Hydrogeological Properties of Groundwater in Karbala'a Governorate – Iraq

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Abstract

The mainly objective of groundwater studies is assessment the physical characterizations of water-bearing layers. The studied area located in southwest of Karbla'a city within Karbla'a Governorate in Midwest of Iraq. The aquifers were divided into two main units, the unconfined and confined aquifers. Depending on (117) wells, the two main aquifers were investigated during field work where geographical position, elevations, static water levels, depths, thicknesses, maximum yields as well as water sampling and pumping test have been carried out. Unconfined aquifer mainly consists of Quaternary deposits and Dibdibba formation, while confined aquifer mainly consists of Dammam, Euphrates, Fatha and Injana Formations. Depending on hydrogeological and hydrochemical properties of both aquifers, promising zone for exploration of groundwater of unconfined aquifer located almost in the central part within the northeast part of the area, and eastern side of area for confined aquifer.

Key words: Hydraulic and Hydrochemical properties. Groundwater.

الخلاصة

ان الهدف الرئيسي لدراسات المياه الجوفية هو تقييم الخصائص الفيزيائية للطبقات الحاملة للمياه الجوفية . درست الخصائص الهيدروجيولوجية والهيدروكيميائية للمياه الجوفية في محافظة كربلاء المقدسة الواقعة الى الجنوب الغربي من العراق حيث قسمت المكامن الجوفية في المنطقة الى المكمن المفتوح المكون من ترسبات العصر الرباعي وتكوين الدبدبة والمكمن المحصور المكون من تعاقب تكوينات الدمام والفرات والفتحة وانجانة ، حيث اشتملت التحريات على تحديد مواقع الابار وبعدد (117) بئراً ومناسيب المياه الجوفية وعمق وسمك المكامن الجوفية فضلاً عن التصريف البئري وعمليات الضخ الاختباري لمجموعة من الابار في المنطقة ، واعتماداً على الخصائص الهيدروجيولوجية والهيدروكيمائية المستحصلة نتيجة هذه التحريات تم تحديد المناطق المؤهلة لاستثمار المياه الجوفية منها حيث كانت المنطقة المؤهلة الاولى للمكمن المفتوح في الجزء الشمالي من المنطقة الوسطى من منطقة الدراسة فيما كانت المنطقة المؤهلة الثانية للمكمن المحصور في الجزء الشرقي من منطقة الدراسة .

الكلمات المفتاحية : الخصائص الهيدروليكية والهيدروكيميائية ، المياه الجوفية .

Introduction:

Worldwide, more than a third of all water used by humans comes from ground water . In rural areas the percentage is even higher: more than half of all drinking water worldwide is supplied from ground water (Harter, 2015).

Determination of physical and chemical quality of water is essential for assessing its suitability for various purposes. Generally, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil-gas interaction, the rock with which it comes into contact in the unsaturated zone, the residence time, and reactions that take place within the aquifer (Fetter, 2000). The continuing of groundwater extraction from the aquifers for all purposes is contributing to groundwater depletion in many parts of the world (Ramesh and Fritz, 2016).

The studied area located in southwest of Karbala city within Karbala Governorate in Midwest of Iraq. Groundwater exploitation in this area is highly important due to extending of several geological aquifers with different thicknesses and suitable depths, figure (1). The climate of the area, according to the climatic atlas of Iraq (1951-2000) is described by (22-24)°C as mean annual temperature, (20-60)%

as mean annual relative humidity, while dryness index was (30) and number of days with snow is zero with (75-100) mm mean annual rainfall (Iraqi General Organization for Meteorological Information, 2010).

This study will emphasis on hydrogeological investigations in the area in order to demonstrate the most important groundwater aquifers and to achieve the best exploitation of these aquifers without any depletion and conserve groundwater storage. The study will investigate, explore and determine the locations of drilling wells in the area as well as calculating hydraulic, physical and chemical properties of groundwater aquifers.

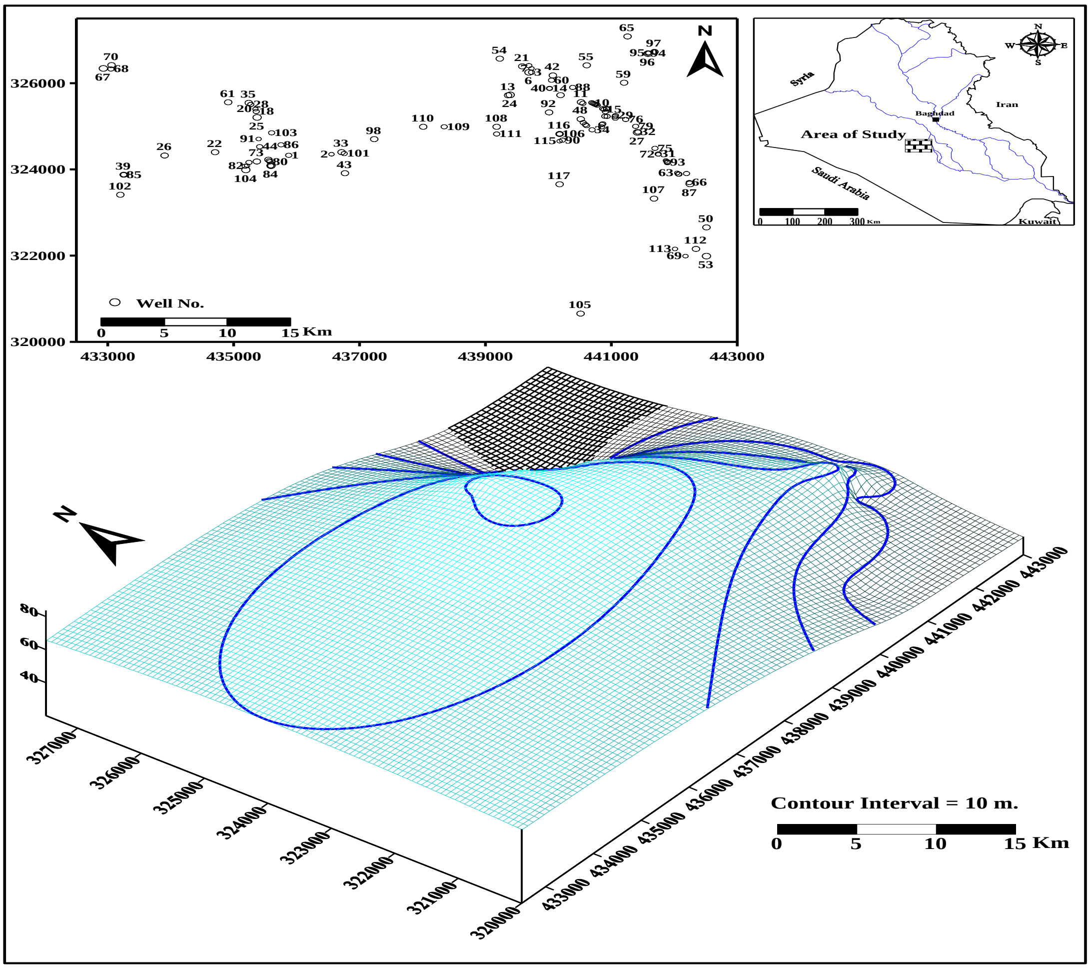

Fig (1): Topographic and location map of the studied area.

Previous Studies :

Several previous studies have been done within the region as mentioned below, generally these studies was not addressing the comprehensive details of the area regarding hydraulic properties, pumping test and hydrochemical properties.

1 - Assessment of groundwater resources in Iraq and management of their use (Jawad and Ridha, 2008).

2 - Transboundary aquifers between Iraq and neighboring countries (Jawad *et.al.*, 2008).

3- Hydrogeology of groundwater aquifers in the Western Desert - west and southwest of the Euphrates River (Jawad *et.al.*, 2001).

4- Hydrogeological Study of Area between Najaf - Karbla’a Cities (Al-Azawi, 2012).

5- Evaluation of groundwater recharge in arid and semiarid regions (case study of Dibdiba formation in Karballa-Najaf plateau) (Ramadhan *et.al*.,2013) .

Work Plan:

The work plan in the studied area included the following items:

1- Office work, including preparing data and preliminary information about the area.

2- Field work including:

- Inventory of water points and measuring water levels in the wells as well as determine Geographical positions and levels of (117) water points using (GPS) device.
- Water sampling of inventoried wells within water surplus and deficit periods during 2013-2014.
- Pumping test depending on specific wells.
- Laboratory analysis of water samples to identify of all ionic concentrations in addition to other physical specifications.

Geology of the Study Area:

The studied area consists of more than 80% of Quaternary deposits. Upper Eocene to Upper Miocene is overlain by Pre-Quaternary rocks. The sequence of formations represent as Dammam, Euphrates, Fatha, Injana, Zahra and Dibdibba.

1. Stratigraphy:

1.1. Dammam formation (Middle Eocene): It consists mostly of recrystallized nummulitic limestone, grey, creamy, yellowish and white in color, cavernous and Karstified, thickness is less than 20 meters.The upper contact is marked by breccia and overlain uncomfortably by the Euphrates Formation (Jawad and Ridha, 2008).

1.2. Euphrates formation (Lower Miocene): The formation consists of basal breccia, limestone and marl. Thickness of the formation is about 20 m. The depositional environment took place in shallow warm, near shore, marine water of normal to hyper saline lagoons (Anwar and Naseira,1995).

1.3. Fatha (Lower Fars) formation (Middle Miocene): The formation is exposed in south and western parts of the area, and is divided into Nfayil beds and clastic member. Nfayil beds generally consist of green, partly reddish in places sandy, dolomitic and gypseous marl with interbedded calcareous, partly sandy claystone and fossiliferous limestone. The thickness of these beds reached 15 m. The clastic member is developed in the southern parts of the area and along the eastern bank of Al-Razzaza Lake. The member has a thickness up to 12 meters. It consists of an lenticular sequence of reddish sandy calcareous claystone and brownish coarse grained sandstone. Depositional environment is shallow, near shore lagoons of warm marine water of normal-hypersaline salinity (Anwar and Naseira,1995).

1.4. Injana (Upper Fars) formation (Upper Miocene): The formation exposed on both ridges of Tar Al-Najaf as well as Tar Al-Sayid located on the eastern bank of Al-Razzaza lake. Generally, the formation consists of red, partly greenish silty, sandy calcareous claystone and lenticls of grey, brownish, greenish and yellowish sandstone. Thickness is up to 35 meters. The environment of deposition in continental, the salinity ranges from brackish to fresh water (Jawad *et al*. 2001).

1.5. Dibdibba formation (Pliocene-Pleistocene): It exposed along both ridges of Tar Al-Najaf and Tar Al-Sayid, where this formation making up the bedrock of the desert plain between Karbala and Najaf and occupying most part of the exposed sequence in the area. The predominant lithological component is sandstone, which is generally white, pink and light grey, fine to coarse grained small pebbles are often reported. The other types of rocks are silty claystone-clayey siltstone. Thickness of this formation is 10-22 m. The formation devoid of fossils and it has been deposited in continental environment (Ramadhan *et.al*.,2013).

1.6. Quaternary deposits:

1.6.1. Gypcrete (Pleistocene – Holocene): It represents the basic surficial rock type of the desert plain between Karbala and Najaf, and North West of Karbala too. It is found as white, granular, powdery form or as fibrous prismatic, hard well crystallized form, and/or as a brownish spongy form. Thickness is up to 2 m. and maybe more (Al-Azawi, 2012)

1.6.2. Shallow depression deposits (Holocene): They are either flood basins or playas. Besides, there are plenty of shallow depressions the origin of which is connected either with river or with piedmont plain. Shallow depressions are covered by silty clay, sands and silts. The most important characteristic feature of their deposits is the highest biological activity, which was closely connected with higher soil moisture.

1.6.3. Aeolian deposits (Holocene): Wind has blown deposits are spread over the whole area because of the low rate of precipitation. Their thickness is less than a few tens of centimeters and they still are discontinuous.

1.6.4. Valley fill deposits (Holocene): Lithologically, these deposits express the provenance and country rocks. Recorded thickness is variable, up to 1.5 m. The top laminated layer represents fine aeolian deposits. Generally, they are composed of loose admixture of silt sand and fine pebbles (Anwar and Naseira,1995).

2. Tectonic and Structure Setting:

Tectonically, the area located in two zones, Stable Shelf (Salman Zone), and Mesopotamian Zone (Tigris Subzone) (Anwar and Naseira ,1995). The position of the area is partly within the north eastern slopes of the African - Arabian Platform or the stable shelf - Salman Zone - (Western parts), while the eastern parts are within the Mesopotamian Zone (mainly Tigris subzone and partly Euphrates subzone). The structure of the area is not expressive on the surface, due to the nearly flat lying nature of the bed rocks, lack of good continuous exposures and due to quaternary deposits cover. Regional dip direction is to the NE, ranging between 0°-2°, in average, it is around ½°. Compact rocks of Miocene age are slightly jointed. A normal fault with E-W trend brings the Upper Member of the Fatha Formation in contact with the Euphrates Formation, southwest of Tar Al-Najaf. In the extreme southwestern corner of the map area a NW-SE trending fault exist, brings the Zahra Formation in contact with the Nfayil Beds, the extensions of this fault off the area is clear. In both cases the fault displacement is not clear (Anwar and Naseira,1995) Figure (2), table (1).

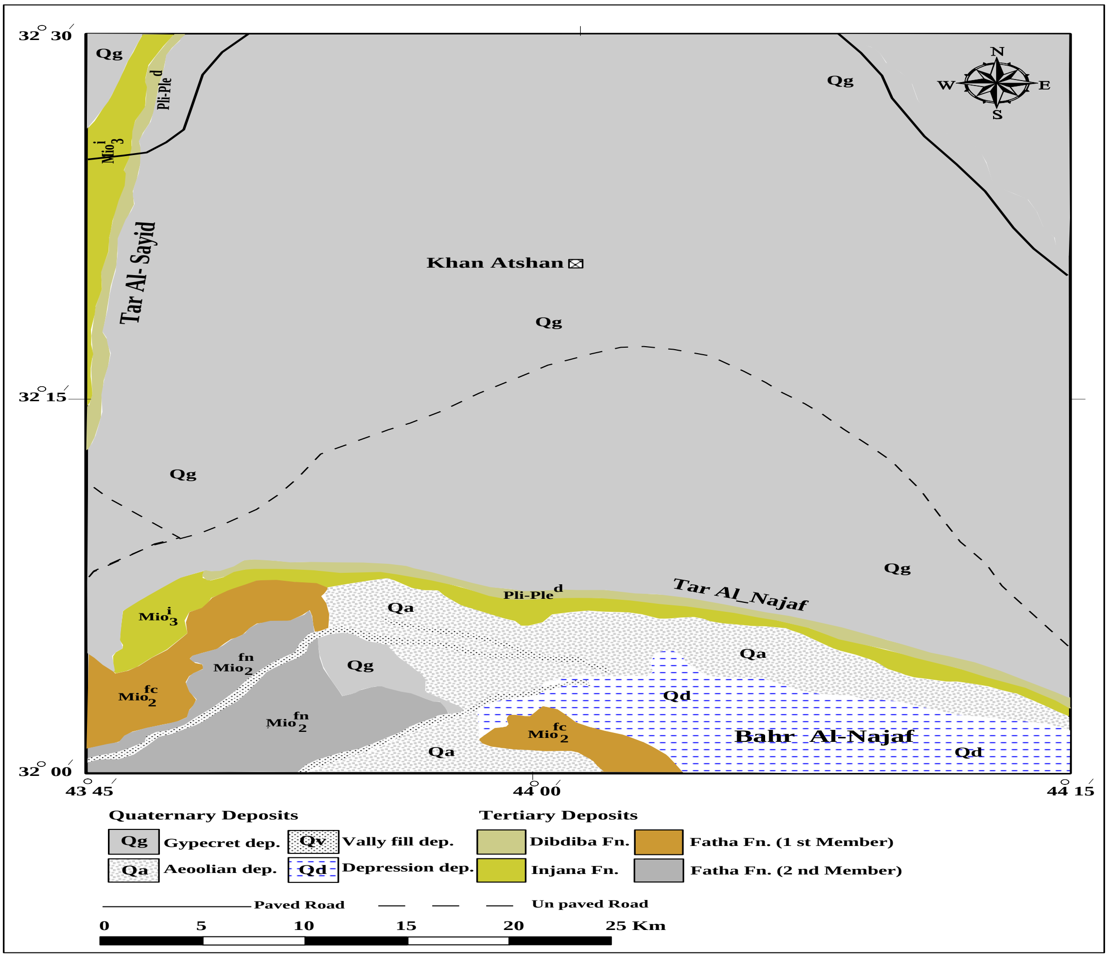

Fig (2): Geological map of studied area (Anwar and Naseira,1995)

Table (1): Stratified sequence of geological formations in the studied area (Al-Azawi,2012)

Era	Period	Epoch	Age	Formation	Lithology
CENOZOIC	Quaternary	Holocene		Aeolian deposits	
				Valley fill deposits	
				Depression deposits	
		Pleistocene		Gypcrete deposits	
	Tertiary	Pliocene		Dibdibba	
		Miocene	Upper	Injana	
			Middle	Fatha	
			Lower	Euphrates	

Materials:

1- Topographic maps at a scale of 1:250000.

2- GPS device to determine wells locations and elevations.

3- Stratigraphic sheets and hydrogeological data bank (General Commission of Groundwater, 2013).
4- Mathematical programs (Surfer and Grapher) in analyzing data and information obtained and draw of all types of contour maps.

Methodology:

Comparing the stratigraphic sheets of (117) drilled wells with table (1), and taking into consideration the water levels measured in these wells as well as types of water bearing layers; the aquifers were divided into two main units, the unconfined and confined aquifers. The two main aquifers were investigated during field work where geographical position, elevations, static water levels, depths, thicknesses, maximum yields as well as water sampling have been carried out. hydrochemical properties of water samples such as pH, electric conductivity (EC), and major Cations and Anions were measured and analyzed by standard methods (APHA. 2005). Mathematical programs (Surfer and Grapher) were used to demonstrate the obtained results in contouring maps of hydrogeological and hydrochemical properties as well as standard pumping test results by depending on few wells to estimate and calculate hydraulic properties of these aquifers.

Rustles and Discussion:

Depending on (117) wells investigated in the area, the results showed that (73) wells belongs to unconfined aquifer while (44) wells belong to confined aquifer.

1- Hydrogeological and Hydrochemical properties of unconfined aquifer:

Table (2) and (3) shows the statistical data of hydrogeological and hydrochemical properties in unconfined aquifers.

Table (2): Statistical data shows Hydrogeological properties of unconfined aquifer.

Statistics	Elevation (m)	Static Water Level (m)	Water table (m.a.sl.)	Maximum Yield (m*3/day)	Transmissibility (m*2/day)	Total Depth (m)	Thickness (m)
Number of values	14	73	14	67	20	73	73
Minimum	16	0.75	12.16	172.8	15.24	12	8.16
Maximum	79	37	59	518.4	311.04	65	42.5
Mean	38.95	8.1707	28.958	343.67	83.020	25.8	17.59
Variance	552.3	59.162	285.63	6923.9	3846.2	213	71.13
Average deviation	20.61	5.9095	13.987	67.018	41.276	12.6	7.159
Standard deviation	23.5	7.6917	16.901	83.21	62.018	14.6	8.434

Table (3): Statistical data shows Hydrochemical properties of unconfined aquifer (APHA. 2005).

Statistics	PH	E.C. (µmoh/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)
Number of values	62	65	65	65	65	65	62	65	64	65	65
Minimum	7.1	1725	1100	95	41	161	2	191	64	340	0
Maximum	7.91	23600	15200	1102	540	2331	273	3799	2013	3269	9
Mean	7.25	5374	3878	322.4	151.3	527.7	55	728.1	457.8	1128	2.95
Average deviation	0.115	2159	1558	125.8	53.55	225.6	50.06	314.4	212.4	455.3	1.65
Standard deviation	0.164	3450	2457	188.5	85.18	361.2	58.73	555.3	358.3	619.5	2.12

Unconfined aquifer mainly consists of Quaternary deposits and Dibdibba formation according to lithological columns of wells investigated in area. Depth and thickness of this aquifer shown in figure (3 A&B) where topography of the area was a major influence on distribution of increasing depth and thickness towards southwest direction of map area, while gradually decreasing shown towards northeast direction. The topographic map, figure (1) showed the sudden inclination in topographic levels in the northeast corner of the map area where the minimum depth and thickness where recorded. In other hand, the inclination of topographic levels where more gentle in the southeast corner, thus both depth and thickness were gradually decreased. The aquifer depth reached (65) m. while the thickness reached (42) m.

The transmissibility of this aquifer was determined by pumping test from (20) wells. The results shown in figure (3C) where increasing values were recorded in the northeast direction due to decreasing of Quaternary deposits in this region while Dibdibba formation with highly sandstone thick beds increased this value. The geological map showed that aeolian and depression deposits spread out in the southern area where these deposits consist of silty clay, sands and silts with the lowest capacity of transmit groundwater. The maximum value of transmissibility was (311) m^2/Day.

The groundwater movement depends on hydraulic heads in aquifer as well as dipping and inclination of water bearing strata (Domemico and Schwartz, 1998). The influence of topography and aquifer layers dipping was the major cause of groundwater movement in this aquifer as shown in figure (4A). The water table (groundwater flow direction) map has a radial flow from middle area and finally towards east side of region. The nature of Quaternary deposits and Dibdibba formation allows percolating and infiltrating rainfall to recharge this aquifer although the low rate of annual rainfall records in the area.

In other hand the maximum yield (well discharge) of (67) wells was demonstrated in figure (4B) where maximum values located on the eastern side of the map while gentle decreasing values of maximum yield located in the northwest and northeast directions. Maximum yields depend on transmissibility of lithological of water bearing and groundwater flow direction (Fetter.2000), taking in consideration thickness of aquifer. The hydrogeological properties of this aquifer indicate that thickness was the lowest values in northeast part of area while transmissibility was the highest value with assemble of groundwater flow. As mentioned before the unconfined aquifer mainly formed by Quaternary deposits and Dibdibba formation where Quaternary deposits is suddenly decreased in northeast part of the map and aquifer assumed to be formed by Dibdibba formation only, which consists of good sandstone bed.

The salinity of unconfined aquifer presented as total dissolved salts (T.D.S.) as shown in figure (4C) with radial increasing shape. Groundwater salinity increased with flow path due to reaction and dissolution of chemical components of geological formation (Appelo and Postma, 1999). The Gypcrete as one of Quaternary deposits, spread out in the area which may be the main cause in salinity increasing because it contain rock fragments derived from older geological formations such as Injana, Fatah or Euphrates were they all have some of limestone rock and gypseous marl in their stratigraphic sequences which react and dissolute with rainfall during wet season and infiltrate to water bearing. The map showed that minimum values were at highest topographic elevations which indicate the possibility of aquifer recharge by rainfall causing salinity decreasing (Al-Sudani,2017). Kurlov formula is a very useful method for primary characterization of the chemical composition of water (Zaporozec, 1972), where the groundwater in unconfined aquifer was (Na_2SO_4).

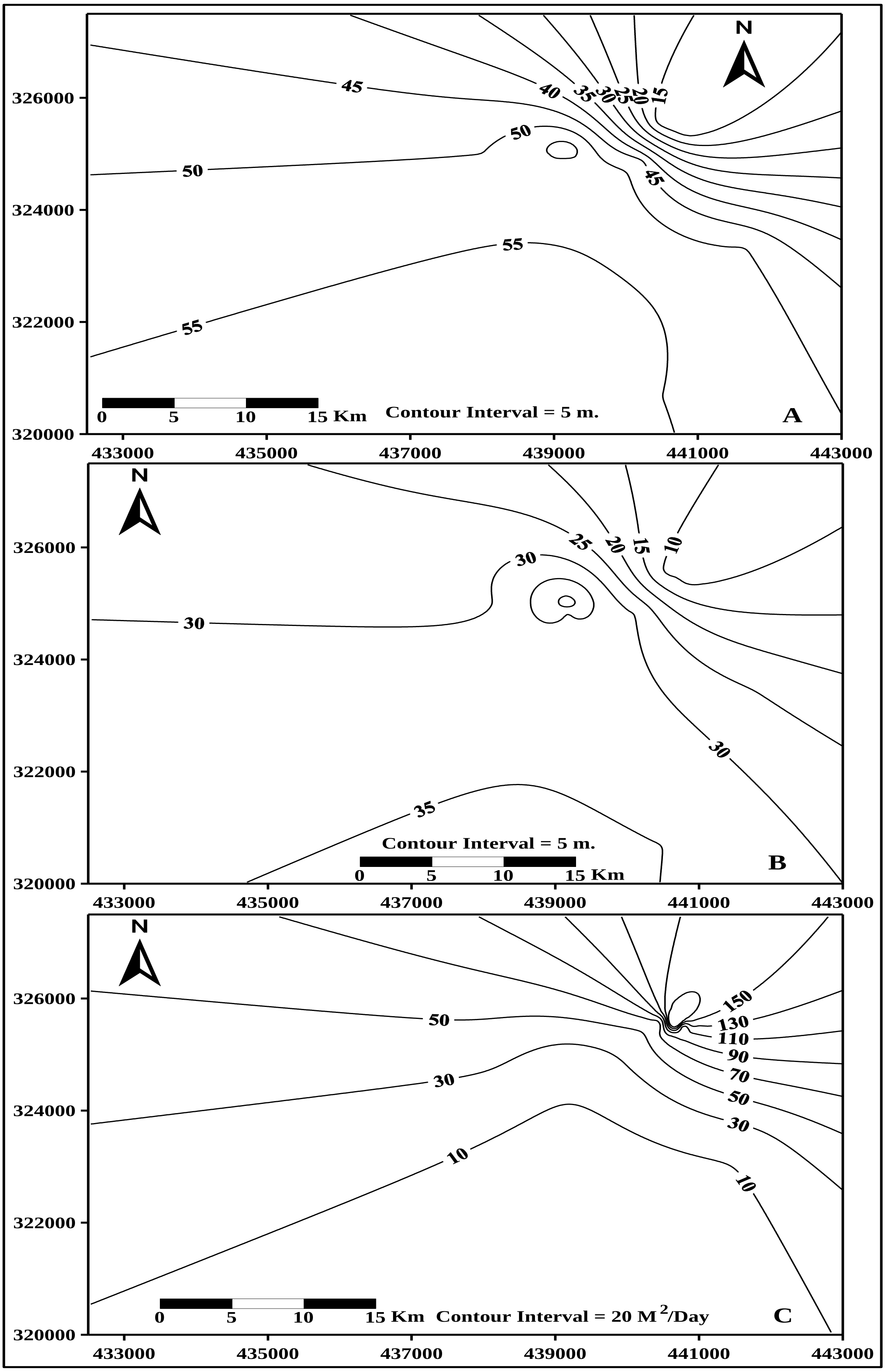

Fig (3): Depth (A), Thickness (B) and Transmissibility (C) of unconfined aquifer.

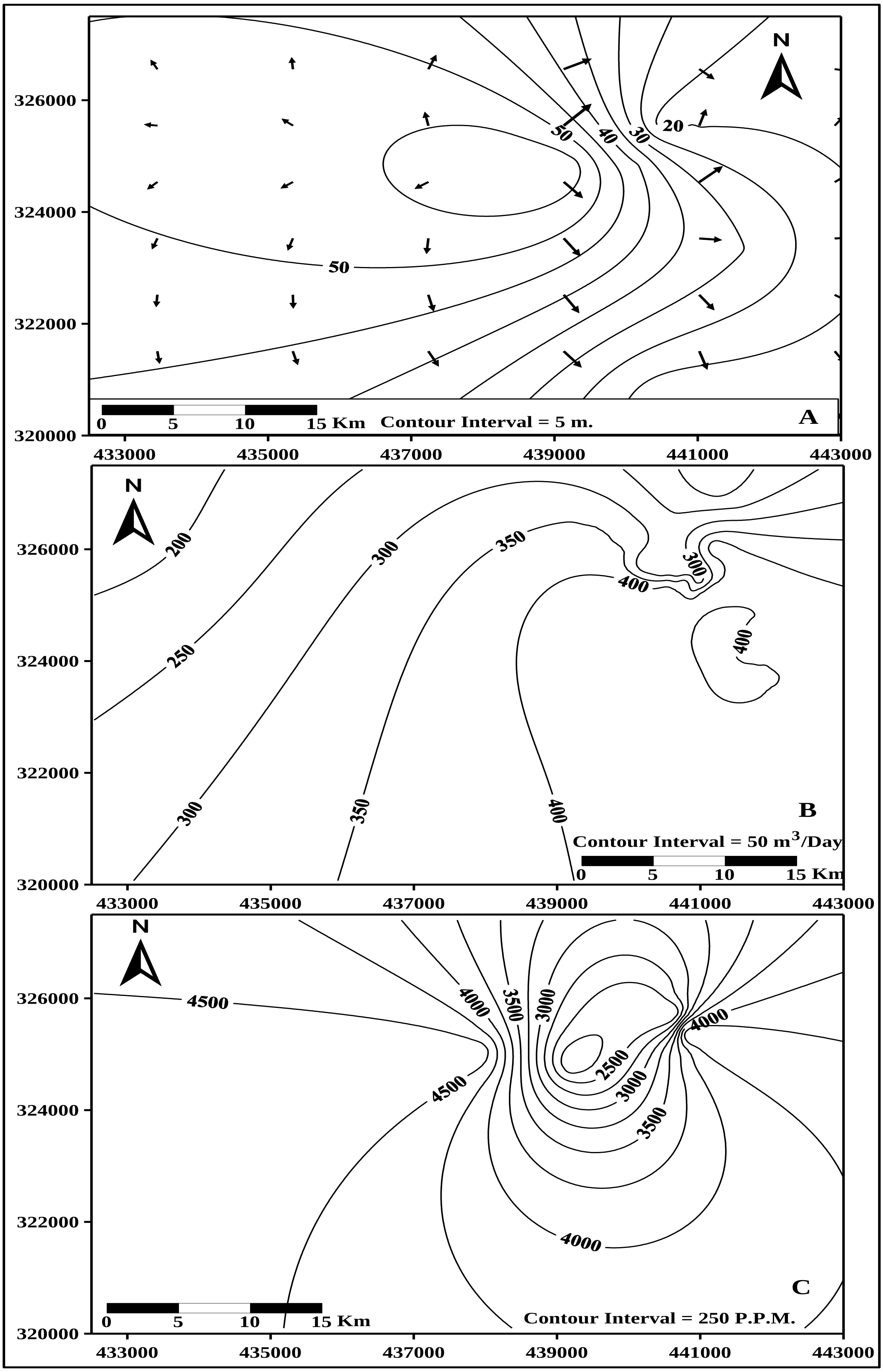

Figure (4): Water Table (A), Maximum Yield (B) and T.D.S. (C) Maps of unconfined aquifer.

2- Hydrogeological and Hydrochemical properties of confined aquifer:

Table (4) and (5) shows the statistical data of hydrogeological and hydrochemical properties in confined aquifers which mainly consist of Dammam, Euphrates, Fatha and Injana Formations according to lithological columns of wells investigated in area.

Table (4): Statistical data shows Hydrogeological properties of confined aquifer.

Statistics	Elevation (m)	Static Water Level (m)	Piezometric level (m.a.s.l.)	Maximum Yield (m*3/day)	Transmissibility (m*2/day)	Total Depth (m)	Thickness (m)
Number of values	10	44	10	34	35	37	37
Minimum	37	0	25	432	2	72	55
Maximum	84.4	74.5	64	950.4	2073	270	261
Range	47.4	74.5	39	518.4	2071	198	206
Mean	56.74	17.18	46.85	841.1	320.18	115.2	95.35
Median	56.5	16.65	45	864	106	100	88.2
Standard deviation	15.2	15.431	12.83	102.6	498.15	44.39	41.43
Coefficient of variation	0.267	0.897	0.273	0.122	1.555	0.385	0.434

Table (5): Statistical data shows Hydrochemical properties of confined aquifer (APHA. 2005).

Statistics	PH	E.C. (µmoh/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)
Number of values	27	32	32	32	32	32	27	31	32	32	30
Minimum	7.12	1835	1416	70	32	81	1.99	149	37.5	293	0.017
Maximum	7.8	5732	4638	660	340	518	22	1065	449	2726	37
Range	0.68	3897	3222	590	308	437	20.01	916	411.5	2433	36.98
Mean	7.28	3084	2245	205.7	99.8	295.3	8.211	424.8	211.6	777.7	4.639
Median	7.23	2825	1973	162.5	91.5	313.5	6.1	427	224.5	645	2.15
Standard deviation	0.175	856.1	727	142.7	63.4	107.1	5.621	165.5	102.5	485.7	7.57

Depth and thickness of this aquifer shown in figure (5 A&B) where topographic has the same influence on distribution of increasing depth and thickness towards northeast and southwest direction of map area, while gradually decreasing shown towards southeast direction. The confined aquifer depth reached (270) m. while the thickness reached (261) m.

The transmissibility of this aquifer was determined by pumping test from (35) wells. The results shown in figure (5C) where increasing values were recorded in the southwest and northeast directions of the map area due to decreasing of aquifer thickness. The maximum value of transmissibility was (2073) m^2/Day.

The piezometric (groundwater flow direction) as shown in figure (5A) has the same radial flow from middle area and finally towards east side of the map area as in unconfined aquifer where influence of topography and aquifer layers dipping was the same cause in flow direction.

In other hand the maximum yield (well discharge) of (34) wells was demonstrated in figure (5B) where maximum values located in eastern and western sides of the map. As mentioned before the confined aquifer thickness increased in these two locations and transmissibility was highest value with assemble of groundwater flow caused increasing the maximum yield to reach the (950) M^3/ Day.

The salinity of confined aquifer presented as total dissolved salts (T.D.S.) shown in figure (5C). The increasing in salinity has the same direction as groundwater flow in this aquifer due to reaction and dissolution of chemical components of geological formation with groundwater within porous media. The maximum value of salinity was recorded as (4638) PPM. The groundwater in confined aquifer was (Na_2SO_4).

Depending on table (6), groundwater utilization indicated that it can't be used for drinking purposes, while few wells can be used for agricultural and animal purposes. However, the nature of the soil in the area and the depth of the groundwater coalfield water for agricultural uses in significant and wide ranges. It was noted that the soil of the region contains a high percentage of sand which holds only (20%) of the irrigation water and it is irrigated daily to maintain the nutrients needed by the plant.

Table (6): Groundwater Utilizations standards

Utilization	**Human Purposes**		**Irrigation purposes**		**Animal purposes**	
Parameter	**WHO(2007)**	**IQS (2005)**	**Standard FAO/1989**		**Standard FAO/1989 Poultry + Livestock**	
Ph	**6.5-8.5**	**6.5-8.5**	**SAR (epm)**	**15**	**Ec (ds/m*)**	**5**
TDS(mg/L)	**1000**	**1000**	**TDS (mg/L)**	**2000**	**Mg (ppm)**	**250**
Ca(mg/L)	**75**	**50**	**Ca (epm)**	**40**	**NO_3 (ppm)**	**100**
Mg (mg/L)	**125**	**50**	**Mg (epm)**	**5**		
Na(mg/L)	**200**	**200**	**Na (epm)**	**20**		
K(mg/L)	**12**	**12**	**Cl (epm)**	**30**		
CL (mg/L)	**250**	**250**	**SO_4 (epm)**	**20**	***ds/m = 1000 MS/Cm**	
HCO_3 (mg/L)	**200**	**200**	**HCO_3 (epm)**	**10**		
SO_4 (mg/L)	**250**	**250**				
NO_3 (mg/L)	**50**	**50**				

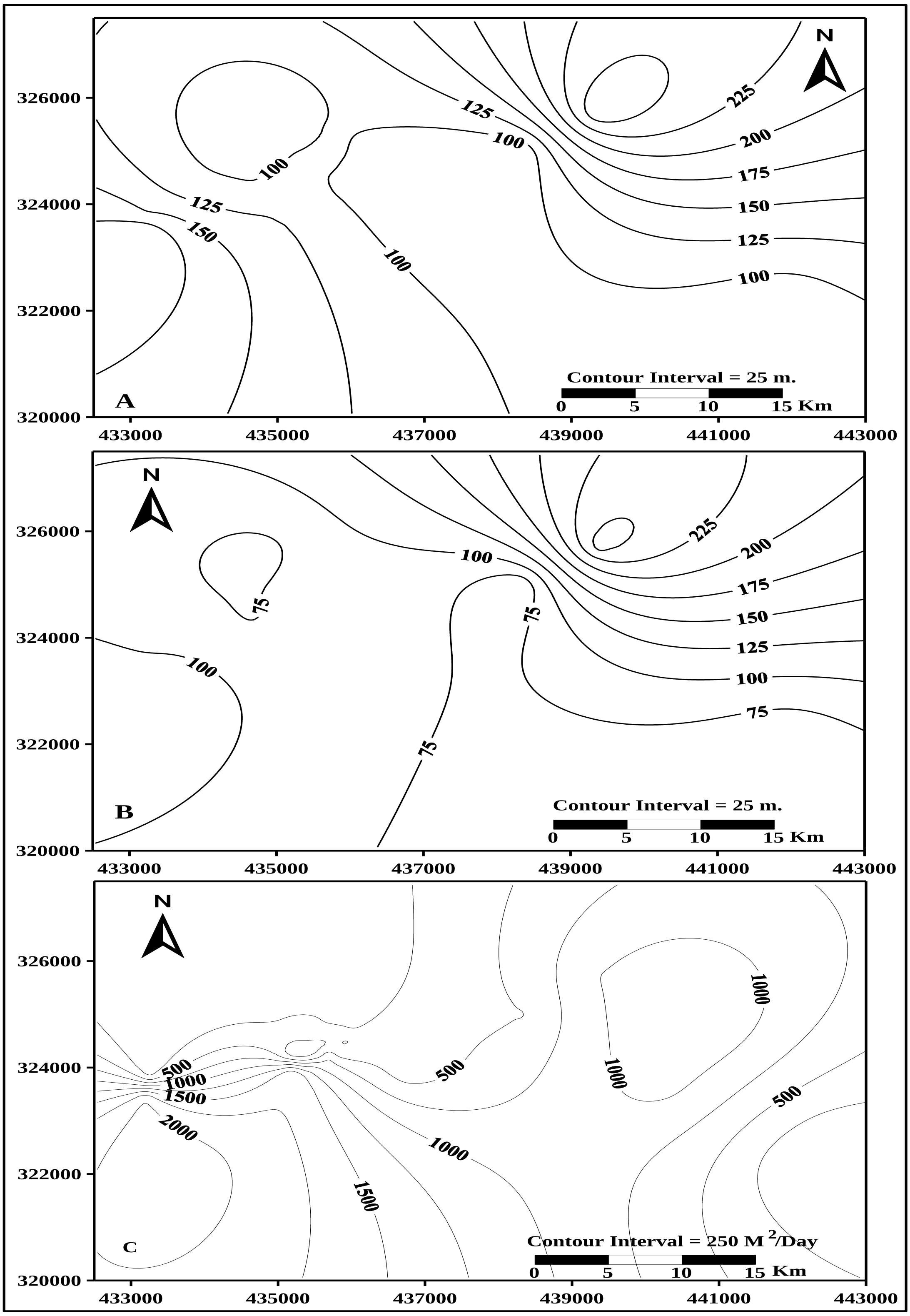

Figure (4): Depth (A), Thickness (B) and Transmissibility (C) of confined aquifer.

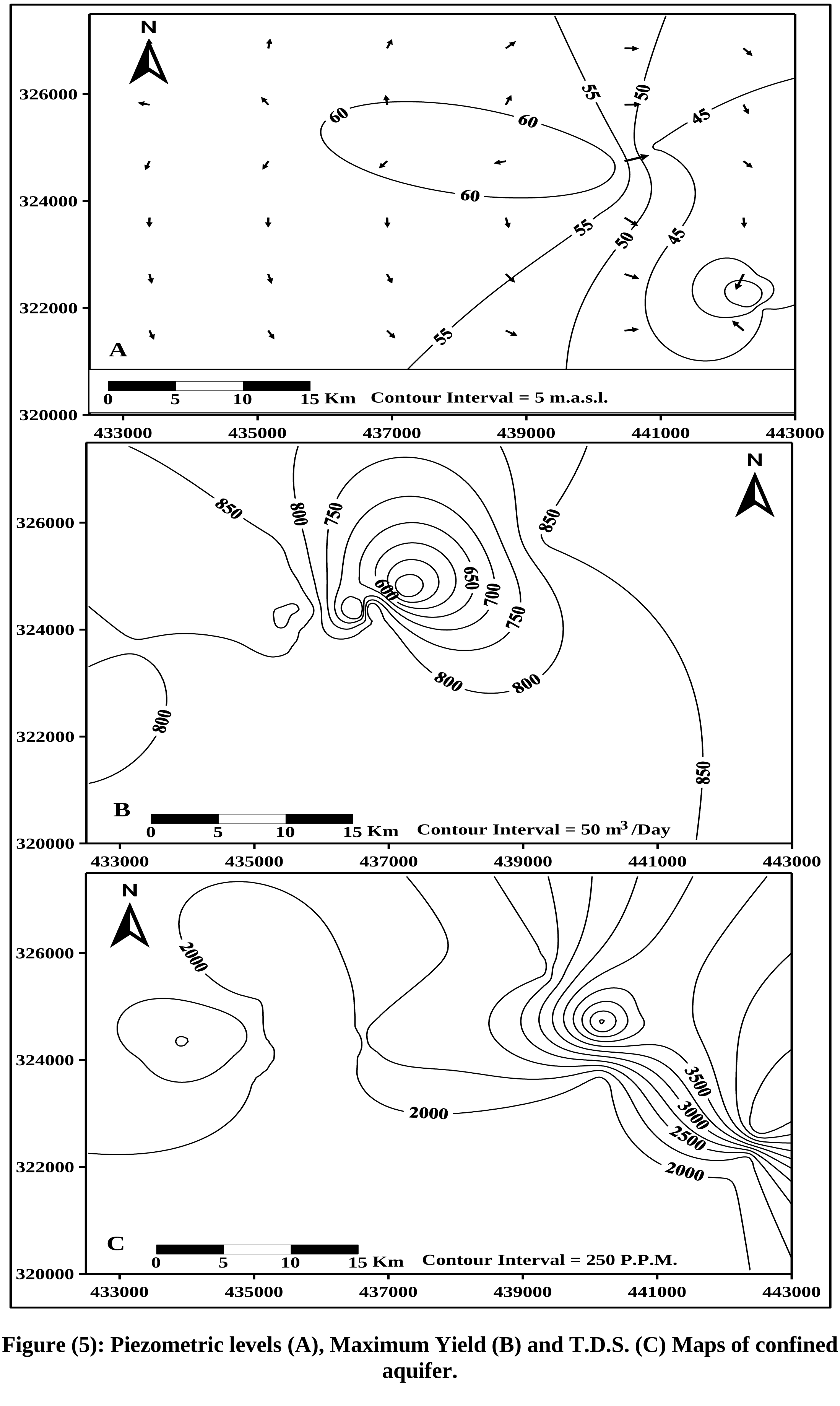

Figure (5): Piezometric levels (A), Maximum Yield (B) and T.D.S. (C) Maps of confined aquifer.

Conclusions:

1- Depending on hydrogeological and hydrochemical properties of unconfined aquifer, the promising zone of useful exploration of ground water located almost in the centre of map area within the northeast part of the region. Depth, thickness, maximum yield and groundwater quality nominate this location to be promising zone although transmissibility with moderate values.

2- The promising zone in the confined aquifer located in the eastern side of area where all hydrogeological properties nominate this region to be a suitable location for exploration, although the groundwater quality was highly concentrated.

3- Groundwater quality of both aquifers not recommended to be used for human and irrigation purposes, even so the farmers used this water for irrigation and animal purposes depending on soil nature and plants.

Recommendations:

1- A study of groundwater recharge levels is required based on the preparation of a comprehensive meteorological water balance to determine the natural recharge of the Debdibba unconfined aquifer due to easily accessible of rain water as a new water source to increase its groundwater reserves.

2 - Isolation the geological formation whenever new wells drilled to prevent the mixing of groundwater qualities using only groundwater of confined aquifer as it less salinity concentration.

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