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Groundwater Quality and Their Uses in Iraq

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Abstract

Aquifers are porous media with various physical criteria and hydraulic conditions that largely affect the quality of water they contain. When an aquifer is a sedimentary rock, its depositional environment draws along with its present recharge condition and the footprint of its groundwater quality. The geologic setting of Iraq consists of a sedimentary cover 4 – 13 km thick with a sequence of alternating pervious and impervious sedimentary rock beds of coarse clastics and fractured carbonates with fine clastics and hard rock carbonate. This succession has developed a successive multi aquifer systems. The present study has recognized the major formations that so far have been explored and sampled using available data to identify the probability of their water quality which might be obtained when drilling a well through any of the formations. From among tens of thousands of wells drilled to produce water from whatever horizons they encounter, only those wells which penetrate a single formation were considered. The results show that groundwater quality expressed as total dissolved solids in the explored 17 aquifers or aquifer systems are highly variable. Nevertheless, an indicative medium range value can be deduced for each. In principle, lower salinity values and carbonate water type associate with the unconfined aquifers that receive active contemporary recharge as in the case of the exposed aquifers in the High, and to less extend the Low Folded Zones. Even in the Stable Shelf where present recharge is limited, unconfined part of the aquifers is differentiated by their lower salinity and water type. On the other hand, a partial displacement of sea water in the marine deposit carbonates has as well occurred due to previous recharge periods. This was possible to the karstified carbonates of the Stable Shelf due to their high porosity. The finer marine deposits in the Mesopotamia Basin maintained their high groundwater salinity and marine water type. Water suitability for human drinking can be found in most of the aquifers especially

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aquifers in the High and Low Folded Zones. In the Stable Shelf, Al-Jazira, and even in the Mesopotamian Plain, recharge boundary conditions of the aquifer in the selected drilling spot should be carefully examined. The high variations of water quality in the aquifers in the latter zones requires an evaluation of water suitability well by well. However, most of the groundwater derived from the northern parts of the Stable Shelf and Al-Jazira Zones aquifers are suitable for agriculture, while that those of the southern parts and the Mesopotamian Plain are questionable or unsuitable.

Keywords: Water quality, aquifer, Groundwater, Iraq

1 Aquifer Systems Water Quality Approach

Groundwater quality normally varies laterally and vertically affected mainly by aquifers' boundary conditions moving from an aquifer system to another or even from a geological formation to another in one system. Moreover, water salinity usually develops progressively within a flow media even if it is a single bed due to its salts content dissolution as a result of groundwater migration between recharge and discharge zones. The geological setting of Iraq allows such a quality profile with its sedimentary cover of 4 -13 km thick that overlies the pre Cambrian basement (Jassim & Goff 2006). A sequence of alternating pervious and impervious sedimentary rock beds of coarse clastics and fractured carbonates with fine clastics and hard rock carbonate, has developed a successive multi aquifer system particularly noted at the Stable Shelf in the western part of Iraq. The space covered by each system or subsystem is that occupied by the spatial surface and subsurface extensions of the composing beds or formations. For simplicity, a formation is considered an aquifer if it can be shown that one or more of its beds is a water-bearing horizon. The hydro geological studies performed in Iraq between Parsons (The Ralf Parsons, 1955) and ASHRI II (SGI, RTI, T-ZERO, and USGS,2016) have revealed the presence of at least 16 such explored formations in Iraq (Al Jjawad & Ridha 2008). Hence, the mapping of these formations may help identifying the lateral boundaries and the vertical overlap between these aquifer systems. It will as well allow to draw a limit between the different water quality groups (salinity range and water type) associated with each aquifer or aquifer system.

2 Approach Limitations

Defining an individual water quality criterion to each aquifer or aquifer system has however some limitations due to some aquifers natural conditions as well as to special type of data availability. Thus, for example, a sedimentary bed or a sequence of beds that usually form a formation may exhibit aquifer condition in one place but not in another. This was found true for beds extending at both sides of the Mesopotamia Basin. Sediments of the same age deposited at the axis basin trough have shown to be of finer texture and less fracturing than those at the flanks. Accordingly, well identified aquifers extending in the western desert may cease to be so under the Mesopotamian Plain. Such lithological and textural changes of geological formations will be reflected in groundwater quality under the plain. Another identified natural change is the change of aquifer hydraulic condition from unconfined to confined. This is particularly important when the aquifer is renewable.

Difficulties in characterizing an aquifer water quality may arise from a common wrong well drilling practice. Often wells are drilled to penetrate more than one aquifer or water horizon in order to augment their discharges causing groundwater of two different water qualities to mix during production. On the other hand, available water quality data of any aquifer system belong rarely to the same period of time. They may as well taken from a limited surface area of that aquifer.

3 Major aquifers and aquifer systems

To a depth of one kilometer, the aquifer systems in Iraq are sedimentary rocks ranging in age between Quaternary and Paleozoic., though Tertiary aquifers are dominant throughout the country. The explored areal extension of each aquifer is introduced by (Al Jawad and Ridha (2008) who also described their hydraulic conditions and delineate the outcrop extensional areas of their geological formations. In the following, aquifers are briefly described in order to introduce their water qualities and their suitability. In order to orient their locations, the main divisions of the Tectonic Map of Iraq published by Jassim and Goff (2006) and the hydro geologic zones proposed by Al Jiburi and Al Basrawi (2013) as in Figure 1 will be used here for referencing.

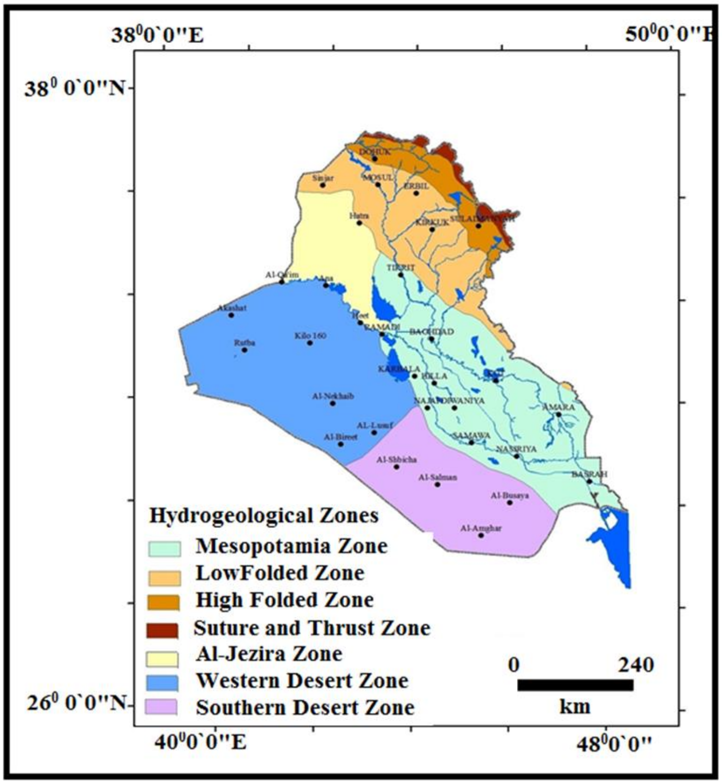


Figure 1: Hydro geological zones in Iraq according to (Al Jiburi and Al Basrawi, 2013)

A. Recent Deposits Aquifers:

a. Plio – Pleistocene (Undifferentiated Quaternary Deposits) aquifers

The Quaternary deposits form aquifers that shallow wells may benefit from. Their major presence is in the Mesopotamian Zone, Al Jazira Zone between the two rivers, and in the Low Folded Zone. They do not make a continues system since they often are connected to surface water boundaries or separated by topographic heights. For this reason, their water quality is highly variable depending on their boundary conditions. Assessment of water quality of 13248 wells that produce groundwater from shallow undifferentiated Quaternary deposits in the Low Folded and Al-Jazira Zones, and the Mesopotamian Plain (south of Baghdad and near the Iraqi-Iranian border) has revealed the following (SGI et al., 2016):

Total dissolved solids (TDS): In the Low Folded Zone (Erbil, Daibaga, Altun Kupri, and middle parts catchment Diyala River) and the southern Al Jazira (Sammara , Tiktit , and Tharthar area) wells with fresh water of <500 mg/l may be found, but in the other extreme there exists also wells with a water salinity of nearly 10000 mg/l. The mean TDS value for the undifferentiated Quaternary deposits in these regions however ranges for multisampling groups between 1800 to 2600 mg/l.

In the Mesopotamian Plain, fresh water of nearly 600 mg/l may also can be found in wells drilled near fresh water bodies, rivers or irrigation canals, but groundwater salinity in certain troughs between the two rivers south of Baghdad may be higher than seawater reaching 60000 mg/l.

At the eastern edge of the Mesopotamian Plain near the Iraqi - Iranian border, the very extreme high TDS values disappear maintaining a maximum of nearly 9000 mg/l level and a minimum of only 510 mg/l. The mean TDS value for the Mesopotamian Plain as a whole range between 2500 and 4000 mg/l.

Water type also varies according to the location of deposit appearances. In the northern part of the Low Folded Zone occurrences like in Daibaga basin sulfate and occasional carbonate types are common, in the southern part of Al Jazira east of Tharthar, calcium then magnesium sulfates are predominant (Jassim & Goff, 2006) and in the Mesopotamian Plain in the southern part of Iraq it is the sodium chloride type predominance.

B. Pleistocene (Alluvial Deposits)

River terraces and alluvial fans are terrains with high groundwater content potential. They have; however, limited extents along the river courses and down the ridge slopes. Sometimes the river terrace is hydraulically well connected to the watercourse conserving its water quality. Alluvial fans on the other hand make limited extent unconfined aquifers replenished directly from infiltrated rainfall. Groundwater content of total dissolved solids in these types of deposits may not therefore be high. However, it is often not easy to distinguish between alluvial fans and undifferentiated Q

uaternary deposits. A water quality assessment of 830 locations believed to represent side of these deposits show that frequently alluvial deposits contain groundwater with a TDS equals to less than 1000 mg/l. The mean of several sampling campaigns' value ranges between 1160 – 2800 mg/l with the higher mean value being possibly influenced by aquifer identification errors.

C. Neogene Aquifers

a. Dibdibba

The Dibdibba Formation is a terrigenous clastics deposited during late Miocene – Pliocene to the NE of the Abu Jair – Euphrates Fault Zone (Jassim & Goff, 2006). It outcrops in the Iraqi Stable Shelf at two locations with a fan shape: a trans boundary fan that originates in Hafr Al Batin in Saudi Arabia extending through to cover the border area between Iraq and Kuwait, and a triangular shape fan with its apex bordering the Mesopotamian Plain between Kerbbala and Najaf (Figure 2).

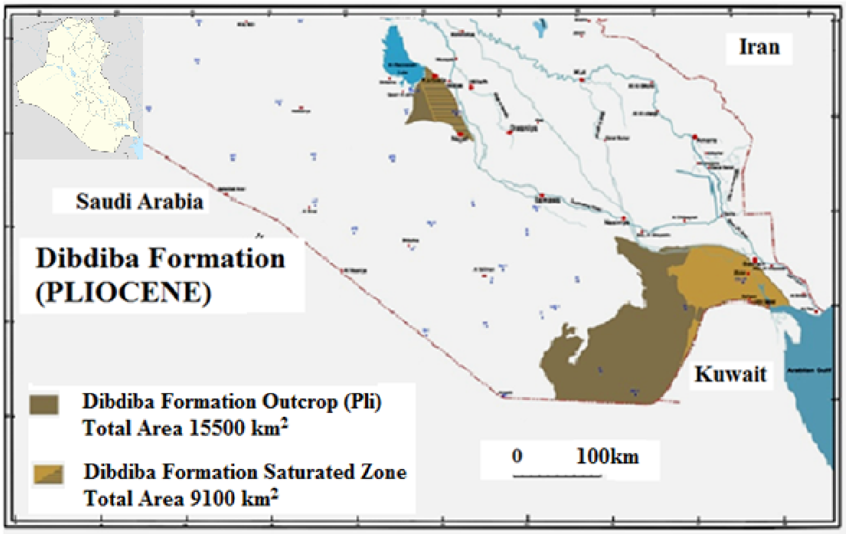


Figure 2: Explored extension of Dibdiba aquifer south and middle Iraq (Al Jawad & Ridha, 2008)

The Dibdibba Formation forms an unconfined aquifer system with a thinning saturated thickness westward leaving large part of the formation unsaturated (ESCWA & BGR, 2013).

Groundwater contained in the Miocene – Pliocene aquifer is in general brackish to saline with great lateral and vertical variations. In the southern Iraq location, two salinity layers are distinguished for the aquifer with the upper horizon having normally lower salinity level than the lower horizon. Nevertheless, its electric conductivity (EC) varies between a low of 2.4 and a high of about 11 dS/m with more than 50% chance that groundwater (EC) of the upper layer would range between 2.5 and about 7 dS /m (Hassan et al., 1989). Lower salinity values of about 1000 mg/l were however reported at certain localities (depressions) where present day recharge is believed to occur (Al Jawad et al., 1970). The total dissolved solids (TDS) contained in the second layer exceeds normally 15000 mg/l. The separation between the two layers is may be by a less permeable bed or just a transitional interface whereby less saline water is floating over more saline one. The cause of the high salinity in the deeper horizons of the aquifer was speculated by authors like Parsons (1955) who assumed possible connection with sea water, or a possible communication with the deeper carbonates (Dammam Formation of Eocene age) which contains saline groundwater in this part of Iraq. (Jawad et al., 1970), (Al Rawi et al 1983). Water type of the upper layer is generally of calcium or sodium carbonate with high possibility that the deeper layer contains sodium chloride type. The concentration of Boron was found to be relatively high ranging between 0.9 and 2.5 mg/l.

At the second location in mid Iraq, the aquifer demonstrates a lower salinity levels. Mean TDS values of several sampling campaigns range between 2000 and 3800 mg/l varying between a low of 300 and a high of 8800 mg/l (SGI & al., 2016). Its dominant water type is calcium sulfate.

b. Bai Hassan

The Bai Hassan Formation is a conglomeratic facies deposited as alluvial fans originated from the High Folded Zone and the Zagros Suture Zone (Jassim & Goff, 2006). It appears in the north east and central parts of Iraq filling several synclinal troughs separated by NW –SE trending anticlines. The highly pervious continental deposit forms unconfined and sometimes semi confined aquifers under younger Quaternary deposits (Figure 3), (Al Jawad & Ridha,2008). It is within a region of potential annual renewability.

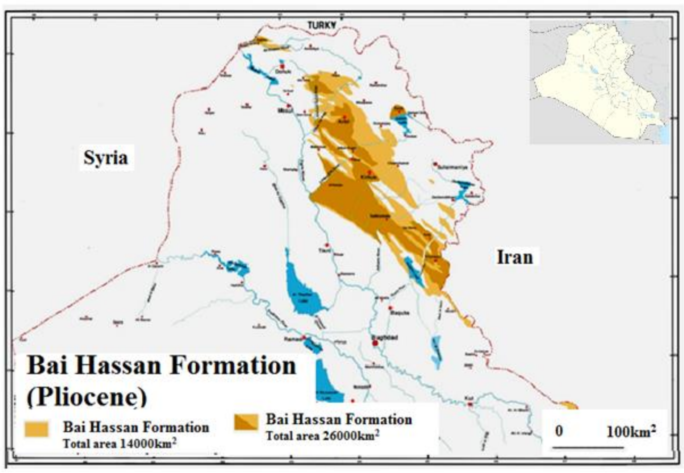


Figure3: Extension of explored Bai Hassan aquifer in the low folded zone (Al Jawad & Ridha, 2008).

A total of more than 1500 water samples have indicated that the total dissolved solids (TDS) of this aquifer has a high range extending between as low as 150 mg/l to as high as 10718 mg/l (SGI & al., 2016). The mean and most frequent values however are expected to lie between 673 and 3964 mg/l. Salinity increases in the southwest moving from Erbil toward Daibaga and Kirkuk. This increase is associated with a change of water type from a predominant carbonate in Erbil basin (Al Jiburi & Al Basrawi, 2013) to sulfate in the Daibaga basin (Al Jawad et al, 2007).

c. Mukdadiya

The Mukdadiya Formation is a Late Miocene – Pliocene clastics of gravely sandstone, sandstone and red mudstone deposited in fluvial environment (Jassim & Goff, 2006). It associates and underlies Bai Hassan Formation in the Low Folded Zone being formerly designated as upper and lower members of one formation. It appears alone however further to the south in Kirkuk and even Mendili area. Due to its finer depositional material, it has a less pervious matrix but still a potential renewable aquifer.

The total dissolved solids (TDS) of about 1300 water samples taken from wells penetrating only Mukdadiya aquifer indicate that the extreme values could go as low as 204 and as high as 7082 mg /l with the mean being nearly 2800 mg/l. Water type is predominantly calcium sulfate.

d. Injana &Fatha aquifer system (Middle to Late Miocene):

The Injana (ex-Upper & middle Fars) Formation is a fine grained clastics deposited in coastal and fluvio lacustrine environment. At base, it consists of thin beds of calcareous sandstone, mudstone and gypsum beds coarsens upward with thicker alternating beds of sandstone, siltstone, and mudstone (Jassim & Goff, 2006). The sandstone constitutes several horizons of water bearing beds that furnish hundreds of moderately productive wells in Al-Jazira area north and North West of Iraq. It occurs usually as a renewable unconfined or semi confined aquifer and forms with the underlying lagoon evaporite (gypsum) karst beds of Fatha Formation a Neogene trans boundary aquifer system with Syria (ESCWA & BGR ,2013).

Groundwater quality of this aquifer system is in general brackish to saline with sulfate water type. Although with high variations, the Injana aquifer has usually a better groundwater quality than Fatha. In the northern Rabia basin, the total dissolved solids of the groundwater were reported to vary between less than 1000 to 4000 mg / l in the majority of the wells. Water type is predominantly of sodium sulfate (Jawad, 1982). Limited Locations within this basin where groundwater salinity is found to exceed the mentioned range is attributed to mixing with groundwater contained in Al Fatha aquifer. In the southern Al Jazira, where wells penetrate Injana aquifer alone, there is a high probability that the tapped groundwater has a total dissolved salts of < 4500 mg / l; though potable water of less than 1000 mg/l is frequently encountered especially in shallow wells. Water type is generally calcium sulfate type and sometimes bicarbonate when shallow or sodium chloride when deep. Groundwater of Fatha aquifer however is reported with a general total dissolved solid of 3000 – 5000 mg/l, increasing to 20000 mg/l in salt lakes (Jassim & Goff, 2006). Other reports mentioned the presence of fresher water < 500 mg/l in some shallow wells with saline water of over 30000 mg/ l in playa and salt lakes, and a range of 5000 -20000 mg / l for deeper wells (Al Jiburi & Al Basrawi, 2013).

A recent assessment based on over 2400 wells penetrating Injana Formation only has revealed that the groundwater TDS of that aquifer could range between as low as 197 mg/l and as high as 17000 mg/l with a mean range of (1928-2715) mg/l. A parallel assessment of about 650 wells penetrating Al Fatha Formation only indicated that the groundwater TDS might be as low as 255 mg/l and as high as 17450 mg/l but the mean ranges between 3000 and 3620 mg/l (SGI 7 al., 2016).

e. Euphrates (Early Miocene)

The Euphrates Formation is a heterogeneous formation consists mainly of limestone often recrystallized and siliceous with a texture ranging from oolitic to chalky. It also contains marl, breccia's, and conglomerate beds (Jassim & Goff, 2006). Its major appearance is along the northern reach of the Euphrates River between the river's first entrances to Iraq to the lake Al Razaza,

The western half of the outcropping formation is dry rock, while the second eastern half is partially an unconfined aquifer with a confined aquifer strip near and by the river (Figure 4)

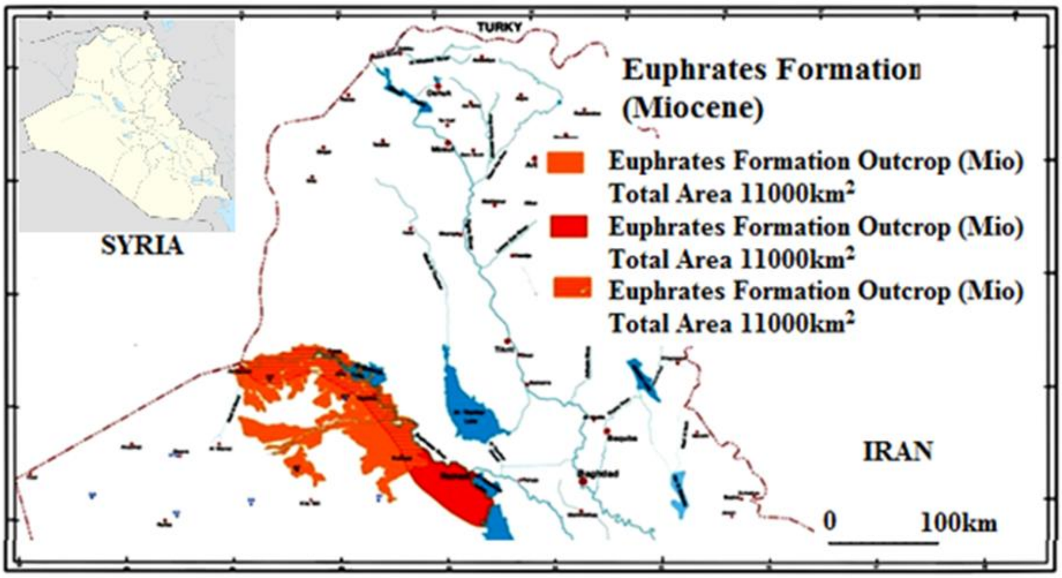


Figure 4: Explored Extension of Euphrates aquifer in the western desert (Al Jawad & Ridha, 2008)

Groundwater quality was assessed using 226 wells producing from the Euphrates aquifer alone. The total dissolved solids (TDS) of the aquifer samples ranges between a low of 368 mg/l and a high of 8898 mg/l with the mean values ranging between 1692 and 3900 mg/l. Water is predominantly of sulfate water type.

D. Paleogene:

a. Dammam (Eocene)

The Dammam Formation is composed of at least two carbonate members the lower of which was deposited in a shallow marine shelf and the upper in a lagoonal environment. With basal conglomerate or brecciate limestone at base, both members are constituted of recrystallised fossiliferous limestone or dolomitic limestone beds occasionally chalky, silicified or argillaceous. The formation spread widely in the Stable Shelf to the west of Euphrates River particularly in the southern desert zone where all formation members appear. Due to erosion, the higher member is absent in the northern desert zone.

Near the Euphrates River in the southern desert, full formation thickness is saturated and the formation features a confined aquifer condition. Further to the west, the aquifer becomes unconfined and its saturated thickness faints gradually. Dammam Formation presence as an aquifer is usually confined in the southern desert south of Al Ramadi with the exception of a small appearance in the northern part close to the Euphrates River (Figure 5).

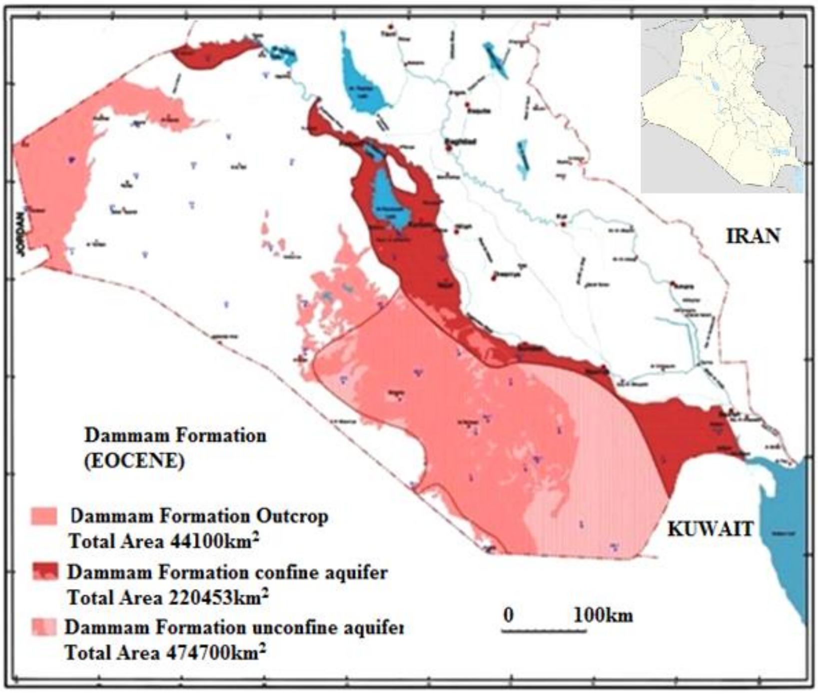


Figure 5: Explored Extension of Dammam aquifer in the western and Sothern desert zones (Al Jawad &Ridha, 2008)

Groundwater quality of Dammam aquifer is highly variable between its recharge and discharge zones. An increasing gradient of (TDS) value from 3000 mg/l to > 5000 mg/l was reported by (Al Jawad et al. 2001) moving from aquifer's unconfined condition to the west and its confined condition to the east. Moving to the south however, the aquifer is further polluted with the presence of the underlying Rus Formation consisting predominantly of anhydrite. Total dissolved solids in deeper parts of the confined Dammam aquifer south of Al Sammawa climbs fast reaching to an extreme value of 80000 mg/l. A more detailed assessment using 562 wells producing uniquely from the Dammam aquifer has shown that the TDS could be as low as 390 mg/l with a mean value for multi sampling campaigns ranging between 1898 and 4069 mg/l (SGI et al., 2016)

Water is generally of sulfate type with a smell of H_2S but with gradually increasing salinity, it becomes of chloride type to the southeast.

b. Pela Spi (Late Eocene):

The Pela Spi Formation is an important water bearing formation in the High Folded Zone of Iraq. It consists of two horizons of bituminous limestone: the lower is hard and porous, while the upper is chalky and crystalline (Jassim & Goff, 2006-page 166). It forms with Sinjar, a limestone of algal reef, lagoonal and shoal facies, one aquifer system separated often by the impermeable Gercus. The system is described as fissured-karstic aquifer with high renewability that maintains the flow of important springs in the High Fold Zone region.

Groundwater quality is rated very good with the total dissolved solids ranging between 500 and 1000 mg/l but often is less than 500 mg/l. Water type is predominantly: calcium – Magnesium bicarbonate (Stevanovic and Markovic, 2004).

c. Umm Er Radhumma (Paleocene)

The Umm Er Radhumma Formation outcrops in the eastern part of the Rutba Uplift and southward along the Iraqi Saudi Arabia border. Its presence however is noticed throughout the southern desert with its thickness increasing eastward as it pinches under the Mesopotamian Zone. Being composed of chalky limestone and recrystallized shelly calcareous dolomite, the formation was deposited in a sub tidal marine environment with its shallower western part passing into phosphatic facies, called the Akashat Formation while the deeper eastern part passing into a more basinal type deposit (Jassim & Goff, 2008)

The Um Er Radhumma Formation forms with the overlying Dammam Formation an extensive upper most trans boundary aquifer system between Iraq and Saudi Arabia (ESCWA & BGR, 2013). The two formations are hydraulically connected except where the lagoonal Rus formation occurs between the two in certain parts of the southern Iraqi desert south of Al Sammawa where Umm Er Radhumma aquifer features confined condition. Otherwise, the system receives recharge not on an annual basis from occasional rain storms at areas where one of them is exposed.

Water quality of Umm Er Radhumma aquifer is therefore greatly variable in the lateral scene following its changing boundary conditions. The total dissolved solids of the groundwater increases gradually on going south moving from a renewable unconfined aquifer condition to the east of Rutba Uplift in the western desert to confined aquifer condition under the Rus Formation and the low groundwater circulation zone under the Mesopotamian Basin (Figure 6).

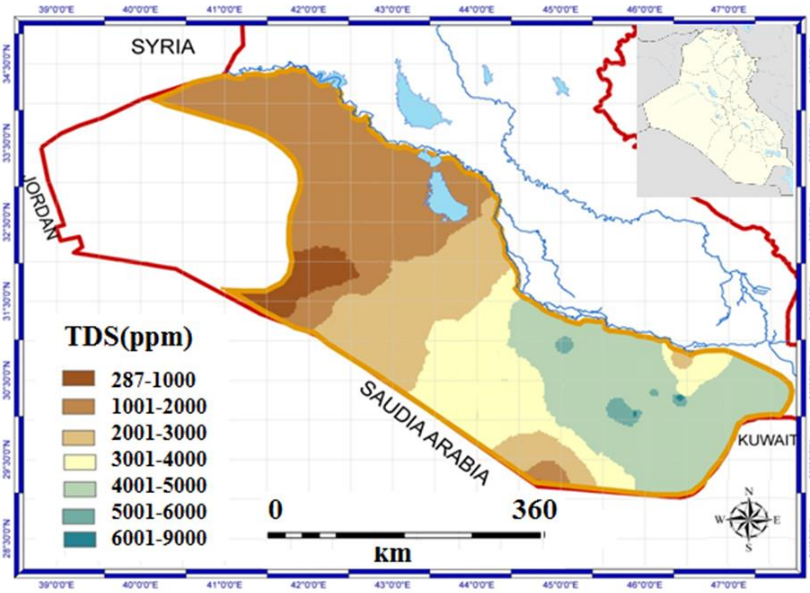


Figure 6: Explored extension of Umm Er Radumma aquifer and the spatial distribution of total dissolved solids in its groundwater (Al Fatlawi, 2010)

The value of ground water (TDS) for Umm Er Radhumma aquifer ranges between a low of 780 mg/l to a high of 6400 mg/l (Al Jawad et al. 2001). The mean value for the (TDS) was reported to be 2200 mg/l with a dominant calcium sulfate water type becoming sodium chloride at higher water salinity (Al- Fatlawi, 2010).

B. Cretaceous Aquifers:

a. Tayarat (Maastrichtian)

Tayarat is a wide spread formation in the western desert with its outcrops appearing to the south and west of Rutba Uplift. At the later location, it has a limited appearance passing into the Digma Formation, a phosphate rich deposit, whereas in the former the major extent and higher thickness occurs at the subsurface to the west side of the southern desert closer to the Iraqi- Saudi border. The facies of this inner shelf carbonate deposit and their distribution were influenced by the Rutbah uplift. The basal unit of the formation is coarse grained calcareous sandstone passing upward into dolomitic limestone while the upper unit is comprised of limestone overlain by mudstone and dolomite (Jassim & Goff, 2006).

The Tayarat Formation does not feature unconfined aquifer condition. In fact, its outcrops as well as major part of its subsurface extension do not contain water. The remaining confined aquifer part makes only 1/3 of the formation extensional area (Al Jawad & al. 2001). The aquifer is recharged however with temporal rainwater through its exposures (Figure 7).

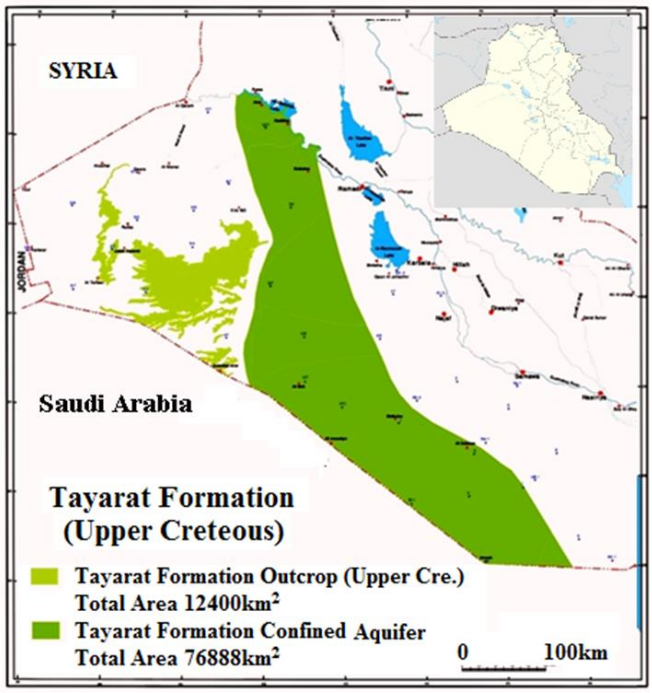


Figure7: Explored Tayarat aquifer extension in the western desert (Al Jawad & Ridha, 2008)

This has been noted by the few bicarbonate water type produced from wells penetrating the aquifer part of the formation, the major water type however is chloride and sulfate as usual (Al Jiburi & Al Basrawi,2013). The total dissolved solids (TDS) in the groundwater of the Tayarat aquifer was found to range between a low of 291 and a high of 3330 mg/l.

In another study, the range was found to vary between 400 and 4000 mg/l with the mean being close to 2450 mg/l (Al Jawad & al., 2001). It is to be noted though that no new data, apart from the old studies in the early 80ies (Consortium,1981) was lately reported.

b. Hartha (Maastrichtian)

Like Tayarat, Hartha Formation crops out in the Western Desert around Rutba Uplift and has important subsurface extension to the south and east under the Stable Shelf and the Mesopotamia Zones. In its outcrop area, it represents a supratidal- subtidal depositional environment by consisting of marl and dolomite beds. In other localities in the same area, a basal clastic unit of calcareous sandstone interbedded with fossiliferous limestone and overlain by dolomite was identified. With the exception of a limited zone near the Iraqi Saudi border, the Hartha aquifer is not tapped by water wells due to its depth. Even here, it is usually associated with the younger and more discovered the Tayarat aquifer.

As in the case of Tayarat, the Hartha does not feature unconfined aquifer condition in Iraq. The Aruma Formation however, which is its equivalent across the border may feature such aquifer condition allowing by thus temporal recharge to both.

The few wells that penetrate the confined aquifer, indicate that the total dissolved solids are similar to that of Tayarat ranging between 1560 and 4770 mg/l with sulfate water type (Al Jawad & al., 2001) and (Al Jiburi & Albasrawi,2013)

c. Bekhme (Late Campanian – Early Maastrichtian)

The so called Bekhme karst aquifer system is a heterogeneous carbonate mass including several formations occurring in various combinations at the High Folded Zone of Iraq composed of: Qamchuqa, Dokan, Kometan, Bekhme. The main members of the system are however two units: Aqra and Bekhme. The younger Aqra consists of conglomerates at the base and limestone with marly limestone in the upper level followed by bitumen impregnations. Similarly, Bekhme consists of conglomeratic base, a reef detrital limestone alternating with fore reef shoal limestone in the middle, and bituminous secondary dolomites on top (Stevanovic & Markovic, 2004). The system is highly fissured, well karstified with many features like channels and caves in surface and at depth. The aquifer system features unconfined condition with high renewability estimated at 50% of rainfall (Stevanovic & Markovic, 2004). Aquifer discharge is often exhibited by springs flow which represents explicitly its water quality. The total dissolved solids (TDS) in spring water varies between a minimum of 104 to a maximum of 1384 mg/l (Gara Bureau, 2002 as in Stevanovic and Markovic, 2004), but normally it is below 1000 mg/l and even less than 500 mg/l). Water type is predominantly calcium bicarbonate with the sulfate being second predominant. Magnesium increases to become dominant at dolomite presence (Kandal Company, 2002 as in Stevanovic and Markovic, 2004)

d. Rutba (Cenomanian)

The Rutba Formation has a limited appearance in the Western Desert outcropping near Al-Rutba, in Wadi Hauran, and to the west of Gaara depression. It extends however in the northern part of the desert to the north, east and south under younger sediments with increasing thickness. The formation was deposited in a continental and shallow marine environment as alternations of fine to coarse quartz grain, occasionally clayey, sandstone and sandy dolomitic limestone. Near ~~Al~~ Rutba Uplift, the exposed Rutba Formation features an unconfined aquifer condition becoming confined or semi confined elsewhere. Nevertheless, less than 1/3 of the formation extent does contain water (Ridha, 2013). To the south and near to the Saudi Arabian border, the Rutba aquifer forms one aquifer system with the younger Msad Formation which consists of chalky limestone deposited in shallow marine environment and clastic deposits of clayey sandstone. This system is believed to be part of the trans boundary Rutba – Sakaka aquifer system between Iraq and Saudi Arabia (ESCWA & BGR, 2013).

Water quality of the Rutba- Msad aquifer system is mentioned in more than one report but with reference to few samples (Al Jawad et al.,2001), Al Jiburi & Al Basrawi, 2013) and (Ridha, 2013). The total dissolved solids ranges between a low of 1270 and a high of 5610 mg/l with the median value being equal to 1996 mg/l. Water type is reported to be sodium chloride or sodium sulfate.

F. Jurassic Aquifers:

Jurassic rocks in Iraq that could be considered as water-bearing formations are few. In the Stable Shelf only Muhaiwir Formation is recognized and tapped by water wells, while in the Low Folded and the High Folded Zones of the Unstable Shelf no Jurassic formation has been hydro geologically investigated.

Muhaiwir is a two unit's formation, the lower of which is deposited in a shallow water inner shelf environment consisting of a basal quartz sandstone with layers of sandy, hard, coralline, recrystallized limestone; while the upper unit is of a basal conglomerate sandstone passing into alternating marl, marly and fossiliferous limestone deposited in an inner shelf marine environment (Jassim & Goff, 2006). The formation has only a limited exposure in the western desert to the east of Al Rutba and in Wadi Hauran. However, its subsurface extension to the east and north has been confirmed by geological sections as well as its presence at the western side of the Rutba Uplift at the Iraqi Jordanian border which could make it a part of a trans boundary aquifer system.

The limited exposures of the formation in Wadi Hauran has provided the Muhaiwir aquifer with an advantage of occasional flood recharge. The aquifer features confined condition elsewhere and possibly makes part of a larger aquifer system including Triassic or even of Paliozoic formations.

Water quality of groundwater samples collected from Muhaiwir aquifer depends on the well location. At its recharge zone in Wadi Hauran, the total dissolved solids were found to be in the range of 585 mg/l with bicarbonate water type, further to the east toward Euphrates River in the confined aquifer it was found to reach 5868 mg/l (Al Jawad et al,2001). At depth, the salinity increases and could be affected by brine water associated with oil and at one location it was found to reach 14398 mg/l and chloride water type (Al Jiburi & Al Basrawi, 2013). It is however in the range of 2000 mg/l in the confined aquifer at the Iraqi Jordanian border.

G. Triassic Aquifers:

The recognized and tapped Triassic water bearing beds are those of the Mulussa Formation of the Upper Triassic which is exposed in ~~Al~~ Rutba sub zone of the Stable Shelf. Other Triassic sediments deposited elsewhere are either fine and deep sediments as in the Mesopotamia Zone or deep untapped sediments as in the High Folded Zone of the Unstable Shelf. The Mulussa Formation crops out at the southern edge of the Gaara Depression in a limited area but has wide subsurface extension to the west and south reaching both the Iraqi borders with Jordan and Saudi Arabia. It is a carbonate rocks type consisting of dolomitic limestone locally sandy with beds of marly limestone. At its exposure areas, it features an unconfined aquifer condition becoming confined for its major part. The aquifer is tapped by wells and used as a water supply source to the city of Al Rutba. Aquifer's water quality is variable depending on the location of the well. Close to Al Rutba where aquifer is believed to receive its recharge, the total dissolved solids would be less than 300 mg/l. Salt concentration in groundwater increases away becoming in the range of 2000 mg/l close to the borders. Values close to 3000 mg/l have been reported for locations at further distances from the aquifer's recharge area. Accordingly, water type changes from bicarbonate to chloride then sulfate (Al Jiburi & Al Basrawi, 2013).

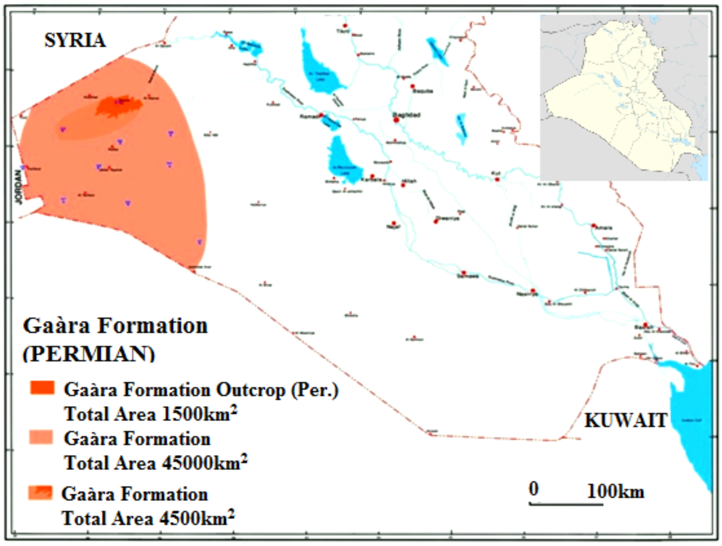
H. Carbo – Permian Aquifers:

Bir El Rah and Gaara formations of Upper Carboniferous- Early Permian are the oldest formations presently tapped by water wells in Iraq. The Gaara sandstone crops out inside the Gaara Depression in Al Rutba sub zone of the Stable Shelf, whereas Bir El Rah Formation is not exposed and can only be found in deep wells. The sediments of the two formations are hardly separated although Bir El Rah is usually composed of finer texture clastics: claystone, shale and thin sandstone beds. The older cavernous Harur limestone of the lower Carboniferous has however been reported to be a water bearing formation but it is not yet well investigated (Jassin & Goff, 2006).

The more important member the Gaara Sandstone is deposited in a fluvio–lacustrine environment. The clastics bellow of which are large river system deposit containing stacked sandstone channels and flood plain facies passing upwards into siltstone, mudstone overlain by ironstone. It normally is an aquifer system composed of two levels with the top being of finer grained and non-homogeneous deposit. It features an unconfined aquifer condition at a limited area around its exposure, whereas its major part is a confined aquifer extending away from the Gaara Depression in all direction under younger deposits and believed to be part of a trans boundary aquifer system shared between Iraq, Syria, Jordan and Saudi Arabia (Jawad et al., 2009) (Figure 8).

Its equivalent in Saudi Arabia is Unaza aquifer, which also features a similar type of sediments. The water quality of Gaara aquifer varies laterally and with depth. Lower total dissolved solids values of less than 500 mg/l have been noticed in and around the unconfined part of the aquifer where it is believed to receive its occasional recharge. In the meanwhile, it has been reported that the bottom horizon has a higher water total dissolved solids by (500 -1000) mg/l than that of its top horizon (Jassim & Goff, 2006). The range of TDS in the upper horizon is between a minimum of 318 and a maximum of 2279 mg/, while the range in the lower horizon is between 1120 and 2208 mg/l (Al Jiburi & Al Bassrawi, 2013). The range according to another report that includes 9 samples collected from both horizons is set to vary between 413 and 2461 mg/l (Al Jawad et al., 2001).

Water type varies according to water salinity and location. It is of bicarbonate where temporal recharge is expected, but in the deep confined horizons, it is sulfate or even chloride where a possible contact exists with deeper aquifers.



4 Groundwater Suitability

It has been noticed from the previous review of aquifers criteria that the original depositional environment of the sedimentary porous media of an aquifer and its present renewability are essential but not obligatory conditions in determining its groundwater quality. As for example, continental clastics and highly renewable marine carbonates have a better chance to contain fresh water than the lagoon deposits and poorly recharged marine sediments. Knowing these conditions may permit an initial evaluation of the expected groundwater quality in a given aquifer. Water suitability for any type of use however requires a further evaluation based on agreed standards. Water suitable for human drinking is required to contain less than 500 mg/l total dissolved solids among other limitations. For agricultural uses, a higher dissolved solids content is allowed but a serious alkalinity limitation rises when the sodium adsorption ratio (SAR) exceeds the value of 10. According to Ayers and Westcote (1985), water suitability for agriculture may be classified depending on its (EC) and (SAR) values among other limitations with regard to sodium percentage content and boron concentration. The upper limit value for EC was suggested to be 3 dS/m or about 2000 mg/l and SAR < 15.

The need for water under certain circumstances such as in remote areas, during drought periods or under water scarcity conditions may impose however a wider range. The maximum tolerable total dissolved solids in potable water may be set at 1000 mg/l as an upper limit. Similarly, a maximum value of 4 dS/m for Ec (TDS = nearly 3000 mg/l) could be accepted under special conditions to irrigate light soils and salt resistive plants (Davis & Dewiest, 1966).

Still to be noted that groundwater salinity is variable even within one aquifer system. The suitability of the produced groundwater for any purpose will often depend on the well location and its tapped horizons. Sometimes, suitability evaluation is done well by well showing two different results for adjacent wells.

Accordingly, the present evaluation is only a conceptual view that helps as a general guide.

1. Recent deposits:

Wells that may produce water suitable for human drinking should tap the following aquifers and in the indicated locations:

- The undifferentiated Quaternary deposits have high probability in the Low Folded Zone at basins of lower and upper Zab Rivers, upper parts of Diyala and Adhaim rivers ‘catchments.
- The alluvial deposit in Al Jazira Zone, near Sinjar mountain alluvial fan and a low possibility near the Tigris River in Tikrit and Sammara area and even in the Mesopotamian Plain in wells drilled near fresh water bodies, rivers or irrigation canals.

With the exception of the Quaternary and alluvial fans deposits in the Mesopotamian Plain, the undifferentiated deposits, river terraces and slope deposits elsewhere have usually a chance to contain water suitable for irrigation.

2. Neogene Aquifers:

Water suitable for human drinking can be produced from wells tapping Bai Hassan aquifer in the Low Folded Zone where the aquifer features unconfined condition at Ain Sifni, Erbil, Altune Kupri, and Bai Hassn south of Kirkuk sub basins.

Groundwater produced from the Dibdibba aquifer in the southern desert zone southwest of Karbala has been used to produce vegetables. Similarly, and in the same fashion, groundwater produced from the shallow horizon of the trans boundary fan (Al-Batin Alluvial Fan) between Iraq – Kuwait and Saudi Arabia has been used as well for decades in the west Basra area.

Moreover, the major part of the area where Bai Hassan unconfined aquifer is present; it is used for agricultural purposes along with its use for drinking purposes. Water contained in Mukdadiya Formation; however, pose some irrigation problems at certain locations including those in central part of Iraq close to the border with Iran.

With the exception of very limited locations, there is a low chance to produce water suitable for human drinking from wells tapping the Injana aquifer. The aquifer however, which spreads over north Al Jazira, Low Folded, and even some parts of the northern part of the Mesopotamia Zones may produce water with marginal suitability for irrigation. Nevertheless, due to the high variability of water quality, an evaluation for each well to determine suitability should be carried out.

3. **Paleogene aquifers:**
Groundwater produced from Paleogene aquifers range from suitable for human drinking; as in the case of water produced from the Pila Spi Formation in the High Folded Zone to unsuitable for any use as in the case of water produced from the Dammam and Umm El Raduma aquifers in the southern part of the Southern Desert Zone. In the northern part of the southern desert and the Western Desert zones both Dammam and Umm El Radhuma can be considered as a source for marginal to permissible irrigation water.

4. **Cretaceous aquifers:**
Cretaceous aquifers are a probable source for potable water in Iraq. Wells that tap Bekhme aquifer system in the High Folded Zone have high probability to produce water suitable for human drinking. Furthermore, at selected areas of the northern part of the southern desert (Qasra- Habbaria) and near the Iraqi- Saudi Arabian border, wells that tap Tayarat aquifer have a good chance to produce drinkable groundwater as well.
In the other parts of the southern desert where Tayarat extends as a confined aquifer, it is considered a source for irrigation water though its suitability becomes questionable in the far south. Similarly, wells that tap Hartha and Rutba aquifers may produce groundwater suitable agriculture in the northern desert zone. The produced water of each well however has to be evaluated due to changes of quality in relation to well location.

5. **Jurassic aquifer:**
Muhaiwir is the only discovered aquifer of the Jurassic Period because it is near or on surface in the Western Desert. At very limited locations near Wadi Huaran, a well taping the aquifer may produce water suitable for drinking. To the west towards the Iraqi Jordanian borders, only water suitable for irrigation may be found, but to the east toward the Euphrates River, this possibility vanishes.

6. **Triassic aquifers:**
There is a high probability that water suitable for human drinking is encountered in wells taping the Mulussa aquifer near the city of Al Rutba. Moving away south and south west however groundwater salinity rises but

nevertheless its suitability to agricultural purposes is maintained within the Iraqi territory.

7. **Carbo – Permian aquifers:**
   Groundwater suitable for human drinking can be acquired in areas where the Gaara aquifer features unconfined condition in the Garra Depression. The probability decreases however with depth on tapping the second horizon of the aquifer and while moving away from the depression to where the aquifer becomes confined. Nevertheless, the produced water from most of the wells tapping the aquifer in these areas is suitable for agricultural purposes.

5 Conclusions

Iraq is a sedimentary basin. The thickness of the sediments varies from 4 to 13 km. These sediments are alternation of pervious and impervious sedimentary rocks of coarse clastics and fractured carbonates with fine clastics and hard rock carbonates, have developed a successive multi aquifer system. The aquifers discussed range in age from Carbo-Permian to Recent.

The results obtained from wells which penetrate a single formation show that groundwater quality expressed as total dissolved solids in the explored 17 aquifers or aquifer systems are highly variable, but an indicative medium range value can be deduced for each.

Generally, most of the aquifers in the High and Low Folded Zones are suitable for human drinking. As far as the Stable Shelf, Al Jazira, and even in the Mesopotamian Plain, recharge boundary conditions of the aquifer in the selected drilling spot should be carefully examined. Due to the variation of the water quality of these aquifers, necessities evaluation of water suitability well by well.

Most of the groundwater within the aquifers of the northern parts of the stable Shelf and Al Jazira Zones aquifers are suitable for agriculture. Groundwater of the southern parts and the Mesopotamian Plain are questionable or unsuitable.

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