuma mixed aquifer are less than the transmissivity values of Tayarat aquifer in a ratio of (36–72) % and less than the transmissivity of Erdhuma aquifer in a ratio of (25-33) percent. This indicates the heterogeneity of aquifer sediments which reflects permeability variation and the differences in layers thickness.

The amount of storage coefficient for the aquifers Mullusi-Ubaid, Muhaywir-Ubaid, Muhaywir-Najma, Tayarat-Erdhuma, Erdhuma, Tayarat, Mullusi and Hartha are (10^{-4}-10^{-3}), (10^{-4}-$7x10^{-5}$), (10^{-3}), ($4x10^{-3}$-10^{-1}), (10^{-3}-$5x10^{-2}$), ($4.5x10^{-3}$-$3.5x10^{-2}$), (10^{-3}), ($6x10^{-4}$-$2.5x10^{-2}$) respectively, (Table 4), [20] and [21]. The results of the storage coefficient show variable values among aquifers originated to the structural setting of each aquifer and the variation of rocks characteristics.

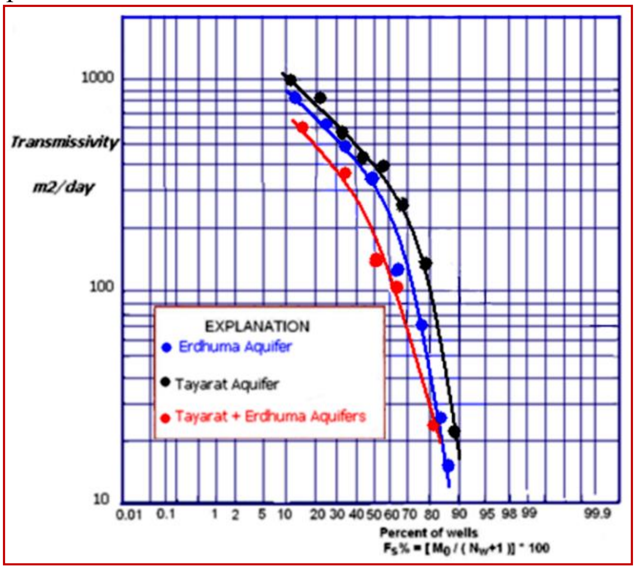

Fig. 12. Spatial variation map of permeability

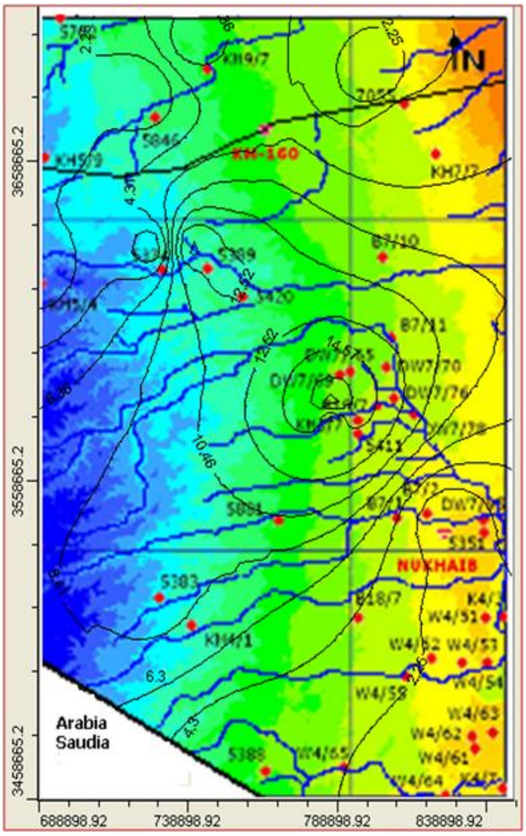

Fig. 13. The distribution model of transmissivity for aquifers on probability logarithmic paper

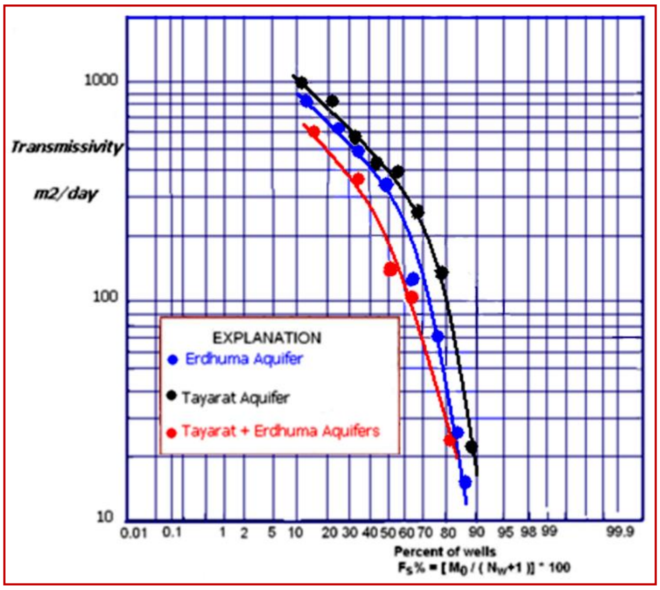

Fig. 14. Transmissivity and percent of wells

3.6. Productivity of wells and specific capacity

The amount of well productivity in the aquifers of Muhaywir-Najma, Mullusi-Ubaid, Tayarat-Erdhuma, Erdhuma, Tayarat, Muhaywir-Ubaid, Mullusi, and Hartha are 505.4, 111-219.4, 1651-2650, 162-2207, 224-2200, 240-247, 151, 329-778 m^3/day, respectively. Depending on Laboutka classification [45], the wells of the study area are classified within the wells of medium-high productive in exclusion wells of Tayarat-Erdhuma classified as wells of high to very high productivity. The specific capacity of the water wells which depths ranged from 125 meters to 913 meters for the aquifers Muhaywir-Najma, Tayarat-Erdhuma, Erdhuma, Tayarat, and Mullusi are 1.56, 3.2-15.0, 0.24-8.84, 1.13-47.2, and 0.875 liters/sec/m respectively.

Table 3 Frequency and Transmissivity within the study area

Tayarat Aquifer				Erdhuma Aquifer				Tayarat - Erdhuma Aquifers			
Well No.	Order No.	Fs %	T m^2/day	Well No.	Order No.	Fs %	T m^2/day	Well No.	Order No.	Fs %	T m^2/day
5420	1	11.11	1000	DW7/78	1	12.5	800	B-7/11	1	16.6	600
KH-7/7	2	22.22	812	DW7/65	2	25	636	KH4/7	2	33.3	377
K4/3	3	33.33	555	DW7/76	3	37.5	500	W4/61	3	50	150
KH-3/7	4	44.44	407	DW7/69	4	50	350	W4/62	4	66.6	110
5411	5	55.55	407	DW7/70	5	62.5	124	W4/64	5	83.3	25
5389	6	66.66	277	5351	6	75	70				
5388	7	77.77	138	DW7/95	7	87.5	15				
7055	8	88.88	20								

Specific capacity distribution map (Fig. 15), confirmed spatial variation in gradually increasing ranging from 0.000001 to 0.0036 l/sec/m towards wells of (Tayarat-Erdhuma and Tayarat aquifers) and when compared to Laboutka classification, it is in the high to a very high category, while in the other part it's decreased to a medium-high class of specific capacity classification. The statistical method is utilized in comparison of specific capacity (Sc) values within Tayarat, Umm Er dhuma, and the mixed of Tayarat-Erdhuma [25], [46] and [47] in order to determine the aquifers that have a significant impact on the well's productivity from mixed aquifers.

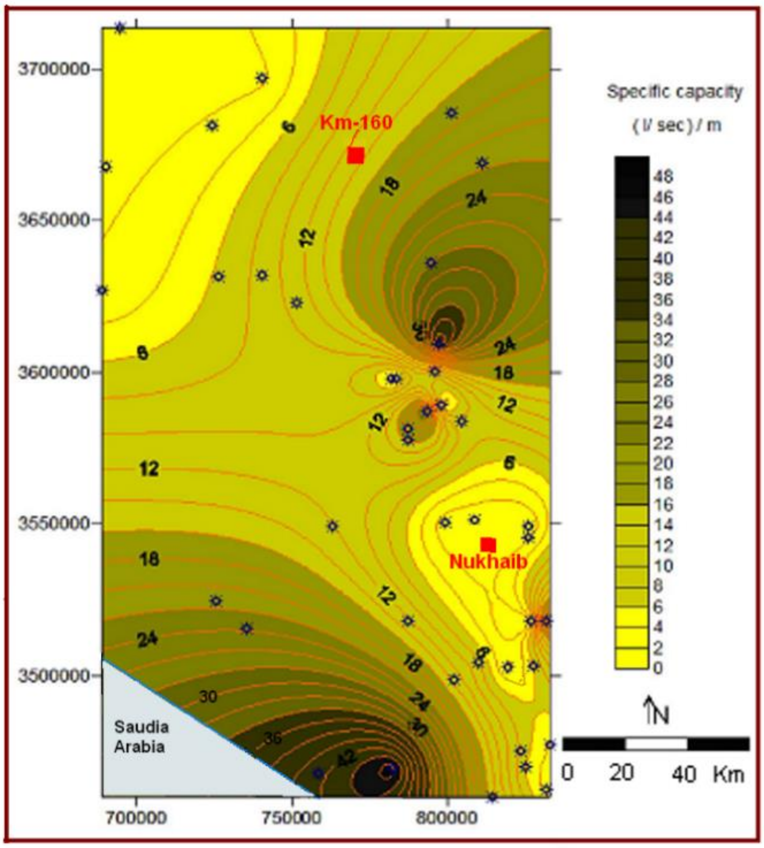

Fig. 15. Spatial analysis map of specific capacity.

Three groups of specific capacity values for Tayarat, Umm Er dhuma, and mixed of Tayarat-Erdhuma aquifers are scheduled in (Table 4). The groups of specific capacity values and their percent of frequency (Fs %) are drawn on the paper of probability–logarithm. The results derived from the probability-logarithm graph paper (Fig. 16) are as follows:

-Erdhuma aquifer: productive wells have a specific capacity (Sc) value of 0.5 liters/ day/ m (of drawdown) at a high probability estimated at 90 %. Wells that are productive can also obtain an Sc of 3 liters/ day / m in moderate probability estimated at 50 %, whereas productive wells can be obtained with an Sc of eight liters/ day/ m in low probability estimated at 30 %.

-Tayarat aquifer: Wells of product that can be obtained have an Sc of 2, 9, and 18 liters/ day/ m in a probability of 90 %, 50 %, and 30 % respectively.

-Tayarat-Erdhuma aquifer: Wells of product that can be obtained have an Sc of 3, 15, and 35 liters/ day/ m in a probability of 90 %, 50 %, and 30 % respectively.

Results comparison the three categories as described in (Fig. 15), shows that the Sc of wells produced from mixed aquifers of Tayarat-Erdhuma is more than the specified capacity of Tayarat or Erdhuma aquifer where the outcome feeding ratio of groundwater given to the wells from each aquifer are:

-In the probability 90%: 80% feeding ratio comes from Tayarat and 20% from Erdhuma aquifer.
-In the probability 50%: 75% feeding ratio comes from Tayarat and 25% from Erdhuma aquifer.
-In the probability 30%: 70% feeding ratio comes from Tayarat and 30% from Erdhuma aquifer.

Table 4 Frequency and Specific Capacity.

Tayarat Aquifer				Erdhuma Aquifer				Tayarat - Erdhuma Aquifers			
Well No.	Order No.	Fs %	Sp. Ca (l/sec/m)	Well No.	Order No.	Fs %	Sp. Ca. (l/sec/m)	Well No.	Order No.	Fs %	Sp. Ca. (l/sec/m)
W4/65	1	5.88	47.2	B-19/7	1	8.33	27	W4/62	1	14.2	79
5388	2	11.76	41	B-18/7	2	16.66	12	B-7/11	2	28.5	40.14
K4/3	3	17.64	27	DW7/78	3	25	8.84	B-7/10	3	42.85	28
KH-7/7	4	23.53	21	DW7/70	4	33.33	8.38	W4/64	4	57.14	15.0
KH-3/7	5	29.41	18	DW7/69	5	41.66	3.16	W4/61	5	71.42	5.7
7055	6	35.29	17	DW7/65	6	50	3.04	KH4/7	6	85.71	3.2
5411	7	41.17	16	DW7/76	7	58.33	2.23				
W4/55	8	47.05	13.2	5351	8	66.66	2				
5881	9	52.94	12	B-7/2	9	75	1.5				
5420	10	58.82	11	B-7/1	10	83.33	0.8				
5389	11	64.7	9	DW7/95	11	91.66	0.24				
W4/52	12	70.58	8.9								
W4/53	13	76.47	5.8								
W4/63	14	82.35	3.8								
W4/54	15	88.23	1.56								
W4/51	16	94.11	1.13								

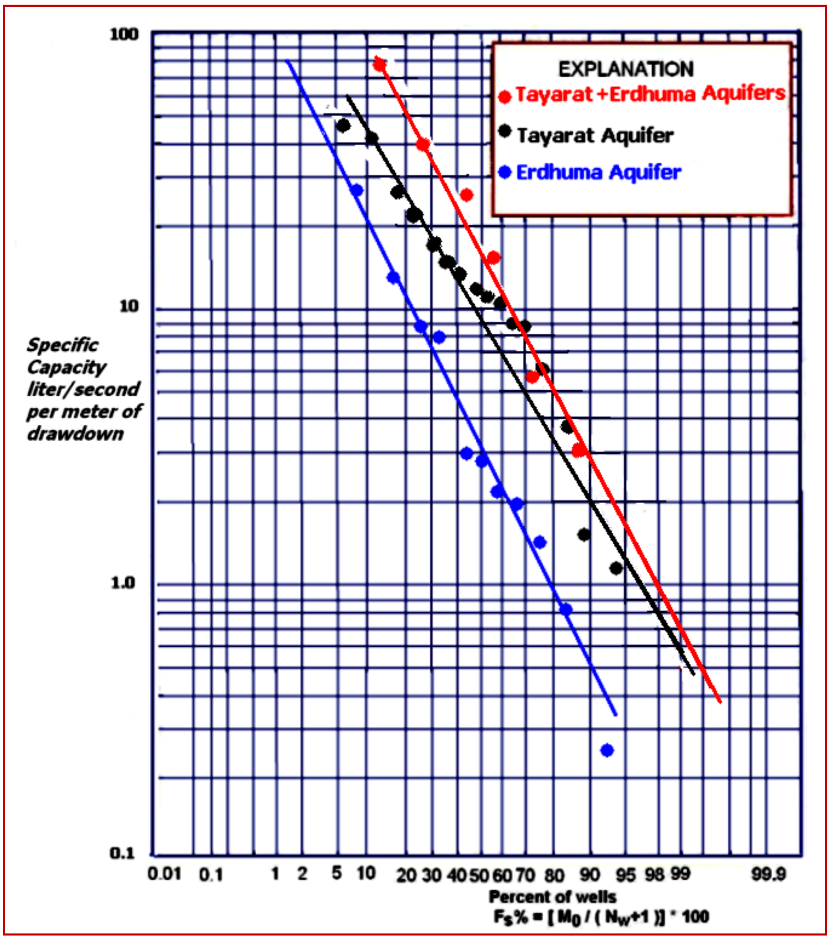

Fig. 16. Specific capacity frequency graph of productive wells on probability logarithmic paper

3.7. *Flow of Groundwater*

Using the groundwater contour program and depending on the results of the measurements, the specifications of the groundwater flow model are determined by observing the groundwater levels. Through the groundwater flow map, the phenomena of important scientific can be extracted (Fig. 17), which is supported by the following equations, which are shown in (Table 5). Groundwater flux (V) = K I, where, I is hydraulic gradient; K is permeability, [15], and [48]. Pore velocity of groundwater (U)= V/s; where, V is Flux of groundwater; s is Effective porosity or (Specific yield), [49] and [50]. The groundwater within Mulussa aquifer flows under the hydraulic gradient was 0.001, flux rate of groundwater of 0.00212 m/day, and velocity rate of groundwater 2.12 m / day. Groundwater within Mulussa-Ubaid aquifers flows under the impact of the hydraulic gradient of 0.0011, the flux of groundwater was 0.00265 m/day, and the velocity rate of groundwater was 5.3 m/day. The groundwater within Muhaywir-Ubaid aquifers flows under the effectiveness of hydraulic gradient amount was 0.00112, flux rate of groundwater was 0.00264 m / day, and velocity rate of groundwater was 31.05 m/day. The groundwater within Muhaywir-Najma aquifers flows under the impact of the hydraulic gradient of 0.00129, groundwater flux of 0.01 m/day, and groundwater velocity of 10 m/day. The groundwater within the Hartha aquifer flows under the effort of hydraulic gradient amount of 0.00067, groundwater flux of 0.0038 m/day, and groundwater velocity of 0.91 m/day.The groundwater within the Tayarat aquifer in the eastern part of (Km-160) flows under the impact of the hydraulic gradient of 0.00625, groundwater flux of 0.0044 m/day, and groundwater velocity of 0.88 m/day.

Table 5 Hydraulic and hydrogeologic data of aquifers extracted from the groundwater flow model.

Aquifer	GW. depth (m)	GW. Head (m.asl)		Hydraulic gradient	Permeability m/day	GW. flux (m/day)	Effective porosity	GW. pore velocity (m/day)
		from	to					
Mullusi aquifer	145-196	295	245	0.001	2.12	0.00212	0.001	2.12
Mullusi-Ubaid aquifer	136-186	305	235	0.0011	2.41	0.00265	0.0005	5.3
Muhaywir-Ubaid aquifer	234-294	285	235	0.00112	2.36	0.00264	0.00085	3.11
Muhaywir-Najma aquifer	160-220	238	196	0.00129	7.77	0.01	0.001	10
Hartha aquifer	253-296	226	195	0.00067	5.675	0.0038	0.0042	0.91
Tayarat aquifer eastern of (Km-160)	105-155	195	170	0.000625	7.045	0.0044	0.005	0.88
Tayarat aquifer in the middle of study area	150-232	240	190	0.0005	13.2	0.0066	0.005	1.32
Tayarat aquifer south of Nukhaib city	97-123	195	175	0.00036	4.3	0.0015	0.02	0.071
Erdhuma aquifer	95-144	190	175	0.00016	9.41	0.0015	0.025	0.06
Tayarat-Erdhuma aquifer in Kasra area	144-152	185	175	0.00022	9.78	0.0021	0.04	0.052
Tayarat-Erdhuma aquifer in Beret area	76-109	190	175	0.0005	1.785	0.00089	0.045	0.0197

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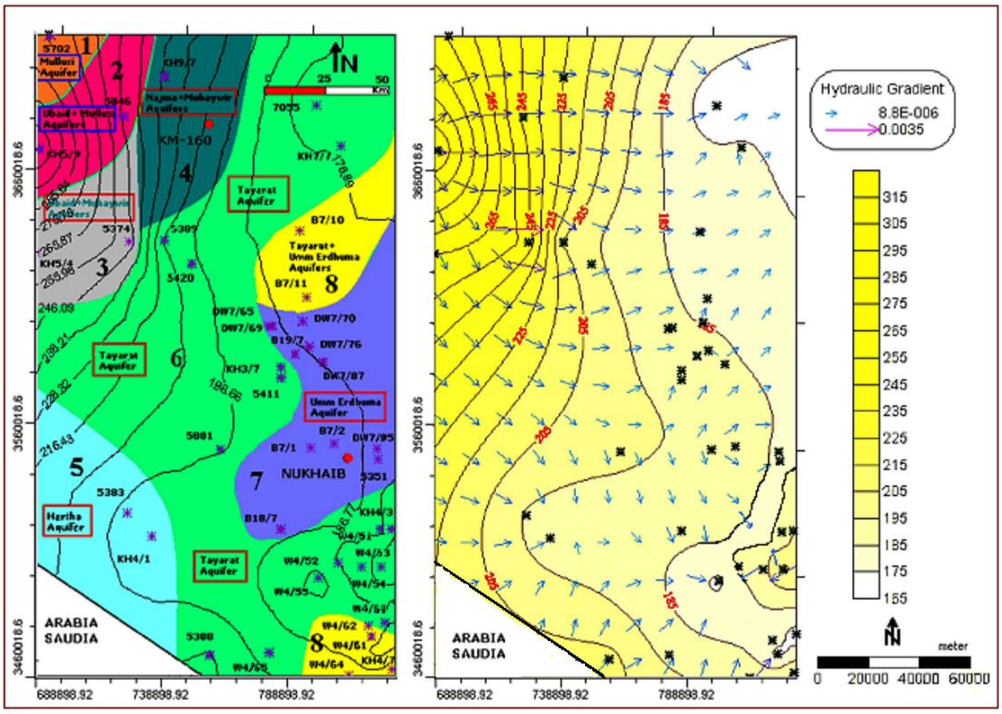

Fig. 17. Groundwater flows within the study area.

- The groundwater within the Tayarat aquifer in the middle part of the study area flows under the hydraulic gradient (I) of 0.0005, flux rate of groundwater 0.0066 m / day, and velocity rate of groundwater 1.32 m / day.
- Groundwater within Tayarat aquifer south of Nukhaib city flows under the effectiveness of hydraulic gradient (I) amount of 0.00036, flux rate of groundwater of 0.0015 m / day, and velocity rate of groundwater of 0.071 m / day.
- Groundwater within Erdhuma aquifer flows under the impact of hydraulic gradient amount of 0.00016, flux rate of groundwater of 0.0015 m / day, and velocity rate of groundwater of 0.06 m / day.
- The groundwater within Tayarat-Erdhuma aquifers in the Kasra area flows under the effort of the hydraulic gradient of 0.00022, flux rate of groundwater of 0.0021 m / day, and groundwater velocity of 0.052 m / day.
- Groundwater within Tayarat-Erdhuma aquifers in the Beret area flows under the impact of the hydraulic gradient of 0.0005, flux rate of groundwater of 0.00089 m / day, and groundwater velocity of 0.0197 m / day.

The inflow and outflow rate to/from the hydrogeologic regime is determined, depending on the groundwater flow map and hydraulic parameters of aquifers, using Darcy equation; Q = T I L [11] and [15] where Q = Outflow or Inflow m^3/day, T = Transmissivity m^2 / day, I = Hydraulic gradient (dimensionless), L = Section length m. The outflow and inflow rates for each aquifer are calculated on various equipotential lines representing the borders of aquifers as mentioned in Table 6 where the groundwater within Tayarat aquifer south of Nukhaib city flows from the hydraulic head of 195 m asl to the head of 175 m asl, towards well (W4/55) from all direction, influenced by intense exploitation or/and deep percolation throughout karst passages forming a boundary of the captured zone. The groundwater balance which is determined by the rate difference of groundwater inflow and outflow (ΔQ) in Mullusi, Mullusi-Ubaid, Muhaywir - Ubaid, Muhaywir - Najma, Hartha, Tayarat-Erdhuma aquifers, is 0.028×10^6, 0.058×10^6, -0.4×10^6, 1.064×10^6, -1.9×10^6 and -0.181×10^6 m^3/year, respectively, where the positive values represent the average difference lost in aquifers (groundwater depletion) originated either to rate of leakage through Faults and fractures deformations to the regional groundwater or the discharge of productive wells within the hydrogeologic basin, or both. The negative values of(ΔQ) for Hartha and Tayarat-Erdhuma aquifers represent the flow coming from the border regions (Saudia Arabia), where the calculation is achieved as partial inflow which obtain the inflow within the study area only. The negative value of balance changes within Muhaywir-Ubaid aquifers may represent lateral or/and vertical leakage recharge through structurally weak zones or groundwater inflow from hydraulic head more than 285 m. asl. Finally, $36.19x10^6$ m^3/year is the total ground-water outflow (Table 10), which forms 30% from the total infiltration amount of ($120.9x10^6$) m^3/year, while the 70% of infiltration rate is retained in the unsaturation zone of (76-296 m thick) as vadose water.

3.8. *Total Dissolved Solids (TDS)*

The total dissolved solids concentration in the groundwater of the aquifers Muhaywir-Najma, Mullusi-Ubaid, Tayarat-Erdhuma, Erdhuma, Tayarat, Muhaywir-Ubaid, Mullusi, and Hartha are (2700), (1500-1700), (1793-6000), (873-6963), (675-3760), (1218-2139), (2850) and (1259-1386) mg/liter, respectively, (Table 5). The groundwater is categorized as slightly saline to saline-water according to the classification of TDS in [15], [51], [52] and [53] except for fresh groundwater in some pockets within Nukhaib depression in Tayarat aquifer (wells; W4/52, W4/65) and Erdhuma aquifer (well-5351).

Table 6 Hydraulic data of aquifers and groundwater balance.

<table>
<tr><th rowspan="2">Aquifer</th><th rowspan="2">T m²/d</th><th rowspan="2">I</th><th colspan="2">Width (m)</th><th colspan="2">Hydraulic head (m.asl)</th><th>GW inflow</th><th colspan="2">GW outflow</th><th>GW outflow</th><th colspan="2">Balance change (ΔQ)</th></tr>
<tr><th>inflow</th><th>outflow</th><th>inflow</th><th>outflow</th><th>m³/day</th><th colspan="2">m³/day</th><th>m³/year</th><th>m³/day</th><th>m³/year</th></tr>
<tr><td>Mullusi aquifer</td><td>20</td><td>0.001</td><td>20000</td><td>18000</td><td>295</td><td>245</td><td>400</td><td colspan="2">324.0</td><td>0.118x10⁶</td><td>76</td><td>0.028x10⁶</td></tr>
<tr><td>Mullusi-Ubaid aquifer</td><td>24</td><td>0.0011</td><td>40000</td><td>34000</td><td>305</td><td>235</td><td>1056</td><td colspan="2">897.6</td><td>0.327x10⁶</td><td>158.4</td><td>0.058x10⁶</td></tr>
<tr><td>Muhaywir-Ubaid aquifer</td><td>29</td><td>0.00112</td><td>28000</td><td>62000</td><td>285</td><td>235</td><td>909.44</td><td colspan="2">2013.7</td><td>0.735x10⁶</td><td>- 1104.3</td><td>- 0.4x10⁶</td></tr>
<tr><td>Muhaywir-Najma aquifer</td><td>452</td><td>0.00129</td><td>70000</td><td>65000</td><td>238</td><td>196</td><td>40815.6</td><td colspan="2">37900.2</td><td>13.833x10⁶</td><td>2915.6</td><td>1.064x10⁶</td></tr>
<tr><td>Hartha aquifer</td><td>299</td><td>0.00067</td><td>32000</td><td>58000</td><td>226</td><td>195</td><td>6410.56</td><td colspan="2">11619.1</td><td>4.241 x10⁶</td><td>-5208.5</td><td>-1.9 x10⁶</td></tr>
<tr><td>Tayarat-Erdhuma aquifers</td><td>413</td><td>0.00039</td><td>285000</td><td>158000</td><td>195</td><td>185</td><td rowspan="2">45904</td><td>25449</td><td rowspan="2">46401</td><td rowspan="2">16.93 x10⁶</td><td rowspan="2">- 496.1</td><td rowspan="2">-0.181x10⁶</td></tr>
<tr><td>Tayarat aquifer south of Nukhaib city</td><td>485</td><td>0.00036</td><td>/</td><td>120000</td><td>195</td><td>185</td><td>20952</td></tr>
</table>

The distribution map of TDS (Fig. 18), shows an increase of concentration in an enrichment grade of 0.00024 to 0.342 mg/liter/m in E and NE direction corresponding with the flow direction within Tayarat and its extensions with Erdhuma aquifer, while TDS values decrease towards the east, south, and southwest of Nukhaib city. The model of TDS distribution indicates, the following phenomena:

- Presence of a recharge source coming from the west and the southwest direction where the TDS concentration is of fewer values, representing the zone of infiltration and replenishment within the valley's catchment area.
- Presence of enrichment mechanism where the groundwater is characterized by slightly saline water, which gradually changes to saline water towards NE direction. These results are explained by the following:

* Dilution process is done in TDS concentration by a percentage of 30% in the area which forms 10% of the study area calculated on concentration contour of 1500 mg/liter, and this indicates that the groundwater is mixed with infiltrated waters and be possibly described within the zone of replenishment or near the recharge zone.
* Enrichment process of TDS concentration at a percent of 150% in the area which forms 30% from the study area, calculated on the iso-line concentration of 2400 mg/liter, indicating that the enrichment

occurred by two impacts including the mixture with waters of saltier or/and the dissolution of minerals forming aquifers.

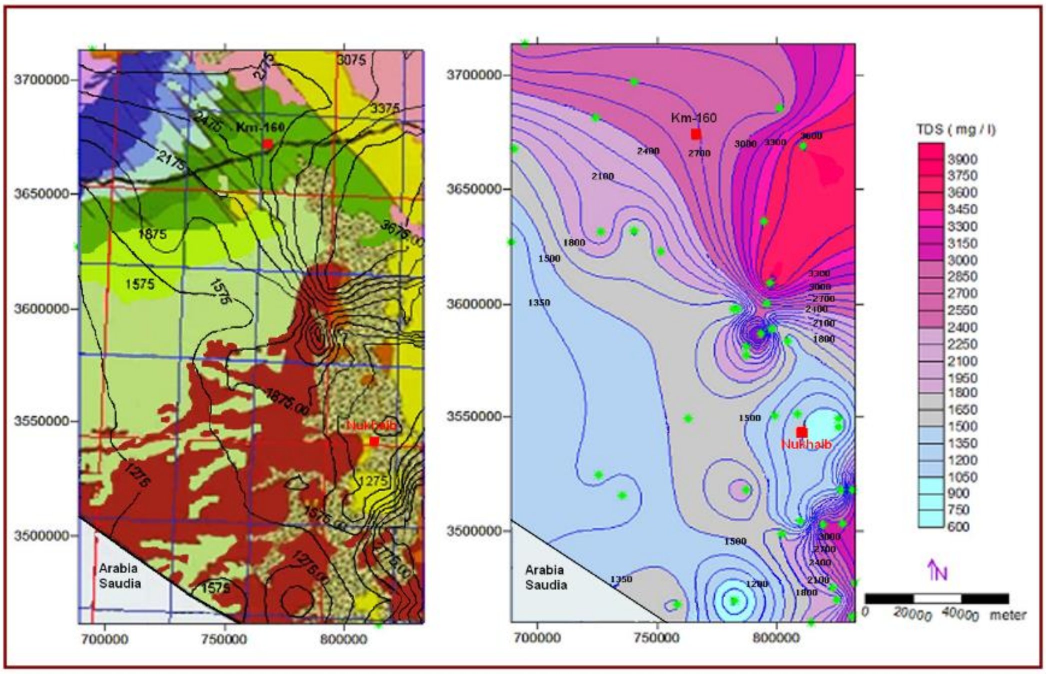

Fig. 18. Distribution map of TDS within the study area

4. Conclusion

The study determines the hydraulic and hydrogeological characteristics of the aquifers within the hydrogeologic regime of Nukhaib-Km.160 using the approach of integrated combining geological boundaries and geo-structural settings to develop the hydrogeological geometry of the aquifers. A spatial bimodal of hydrodynamic distribution is examined in order to calculate the behavior of groundwater flow and recharge within the aquifers of the study area. The study area represents a plateau of dry arid zone having undulant reliefs with an accumulation of pediment sediments on edges. The water-bearing horizons in Nukhaib and Kilo-160 areas are influenced by Horan anticline form a part of a southern limb, with beds dipping between 1.00° and 2.00° in a direction of E and SE. The impact of alpine orogeny initiated in the Cretaceous period and reflected as vertical uplift accompanied by horizontal slip causing plateau form like Al Habbariyia fold. Anticline related to the basement mass movement on the extension of faults system in a direction of (NNE-SSW) may occur on the extension of Safawi block faulting (branch of Hail regional arc). The axis of the fold forms the groundwater divides which controls the groundwater movement by deviating water towards Nukhaib Depression. Tayarat and Erdhuma aquifers in Kasra and Nukhaib are of both lateral and vertical hydraulic connections through faults and cracks systems. Those aquifers are of lateral connection with Hartha aquifer in area west and southwest of Nukhaib towards Hamer and Arar Valleys, also of lateral connection with Muhaywir aquifer due to layers intertangling in the extension of east-west and impact of faults in Tlayha region. As in the northwest parts, there is a vertical hydraulic connection resulting from the impact of faults on Mullusi, Ubaid, and Muhaywir aquifers. Accordingly, and depending on the geo-structural phenomena, the boundary condition of aquifers is determined as follows:

- Mulussa and Ubaid aquifers are of semi-confined conditions recharged from Rutba Uplift zone in the extension of Wadi Horan tributaries of him which represents the divide of groundwater.
- Muhaywir aquifer is recharged from the Amij watershed represented by its exposure area. The aquifer is characterized by unconfined storage conditions in the 3rd and 4th district and gradually changes to a semi-confined aquifer in the western parts of the study area.

- Najma aquifer is recharged from the Amij catchment area. The aquifer is characterized by unconfined storage conditions in the 4^{th} district and gradually changes to a semi-confined aquifer in the eastern parts of districts.
- Hartha aquifer is recharged from the Ghadaff catchment area and from lateral seepage of water that travels between aquifers in the western parts. Hartha aquifer of confined storage condition extends in the 5^{th} and the 6^{th}districts.
- Tayarat's unconfined aquifer is of wide extension represented by the 6^{th} district. The thickness of dolomitic limestone aquifer ranged from 52m to 56 m in the wells (KH7/7, KH3/7) and intra-regional of Km-160 increases in SW and S of Nukhaib city in the extension of wells (KH4/3, KH4/1).
- Umm Er dhuma aquifer is in the interiors area it is considered of unconfined condition restricted in Habbariyia-Nukhaib depression, within the $7^{th}$and 8^{th} districts.

The aquifers are of low permeability except for Tayarat and Hartha which are of the middle class. The increase in permeability variation grade ranged from 0.000002 to 0.0016 m/day/m towards Tayarat and its extensions with Umm Er dhuma aquifer in Habbariyia depression and with Hartha aquifer in Tubal catchment area while the permeability values decrease in the aquifers of Ubaid-Muhaywir and Ubaid-Mulussa (SW Nukhaib and Tlayha). The aquifers are classified as of middle to high transmissivity except for Mulussa, Muhaywir-Ubaid, and Mulussa-Ubaid which are of low to the middle class. An increase in transmissivity variation grade ranged between 0.00007and 0.049m^2/day/m within the zone of Tayarat aquifer and its extensions with Umm Er dhuma aquifer in Habbariyia depression and with Hartha aquifer in Tubal catchment area, while the transmissivity values decreased in the area south of Nukhaib and Tlayha (aquifers of Ubaid-Muhaywir and Ubaid- Mulussa).

The specific capacity of wells produced from mixed aquifers of Tayarat-Erdhuma is more than the specified capacity of wells produced from Tayarat or Erdhuma aquifer where the outcome feeding ratio of groundwater given to the wells from each aquifer is:
- In the probability90%: 80% of the feeding ratio comes from the Tayarat aquifer and 20% from the Umm Er dhuma aquifer.
- In the probability50%: 75% of the feeding ratio comes from the Tayarat aquifer and 25% from the Umm Er dhuma aquifer.
- In the probability30%: 70% of the feeding ratio comes from the Tayarat aquifer and 30% from the Umm Er dhuma aquifer.

The groundwater flow map indicates transmission of water among aquifers from the west and southwest towards the east (Nukhaib depression) and northeast (Amij depression). Also, the presence of another direction of deviated flow is caused by the presence of groundwater divides formed as a result of structural setting such as subsurface Habbariyia fold of (SSE-NNW) axes, just as anticline extends with Safawi uplift which represents a branch of Hail arc. This fold forms a groundwater division causing deviation in groundwater flow towards the Nukhaib area (replenished zone with low TDS values).

The groundwater within the aquifers system flows from a maximum hydraulic head of 305 m asl to the lowest head of 170 m asl, in the direction of E and/or NE considered as groundwater of medium to deep depths, where the depths range between 76 and 296m from the land surface, existing within Amij, Hazimi-Ghadaf, Awaj, Ubayidh catchment areas. The groundwater moves under the effectiveness of hydraulic gradient rate of (0.00016-0.00129), rate of groundwater flux of (0.00089-0.01) m/day, and rate of groundwater pore velocity of (0.0197-10) m/day. The groundwater balance which determined by the rate difference of groundwater inflow and outflow in Mullusi, Mullusi-Ubaid, Muhaywir-Ubaid, Muhaywir-Najma, Hartha, Tayarat-Erdhuma aquifers, are $0.028x10^6$, $0.058x10^6$, $-0.4x10^6$, $1.064x10^6$, $-1.9x10^{6,}$ and $- 0.181x10^6$ m^3/year, respectively.

Depending on detailed information for each aquifer using correlation technique for hydraulic data of the aquifers, the important aquifers that can be classified for best future exploitation are Tayarat-Erdhuma aquifer in Beret and Kasra areas, Tayarat aquifer south of Nukhaib city and east of (Km160) region and also Umm Er dhuma aquifer in Tubal catchment area. The groundwater in these aquifers is classified as groundwater of medium depths (76-155) meters flows from the hydraulic head of 195 m a.s.l. to the head of 170 m.asl, under the impact of hydraulic gradient rate of (0.00016-0.000625), groundwater flux of (0.00089-0.0044) m/day and groundwater pore velocity of (0.019-0.88) m/day. The other aquifers which are classified as of second exploitation grade and characterized by groundwater of high depths (145-296) meters, flow from a hydraulic head of 305 m.asl to the head of 195 m.asl, under the impact of hydraulic gradient rate of (0.0007-0.001), groundwater flux of (0.00212-0.01) m/day and groundwater pore velocity of (0.91-10) m/day.

The model of TDS distribution indicates a presence of recharge source coming from the W and SW direction where TDS concentration is of fewer values representing the zone of infiltration and replenishment within the valley's catchment area.

Dilution process occurred in TDS concentration by a percentage of 30% in the area forms 10% of the study area, calculated on concentration iso-line of 1500 mg/liter, and this indicates that the groundwater mixed with infiltrated waters can be possibly described within the zone of replenishment or near the recharge zone.

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