Journal of Earth Sciences and Geotechnical Engineering, Vol.10, No.4, 2020, 111-124
ISSN: 1792-9040 (print version), 1792-9660 (online)
Scientific Press International Limited

Hydrogeology of the Mesopotamian Plain: A Critical Review

Nadhir Al-Ansari[1], Varoujan K. Sissakian[2,3], Nasrat Adamo[4], Mukhalad Abdullah[5] and Jan Laue[6]

Abstract

The Mesopotamian Plain hydrogeologically is a semi-closed basin where most of the groundwater accumulates in the central and southern parts of the plain. However, small part of the groundwater flows out of the basin to the Gulf. This special character has significant effects on the depth and type of the groundwater in the plain. The depth ranges from (<10 – 100)m; however, the depth in the most of the plain ranges from (10 – 20)m. The type of the ground water is mainly salty water with concentrations of (10,000 – 50,000) mg/l; however, in the central part it is even Brine water (> 500,000 mg/l). No fresh groundwater exists in the plain.

Keywords: Groundwater, salinity, depth to groundwater, aquifer.

[1] Professor, Water Resource Engineering, Lulea University of Technology, Sweden.
[2] Lecturer, University of Kurdistan Hewler.
[3] Private Consultant Geologist, Erbil.
[4] Consultant Dam Engineer, Sweden.
[5] Private Engineer, Baghdad, Iraq.
[6] Professor, Water Resource Engineering, Lulea University of Technology, Sweden.

Article Info: *Received:* March 10, 2020. *Revised:* March 16, 2020.
Published online: May 30, 2020.

1. Introduction

Mesopotamia is a historical region in West Asia situated within the Tigris–Euphrates river system. In modern days, roughly corresponding to most of Iraq, Kuwait, parts of Northern Saudi Arabia, the eastern parts of Syria, Southeastern Turkey, and regions along the Turkish–Syrian and Iran – Iraq borders (Collon, 2011) see Figure 1. Mesopotamia means "(Land) between two rivers" in ancient Greek. The oldest known occurrence of the name Mesopotamia dates to the 4th century BCE, when it was used to designate the land east of the Euphrates in north Syria (Finkelstein, 1962). In modern times, it has been more generally applied to all the lands between the Euphrates and the Tigris, thereby incorporating not only parts of Syria but also almost all of Iraq and southeastern Turkey (Foster and Polinger Foster, 2009). The neighboring steppes to the west of the Euphrates and the western part of the Zagros Mountains are also often included under the wider term Mesopotamia (Canard, 2011, Wilkinson, 2000 and Mathews, 2000). A further distinction is usually made between Upper or Northern Mesopotamia and Lower or Southern Mesopotamia (Miquel et al., 2011). Upper Mesopotamia, also known as the Jazirah, is the area between the Euphrates and the Tigris from their sources down to Baghdad (Canard, 2011). Lower Mesopotamia is the area from Baghdad to the Persian Gulf (Miquel, 2011). In modern scientific usage, the term Mesopotamia often also has a chronological connotation. In modern Western historiography of the region, the term "Mesopotamia" is usually used to designate the area from the beginning of time, until the Muslim conquest in the 630s, with the Arabic names Iraq and Jazirah being used to describe the region after that event (Foster and Polinger Foster, 2009 and Bahrani, 1998).

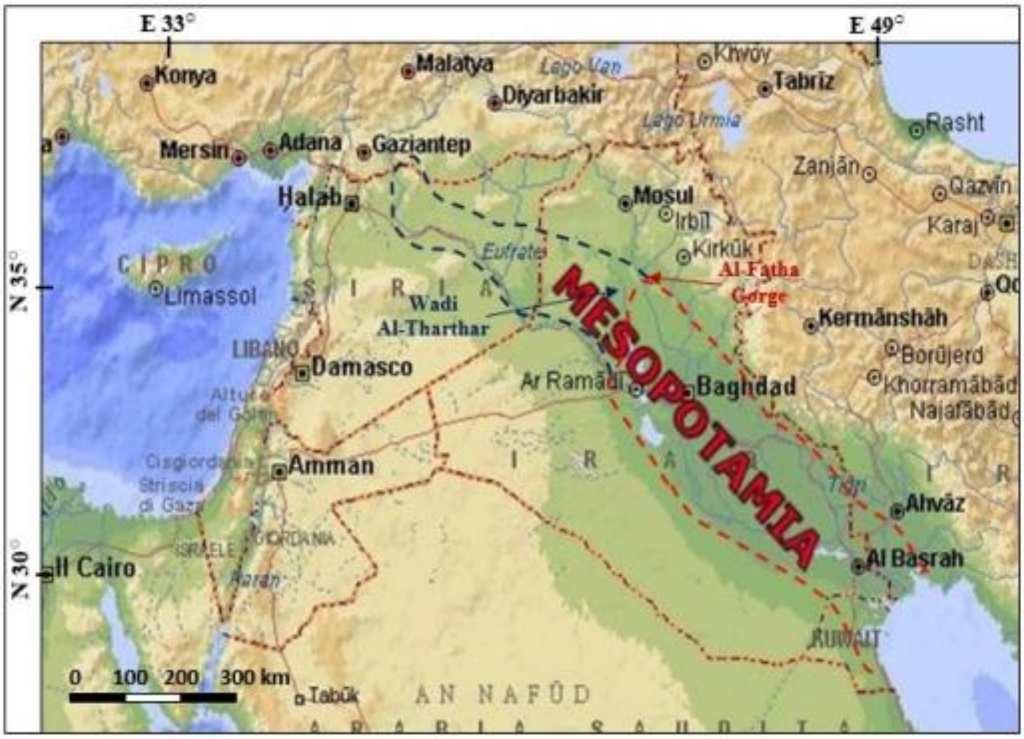

Figure 1: Geographical extension of Mesopotamia (Approximately limited by the dashed blue line including the Mesopotamian Plain) showing the Mesopotamian Plain (Approximately limited by the dashed red line). (Internet data, 2013) (Limits are added by the authors).

The Mesopotamian Plain; however, is different geographically, geologically and historically from the Mesopotamia. The Mesopotamian Plain represents part of the Mesopotamia, and nowadays it represents the existing plain between the Tigris and Euphrates rivers, which is limited south of Al-Fatha gorge in the north. The alluvial plains along the Iraqi – Iranian borders in the east. From the west, it is limited by wadi Al-Tharthar and the eastern limits of the Western Desert; then extending with the northern limits of the Southern Desert (almost parallel to the Euphrates River); forming the southern limits of the plain. From the southeast, it is limited by the upper reaches of the Arabian Gulf, see Figure 1.

The majority of the published data about Mesopotamia is related and concerned with the historical data about different civilizations; since it was the cradle of the civilizations. Therefore, the available published data is related to the late Holocene Period (less than 10,000 years). The majority of the available data is related to irrigation channels, changing and shifting of the river courses, dams' construction and flood controls.

The age of the Mesopotamian Plain goes backs to the Pleistocene (2.558 Ma), and because the alluvial sediments of the plain are not concerned with oil explorations; therefore, very limited data is available from the drilled oil wells, as well as from the water wells; since the water wells very rarely encounter the Pleistocene sediments. Moreover, there is a large similarity between the alluvial sediments of the plain and the underlying Pre-Quaternary sediments (Yacoub, 2011); especially, when the Bai Hassan Formation underlies the Mesopotamian Plain sediments.

2. Hydrogeology of the Mesopotamian Plain

Mesopotamia Plain is topographically a flat plain that slopes gently between Baghdad and Basra city, but it is gently rolling in its northern and eastern parts from all directions towards the center of the basin. This topography causes the ground water to move from all directions towards the central part of the plain. The Quaternary sediments cover the whole plain; they are composed of alternation of clay, silty clay, clayey silt, silt, sand and gravel. Fine sediments represent the aquitards, while sand and gravel form the aquifers. The sediments of the Mesopotamian Plain exhibit abrupt lithological changes, both laterally and vertically; therefore, they are considered regionally as a lithological complex aquifer system. Due to this complex lithological system, there is a hydraulic continuity within the entire Quaternary aquifer system, but the degree of the continuity differs locally depending on the lithology of water bearing sediments. Moreover, there is a hydraulic continuity between surface water and groundwater aquifers. Therefore, effluent and influent river phenomena exist throughout the plain. Moreover, there is a hydraulic continuity between the Quaternary aquifer system in the plain and the underlying pre-Quaternary formations.

2.1 Type of the Sediments and Aquifers

The Mesopotamia Plain is totally covered by Quaternary sediments (Figure 2); the older formations of concern below these sediments are Injana, Mukdadiya, Bai Hassan, and Dibdibba (Yacoub, 2011 and Sissakian and Fouad, 2012). The beds of all pre-Quaternary formations show dip towards the basin from all peripheral parts; however, local subsurface anticlines show local changes from the regional dipping. The exposed rocks at the western and southern sides of the plain have a gentle dip, while those exposed in Makhoul and Hemren Mountains, at northeast and east, have steep dip toward the plain. Both Makhoul and Hemren anticlines have axial trend of NW – SE. Hemren Mountain continues further along the eastern border of Iraq until the area east of Amara city.

The Quaternary sediments of the Mesopotamia Plain are mainly of fine clastics and have abrupt lithological changes, both laterally and vertically. Therefore, lithological units have no large extent throughout the plain, and consequently it is difficult to delineate certain regional aquifers. This is attributed to the lack of adequate information about aquifer geometry in the plain. Therefore, the Quaternary sediments of the plain have been considered regionally as a lithologically complex aquifer system; they are neither aquifers nor aquitards. Consequently, the presentation of the groundwater piezometric level in regional scale is based on the assumption that there is a hydraulic continuity within the entire Quaternary aquifer system, this means that all aquifers are in hydraulic continuity. The degree of continuity of the aquifers and piezometric level differ widely through the plain, depending on the lithological characteristics of the water bearing sediments. Locally, an expressive change might occur in lithological characteristics of water bearing sediments, which may lead to discontinuities in the groundwater distribution. Rivers, lakes and main irrigation and diversion channels form important hydraulic boundaries to the whole aquifer system in the plain; forming effluent and influent rivers phenomena. The authors do believe that the Quaternary Aquifer System and the underlying Bai Hassan and Mukdadiya aquifers are in hydraulic continuity. This is attributed to the lack of a continuous aquitards. Therefore, the water table (level) of these aquifers is considered regionally the same and to be continuous. According to Araim, (1990) and Al-Jiburi and Al-Basrawi (2011) similar conditions exist between the Quaternary sediments with the underlying water bearing carbonates in the southern and southwestern parts of the plain, respectively. However, we don’t think that this assumption is true because in the southern and south western parts of the plain the Quaternary sediments are underlain by clastics of the Dibdibba Formation and not carbonates.

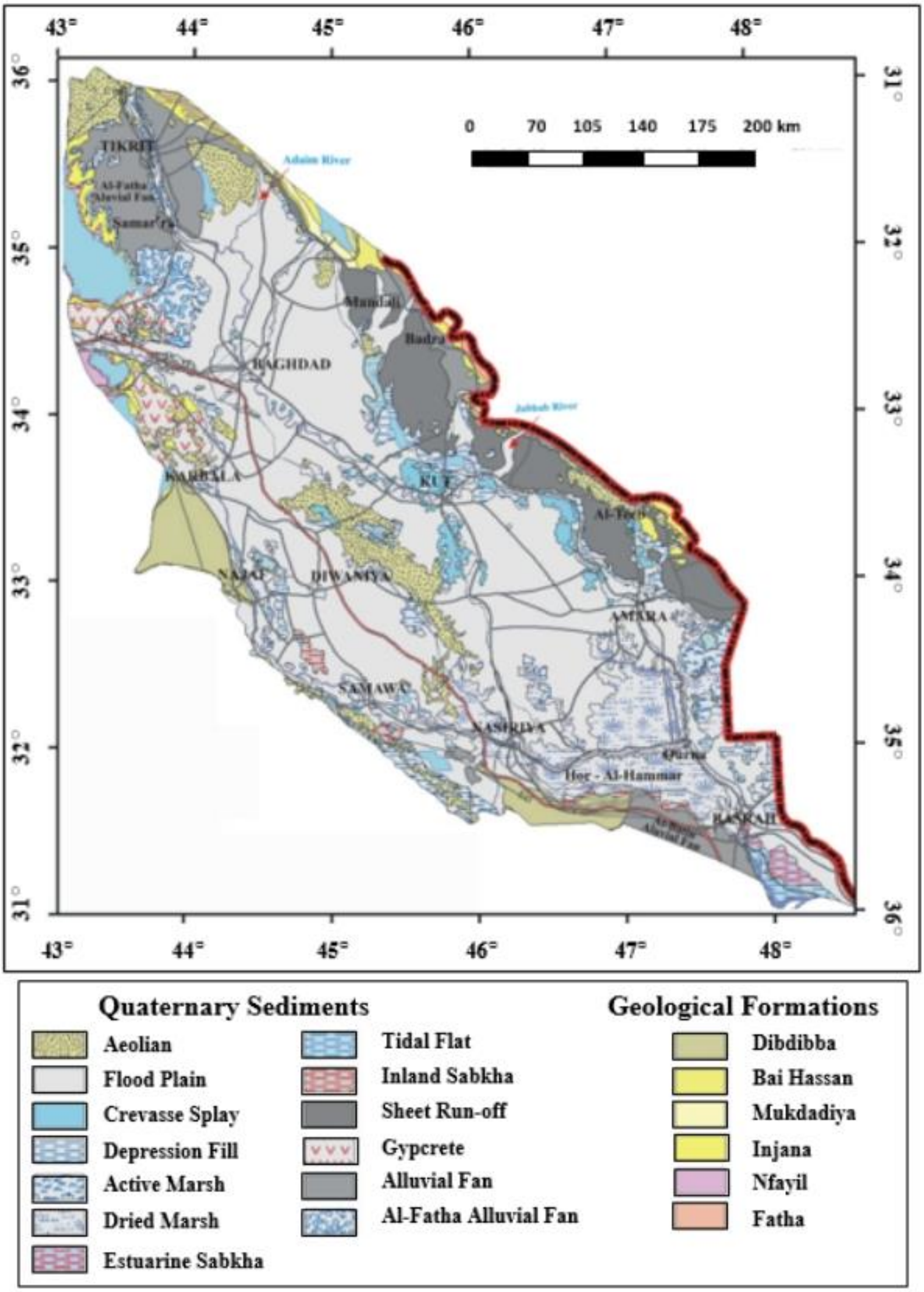

Figure 2: Geological map of the Mesopotamian Plain (After Yacoub, 2011).

2.2 Groundwater Flow Direction

The direction of the groundwater flow in the Mesopotamian Plain is towards the center of the plain from all surrounding regions except the southern side (Figure 3). This is attributed to the character of the basin which represents a regional discharge zone for the whole Mesopotamian Aquifer Mega System of Iraq. The piezometric level of the groundwater is generally inclined from north and northwest; it is < 200m (a.s.l.), near Makhoul Mountain. Towards south and southeast the level reaches 2m (a.s.l.) near Basra city. The flow direction is uniform from the east, north and west directions; however, in the middle parts of the plain there are two abnormal trends. Both of them are parallel to the Tigris and Euphrates rivers, one is between Kut and Amara cities, whereas the second is near Samawa city. The bulges in the contour lines resemble huge longitudinal depression, which may be former courses of both rivers (Figure 3). The existence of subsurface anticlines; however, may play a role in the flow direction especially near Kut and Amara cities (Figure 3) where many subsurface anticlines exist which have parallel trends to the formed bulges in the flow lines.

Concerning he groundwater flow within the central part of the basin which is in the vicinity of Baghdad, the following features can be observed:

1. Influent infiltration takes place from the Euphrates River to areas along its left bank.
2. The left bank of the Tigris River, upstream of the confluence of Diyala River, and its right bank to the south of Baghdad have effluent characteristic; the same characters occur at both banks of the Diyala River. This phenomenon is probably affected by irrigation activities within the northeastern part of the area between the Tigris and Diyala rivers. During flood seasons, this characteristic most probably can be changed into influent character.
   This is probably the case in the Tigris River course, south of Baghdad within the right bank area.
3. Three main piezometric depressions can be observed in the groundwater level within the areas:
   i) between the Euphrates and Tigris Rivers (southwest of Baghdad),
   ii) in the right bank area of Tigris River (northwest of Baghdad), and
   iii) in the southeastern portion of Baghdad (Al-Jiburi, 2004). These features cause the groundwater flow to have different directions (Figure 3).

In the southern part of the Mesopotamian Plain; south of Amara city and southeast of Samawa city (Figure 3), the groundwater flow becomes more uniform; towards the plain from both sides. This is attributed most probably to the presence of the marshes in the area; Hor Al-Huwaizah in the east, Central marshes (west of the Tigris River) and Hor Al-Hammar in the south (Figure 4). These marshes feed the groundwater and because they cover almost the whole concerned area; therefore, the flow direction of the groundwater is more uniform.

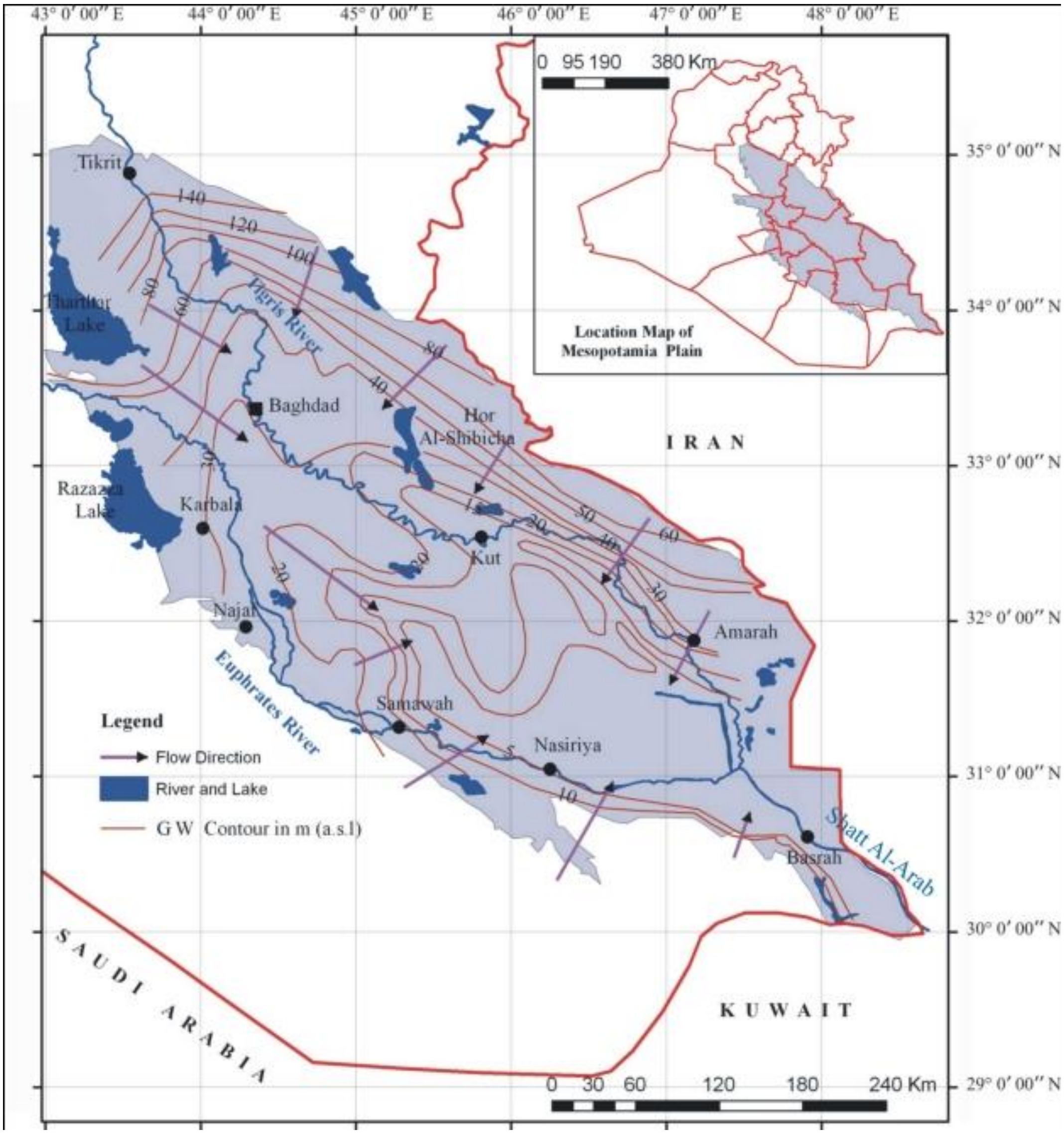

Figure 3: Static ground water level map with flow direction of the Mesopotamia Plain (After Al-Jiburi and Al-Basrawi, 2011)

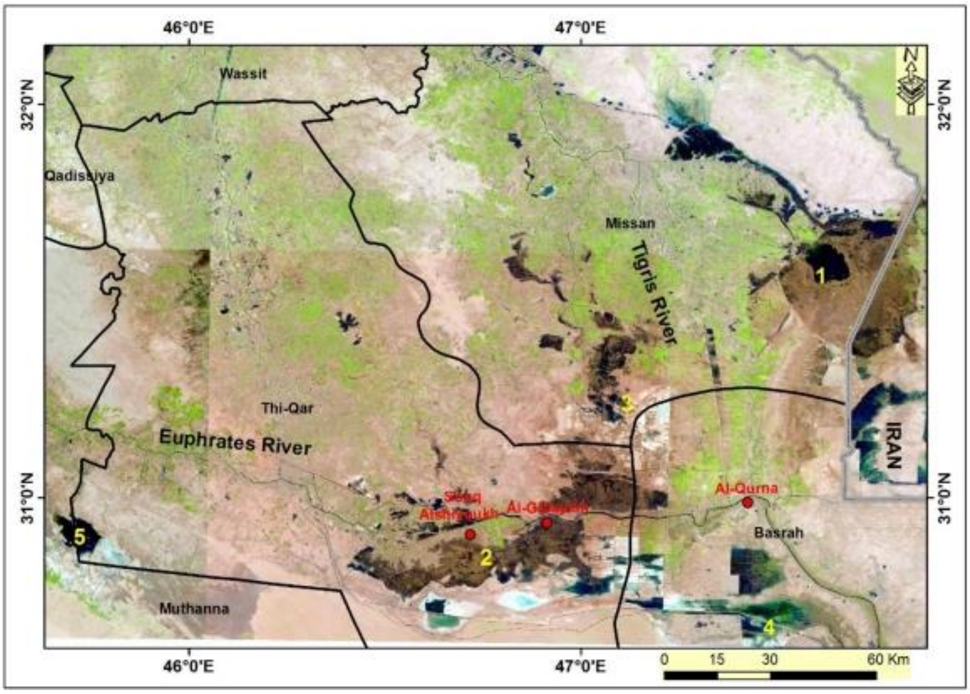

Figure 4: Satellite image of the marshes (2018).
1= Al-Huwaizah, 2= Al-Hammar, 3= Central marshes, 4= Southern marshes, 5= Al-Slaibat Depression.

2.3 Groundwater Level

The groundwater level fluctuations throughout the Mesopotamia Plain depend, mainly on the natural conditions and to some extent on artificial conditions. The former depends on the

1. Existing water bodies on the surface,
2. Type of the sediments,
3. Depth of the Pre-Quaternary sediments,
4. Depth of the existing subsurface anticlines and their activity and
5. The recharge and discharge areas;

Whereas, the latter depends mainly on the intensity of pumping from the aquifers, especially for irrigation purposes. Moreover, the constructed Main Outfall Drain (Al-Mas'ab Al-Am) (Figure 5) plays a big role in the fluctuation of the groundwater. The drain runs in the axial part of the plain and collects the whole drainage water through a dense net of drainage system.

From Figure (5) it is clear that the groundwater depth in the central part of the plain is the lowest (Less than 10 m). It continues from this depth from Bagdad and extends south wards between the two rivers; however, south of Kut city the groundwater depth continues on this depth west wards till Nasiriyah city. There, the depth follows the trend of both rivers covering Hor Al-Hammar and Hor Al-Huwaizah areas and continues as a narrow belt around Shat Al-Arab till the Gulf area (Figure 5).

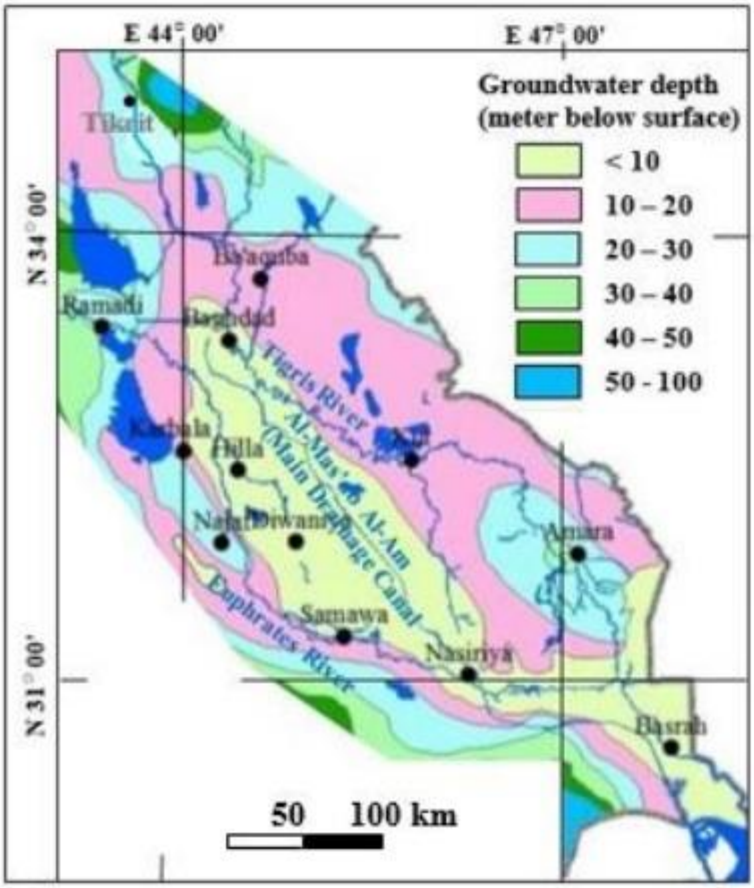

Figure 5: Groundwater depth map (After Al-Jiburi and Al-Basrawi, 2015)

Areas where the groundwater depth ranges from (10 – 20) m form the majority of the Mesopotamian Plain; apart from the peripheral parts and two isolated oval shaped areas (Figure 5) which exhibit depth of (20 – 30) m. One is around Amara city, whereas the second is between Karbala and Najaf cities (Figure 5).

2.4 Groundwater Salinity

The salinity of the groundwater increases generally from the recharge areas towards the discharges areas, within the Mesopotamian Plain (Figure 6). The chemistry of the groundwater changes from sulphatic in the recharge areas to chloric water type in the discharge areas. This change coincides with the groundwater movement directions (Figure 3). It is clear that most of the ground water in the central and southern parts of the plain are salty water type (10,000 – 50,000 mg/l). This area extends southwards from Baghdad and covers of the plain area. In the center of this part, there is a large area of almost circular shape which extends between Kut, Amara and Nasiriyah cities which is with brine water type (> 50,000 mg/l) (Figure 6). In the eastern periphery side of the plain, the water salinity decreases gradually from salty water to very brackish water (5,000 – 10,000 mg/l), brackish water (3,000 – 5,000 mg/ l) and then to slightly brackish water (1,000 – 3,000) (Figure 6). At

Tikrit city and southwards between Tharthar Depression and Al-Adhaim River, there is an area with brackish water also (Figure 6).

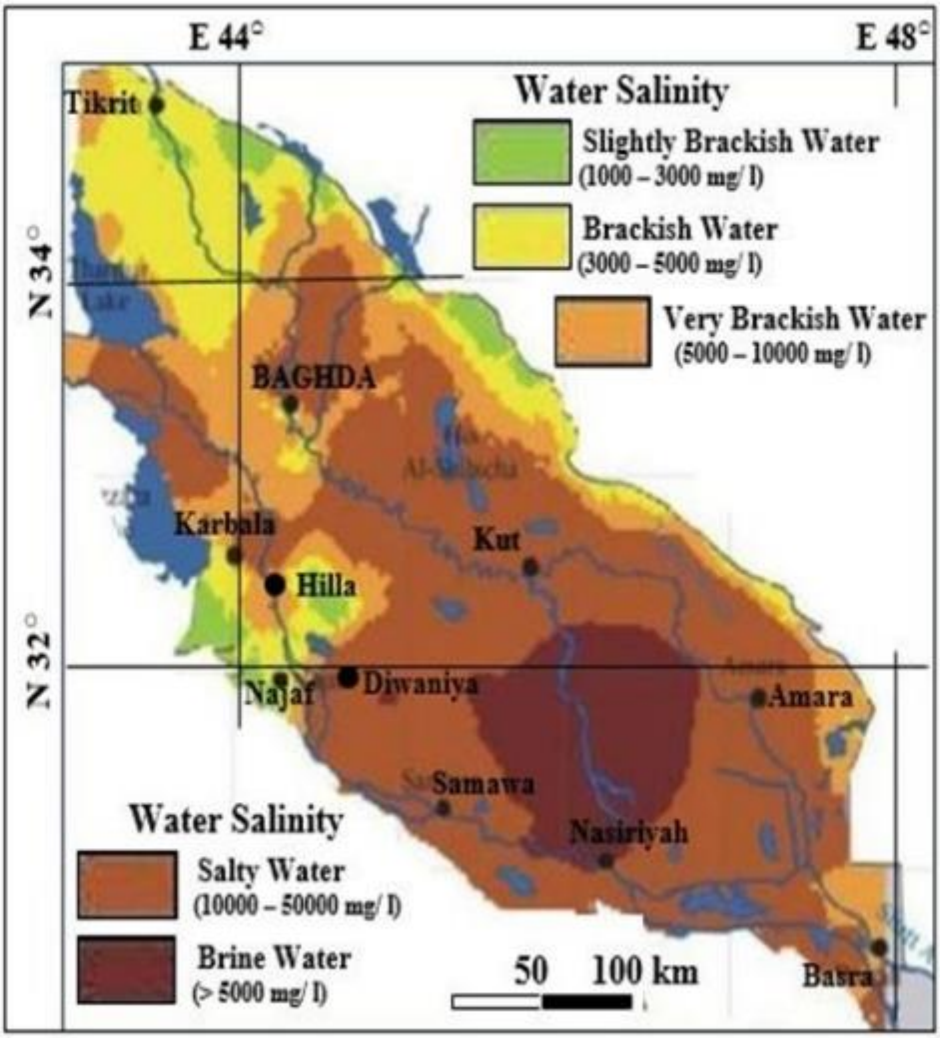

Figure 6: Salinity Zones map of the Mesopotamia Plain.
(After Al-Jibury and Al-Basrawi, 2011).

2.5 Groundwater's Drinkability

The water bearing Quaternary sediments of the Mesopotamian Plain are considered quantitatively promising, but the quality of the groundwater is not favorable for drinking and locally even for irrigation and other industrial uses for high salinity (Figures 6 and 7). Poor quality of water as far as drinkability is concerned prevails in the plain (Figure 7). This is attributed to the high salinity of the groundwater, especially below latitude N 32^o (Figure 7). However, the quality of the groundwater in areas close to rivers and main irrigation canals is better for exploitation and even is used for domestic uses, particularly where phenomenon of induced seepage of fresh water exists. Moreover, in areas along the southern limits of the Low Folded Zone where recharge water zones exist and where the sediments of the alluvial fans cover large areas, the water quality is better (Figure 7).

2.6 Soil Salinization and Solonization

Due to high salt concentration in the groundwater of the Mesopotamian Plain the soil type is changed gradually during decades to more saline soil. The soil type as far as the salinity is concerned is classified following Richards's classification (1954). Accordingly, the soil is classified into five types (Figure 7).

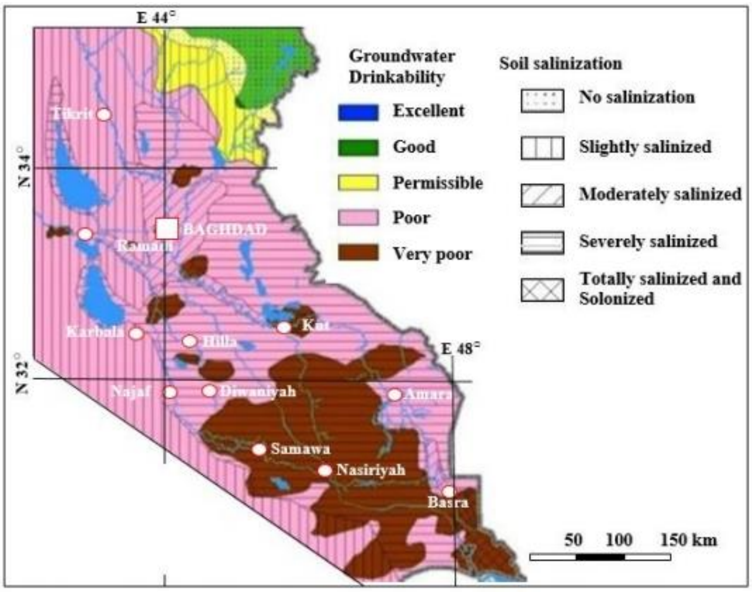

Figure 7: Map of Drinkability of water and soil salinization. (Modified from Al-Jiburi and Al-Basrawi, 2015).

The Severely salinized soil type which prevails in the most of the plain (Figure 7), it increases continuously southwards (east of longitude E 48^o) to become totally salinized soil and changes more to Solonized soil. However, in the northern parts of the plain, at Baghdad vicinity the soil type is moderately salinized and changes to slightly salinized west of longitude E 48^o (Figure 7).

3. Discussion

The following main aspects are discussed hereinafter.

3.1 Groundwater Flow Direction

Figure 3 shows the groundwater flow direction in the Mesopotamian Plain which is towards the center from the peripheral parts with many bulges which change the direction. However, in the southern part, the flow is more regular which means only in two opposite directions but again towards the center of the plain. This is attributed to the surface area which is covered by the marshes (Figures 2 and 4) and means that there is a good conductivity between the surface and ground water and the marshes are also feeding the ground water. However, lack of the data about the true depth of the groundwater due to lack of water wells cannot be ignored in such strange changes in the direction.

3.2 Salinity of the Groundwater

The salinity of the groundwater is increasing continuously in the Mesopotamian Plain. This is mainly due to either climate changes, especially decreasing of annual rain fall or due to man-made, especially wrong water management and abandoning agricultural lands.

4. Conclusions

As conclusion from the current study, we can say the following: The ground water is becoming more saline, with shallower depth. The quality of the groundwater is also affected by the salinity and it is becoming undrinkable and even unsuitable for agricultural uses in large parts of the plain. The soil is also deteriorating as the salinity is increasing due to the aforementioned reasons. The miss-management of functioning of the Main Drainage Canal and using the drain water by most of the farmers are significantly increasing the salinity of the groundwater.

Acknowledgements

The authors express their sincere thanks to Mohammed Al Azzawi (Iraq Geological Survey, Baghdad) for supplying the satellite images and to Mr. Maher Zaini (Iraq Geological Survey, Baghdad) for conducting some of the enclosed figures.

References

[1] Al-Jiburi, H.K. (2004). Hydrogeological and Hydrochemical study of Baghdad Quadrangle (NI38-10), scale 1: 250,000. Iraq Geological Survey Library Report No. 2865.

[2] Al-Jiburi, H.K. and Al-Basrawi, N.H. (2011). Hydrogeology of the Mesopotamian Plain. Iraqi Bulletin of Geology and Mining, Special Issue No. 4, pp. 83 – 103.

[3] Al-Jiburi, H.K. and Al-Basrawi, N. H. (2015). Hydrogeology Map of Iraq, scale 1: 1,000,000, 2nd edition. Iraqi Bulletin of Geology and Mining, Vol. 11 No. 1, pp. 27 – 43.
[4] Araim, H. I. (1990). Hydrogeology Map of Iraq, scale 1:1,000,000, 1st edition. Iraq Geological Survey Publications, Baghdad, Iraq.
[5] Bahrani, Z. (1998). Conjuring Mesopotamia: Imaginative Geography a World Past. In: Meskell, L., Archaeology under Fire: Nationalism, Politics and Heritage in the Eastern Mediterranean and Middle East, London: Routledge, pp. 159–174. ISBN 978-0-41519655-0.
[6] Canard, M. (2011). Aal-ḎJazīra, Ḏjazīrat Aḳūr or Iḳlīm Aḳūr. In: Bearman, P., Bianquis, Th., Bosworth, C.E., van Donzel, E. and Heinrichs, W.P. Encyclopedia of Islam, 2nd edition. Leiden: Brill Online, OCLC 624382576.
[7] Collon, D. (2011). Mesopotamia. BBC, Ancient History in Depth. http://www.bbc.co.uk/history/ancient/cultures/mesopotamia_gallery.shtml.
[8] Finkelstein, J.J. (1962). "Mesopotamia", Journal of Near Eastern Studies, 21 (2), pp. 73 – 92. doi:10.1086/371676, JSTOR 543884.
[9] Foster, B. R. and Polinger Foster, K. (2009). Civilizations of Ancient Iraq, Princeton: Princeton University Press. ISBN 978-0-691-13722-3.
[10] Internet Data (2013). Mesopotamia Research Project/WebQuest http://cybermesowebquest.blogspot.com/2013/10/mesopotamia-researchprojectwebquest.html.
[11] Matthews, R. (2003). The Archaeology of Mesopotamia. Theories and Approaches, Approaching the past, Milton Square: Routledge, ISBN 0-415-25317-9.
[12] Miquel, A., Brice, W.C., Sourdel, D., Aubin, J., Holt, P.M., Kelidar, A., Blanc, H., MacKenzie, D.N. and Pellat, Ch. (2011). "ʿIrāḳ". In: Bearman, P., Bianquis, Th., Bosworth, C.E., van Donzel, E., Heinrichs, W.P., Encyclopedia of Islam, 2nd edit. Leiden: Brill Online, OCLC 624382576.
[13] Sissakian, V.K. and Fouad, S.F. (2012). Geological Map of Iraq, scale 1:1,000,000, 4th edition. Iraq Geological Survey Publications, Baghdad, Iraq. www.iasj.net/iasj?func= fulltext&aId =99666
[14] Wilkinson, T. J. (2000). Regional Approaches to Mesopotamian Archaeology: The Contribution of Archaeological Surveys. Journal of Archaeological Research, Vol.8, No.3, pp.219–267, doi:10.1023/A:1009487620969, ISSN 1573-7756.
[15] Yacoub, S.Y. (2011). Stratigraphy of the Mesopotamia Plain. Iraqi Bulletin of Geology and Mining, Special Issue No. 4, pp. 47 – 82.