Research Article

Geochemical Evaluation of Formation Water, Mauddud Reservoir, Khabbaz Oilfield, Kirkuk Area, Northern Iraq

Fouad M. Qader [1, a, *], Basim Al-Qayim [2, b], Fawzi Al-Beyati [3, c]

[1] Department of Geology, College of Science, University of Sulaimani, Sulaymaniyah, KRI, Iraq
[2] Department of Petroleum Engineering, Komar University of Science and Technology, Sulaymaniyah, KRI, Iraq
[3] Survey Engineering Department, College of Kirkuk, North Technical University, Kirkuk, Iraq

E-mail: [a] fuad.qadir@univsul.edu.iq, [b] basim.alqayim@komar.edu.iq, [c] fawzialbiati@ntu.edy.iq

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Abstract

In this study, formation-water samples were collected by NOC Staff, during drilling time, from the Mauddud Formation reservoir of the Khabbaz Oilfield, for this reason four samples from four wells; Kz-3, Kz-4, Kz-7, and Kz-23 were selected to geochemical analysis. Analyzed geochemical parameters include TDS and the concentrations of the different dissolved cations and anions present in brines (Ca^{+2}, Mg^{+2}, Na^{+1}, $SO4^{-2}$, Cl^{-1}, $HCO3^{-1}$, and NaCl). Variations among the resulted data are discussed by comparison with other Cretaceous Brines. Geochemical ratios of Na/Cl, (Na-Cl)/SO_4) and (Cl-Na)/Mg^{+2} was calculated for formation water classification following Bojarski, (1970). The calculated geochemical ratios of the studied samples in the studied four wells indicate that all of these waters are "chloride calcium" type under subsurface conditions, this type reflect closed system isolated associations reservoir, which are becoming high hydrostatic in deeper zones without influence by infiltration waters. A major transversal fault cutting the structure at its SE plunge had participated in the dilution of the Mauddud reservoir brine effectively.

Keywords: Formation Water, Mauddud, Khabbaz, Hydrochemistry, Brine, Iraq.

1. Introduction

Geochemical evaluation of formation water is an essential tool of reservoir management especially for fields with little studies such as the Khabbaz Oilfield of Kirkuk area of Northern Iraq. This analysis is used for long period in evaluating formation water chemistry as an approach to understand origin, nature and movement of formation water, which in turn helps in understanding the subsurface environment of the associated hydrocarbons accumulations (Collins, 1975).

The studied oil field is located about 20 km to the SW of Kirkuk City, and it represents a part of the Low Folded Zone of the Iraqi physiographic division. The field is surrounded from the northwest by Bai Hassan and Qara Chauq oil fields, from the southeast by Jambour. The Baba Dome of Kirkuk Oilfield is located to the east of Khabbaz Oilfield (Figure 1a). The length of the structure is about 20 km and its width reaches 4 km. It consists of an asymmetrical sub-domal anticline with northwest-southeast trend (Figure 1b). The northeast limb is steeper than the southwest limb. A major transversal normal fault intersects the structure in its south-eastern plunge (Figure 1c). These faults have important influence on field production and development (Al-Qayim *et al.,* 2010) and influences reservoir performance. The first seismic investigation for the area was done by Iraqi Petroleum Company (IPC) in 1955. They indicated this subsurface structure which is plunged toward northwest. The first well (Kz-1) at Khabbaz was drilled in August 1976, and the North Oil Company brought on stream in March 1994 (Al-Qayim *et al.,* 2010). Production comes from three pay zones: (1) The Tertiary reservoirs; (Middle Miocene Jeribe Formation, and Upper Oligocene-Lower Miocene Anah, Azkand,

and Azkand/ Ibrahim Formations); (2) Upper Cretaceous reservoirs Mauddud (Upper Qamchuqa) Formation; and (3) the Aptian Shu'aiba (Lower Qamchuqa) Formation.

Forty wells have been drilled so far at Khabbaz structure, most of which have targeted the Kirkuk Group (Oligocene) although number wells have penetrated the underlying Cretaceous reservoirs (Qader & Al-Qayim, 2016).

The study aimed at examining the hydrochemistry of water samples collected from the Mauddud reservoir in an attempt to elucidate a possible link between formation water geochemical characteristics and the nature of the subsurface environment of the hydrocarbon accumulation.

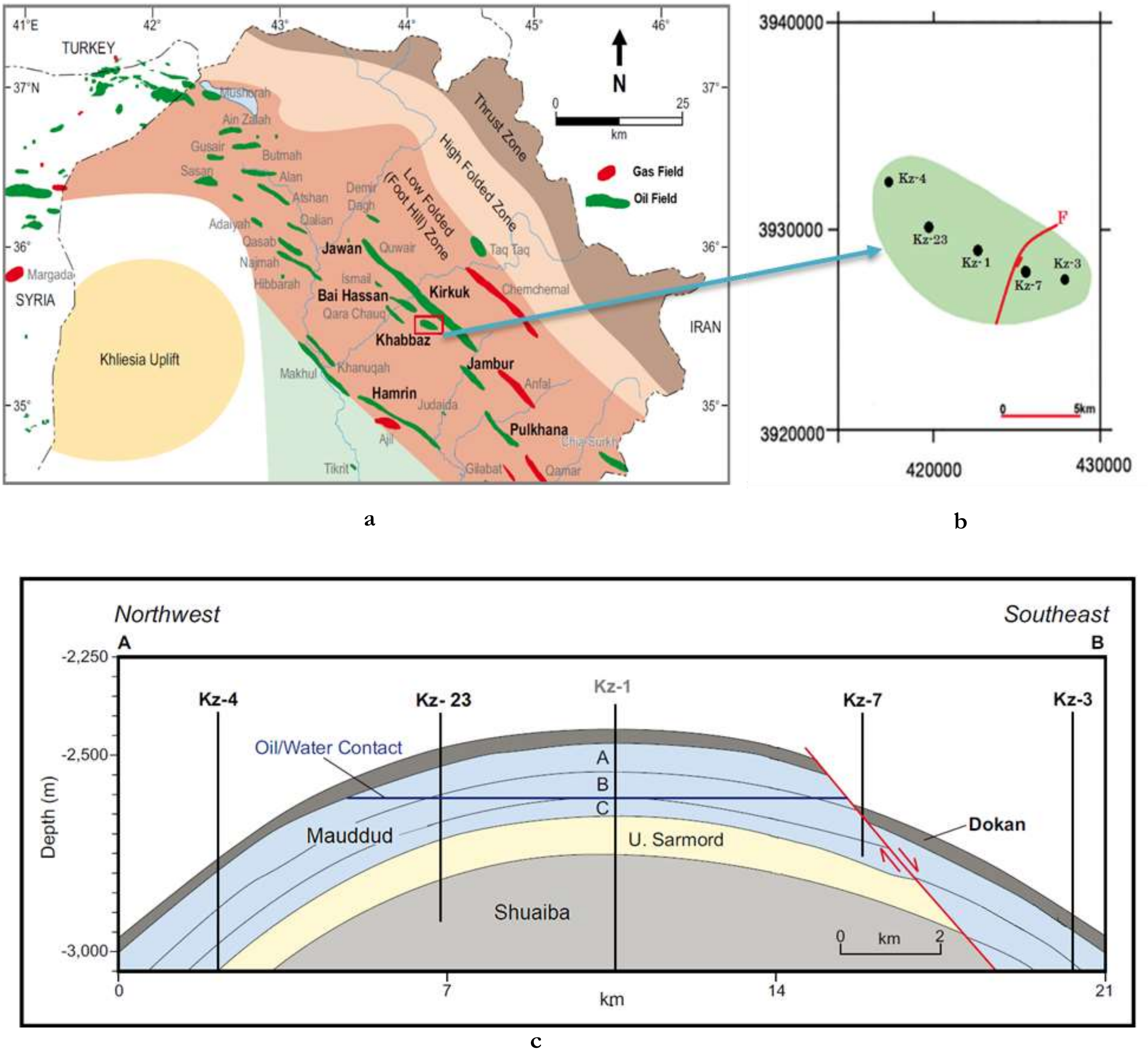

Figure 1. Index Diagram Showing. a) Location Map of Khabbaz Oilfield, b) The Studied Wells Over the Khabbaz Structure, c) Schematic Longitudinal Cross-Section Showing the Mauddud Reservoir Stratigraphy, and the Studied Wells. (Adopted after Al-Qayim *et al.*, 2010).

1.1. Mauddud Reservoir

The Qamchuqa Formation of the mountainous pattern of NE Iraq is formally described by Bellen *et al.* (1959) as a thick section of dolomitic limestone of an extensive distribution of carbonate platform. At Kirkuk area, the formation is stratigraphically better differentiated by Al-Sadooni (1978) into three formations: The Upper Qamchuqa (known as Mauddud Formation in central Iraq), the Upper Sarmord Formation, and the Lower Qamchuqa (known as Shuaiba

Formation in central Iraq) (Figure 2). This subdivision was adopted by most petroleum geologists working in the Kirkuk area and amended by Buday (1980).

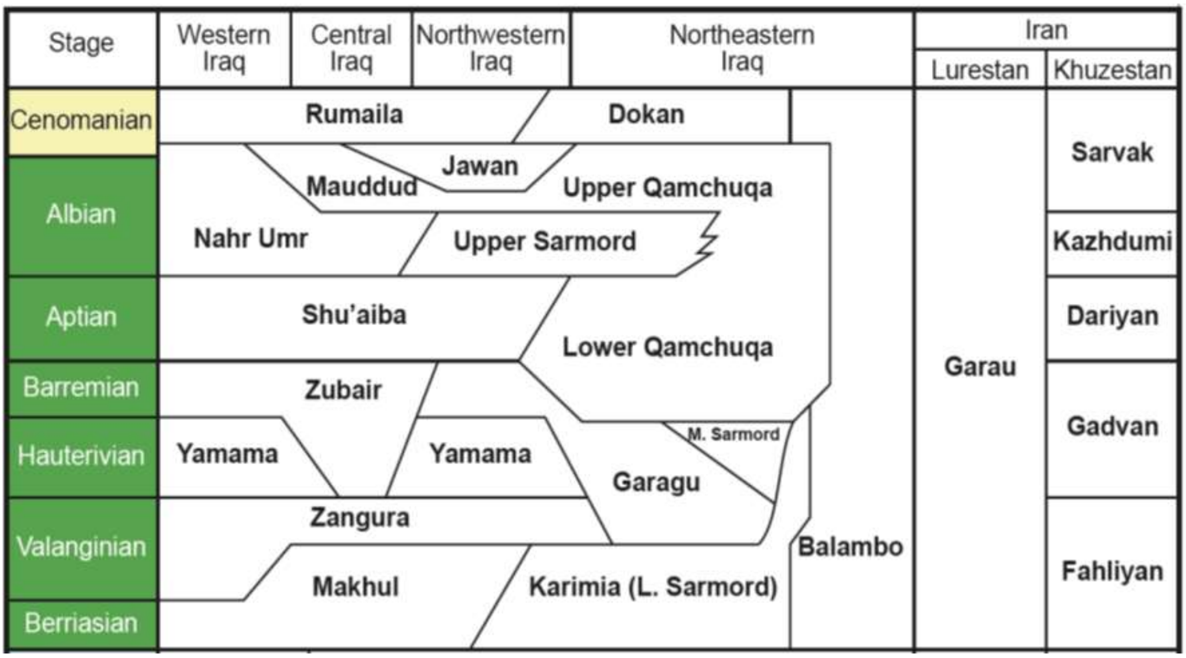

Figure 2. Lower Cretaceous Stratigraphic Chart and Nomenclature for Iraq (Al-Qayim *et al.*, 2010).

The Mauddud Formation is a widespread Late Albian unit, which represents an extensive shallow marine carbonate platform extends over most of the Arabian Platform (Sadooni & Alsharhan, 2003). The average thickness of the formation at Khabbaz Oil Field is around 170 m. The general lithology of the Mauddud Formation is characterized by intercalations (Al-Qayim *et al.,* 2010) of limestone, dolomitic limestone, and dolostone with infrequent marl intercalations. Based on that, the reservoir is subdivided into three units. The upper unit has the best petrophysical properties with potential dolostone horizons having porosities up to 25%. In addition to intercrystalline porosity, vugs and fracturing are also common and enhanced reservoir permeability (Al-Qayim *et al.,* 2010).

Mauddud Formation in Khabbaz Oilfield represents unconformable contact situation with the overlying Dokan Formation; this situation was detected on the **GR** log pattern through abrupt increasing in values at contact within the studied well sections all over the field (Figure 3). Similar case was reported by Al-Peryadi (2002) from Bai Hassan Oilfield, also the sonic transit time (Δt µs/ft) pattern was emphasizing the above indication through recording low values along the limestone rocks of Dokan Formation. The lower contact with underlying Upper Sarmord Formation is conformable which is reflected by a gradational increase of GR from the lower part of the Mauddud Formation toward the upper shale-dominant part Upper Sarmord Formation (Figure 3). The Upper Sarmord Formation is about 120 m, and consists of shale, marl and argillaceous limestone (Qader, 2008).

The Neutron, Density, and Sonic (porosity logs) patterns revealed gradational decreasing in porosity toward the base of the studied formation.

2. Material and Methods

The studied water samples were collected from Kz-3, Kz-4, Kz-7, and Kz-23 wells, which distributed on the stricter of Kabbaz Oilfield during drilling time (Figure 1). Samples were analyzed at the laboratories of the North Oil Company of Iraq (N.O.C.), and resulted data are presented in an internal report (Reports of Petroleum Engineering Department of NOC, 1976-1982). The results of the analysis were calculated first in ppm (Table 1). Analysis includes TDS, Major cations (Ca^{+2}, Mg^{+2}, and Na^{+1}) and anions (SO_4^{-2}, Cl^{-1} and HCO_3^{-1}) in addition to (Na-Cl). The analyzed data is compared to modern seawater chemical composition (after Castro and Huber (2019) and other Iraqi Cretaceous brines with similar hydrochemical analysis were obtained by Awadh *et al.* (2018) and Awadh, *et al.* (2019) in order to highlight variations. This comparison is intended at evaluating general variations in the analyzed samples (Table 1). The resulted analytical values were then recalculated into equivalent per-million (**epm**) values (Table 2), so it can be used later on in the calculation of the percentages of the different parameters (hydrogeochemical ratios) in the water type classification approach. The water type classification is following here Sulin (1946) and its modification by Bojariski (1970) as presented in Collins (1975). This classification is selected here for the classification and its suitability of the analyzed data.

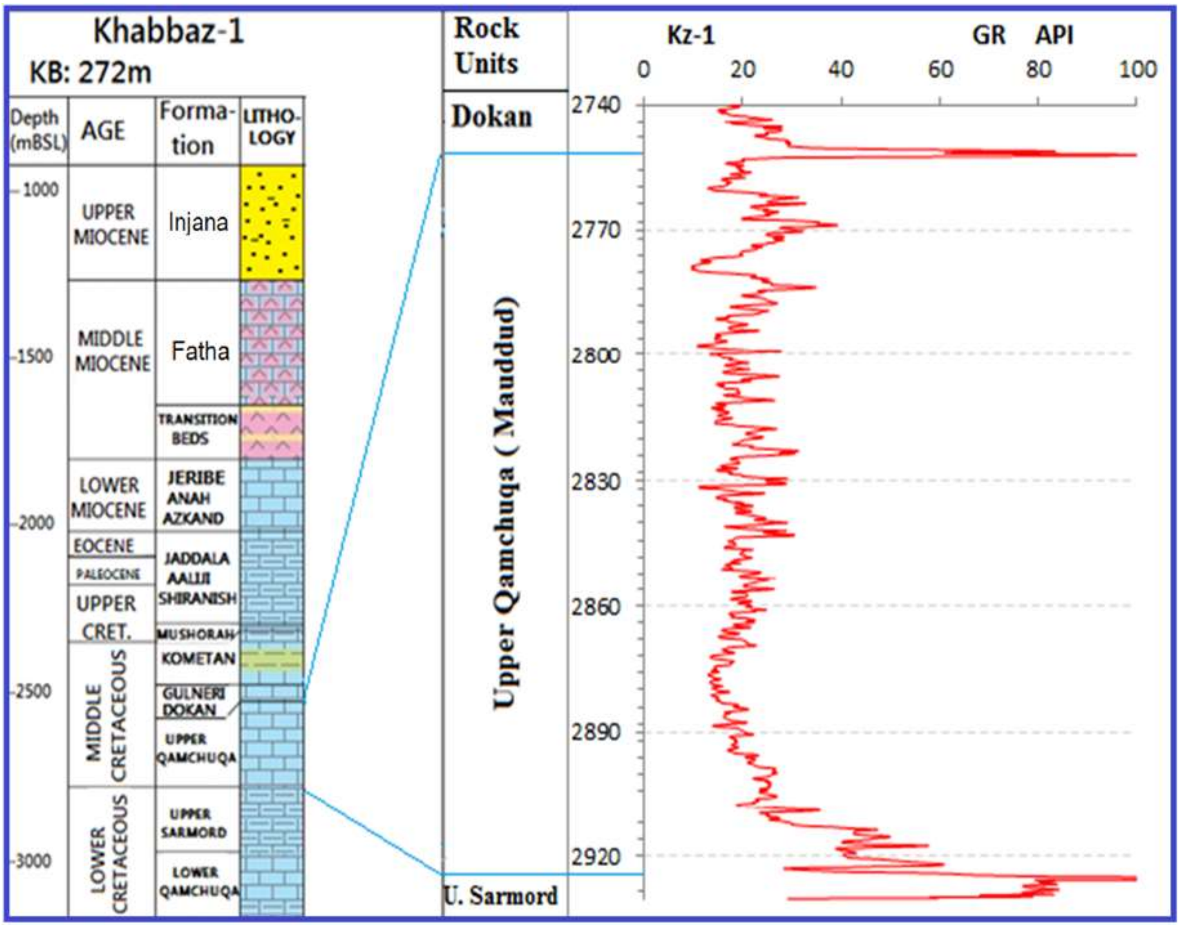

Figure 3. General Stratigraphic Column of the Khabbaz Oilfield at Well Kz -1, Showing Detailed Lithologies and GR log Characters of the Mauddud (Upper Qamchuqa) Formation.

3. Results

The resulted data of the hydrochemical analysis of the selected samples are presented in Table 1. An overall look to the results of the formation water analysis shows sufficiently higher concentration of dissolved salts as compared to the original chemical composition of modern seawater (Table 1). The average TDS value of the analyzed water samples are almost 3 times the TDS value of seawater. This higher concentration is also noticed for most of the cations and anions including Ca^{+2}, Mg^{+2}, Na^{+1}, Cl^{-1}, and HCO_3^{-1}. This high concentration of the formation brine is also noticed in comparison with average values of brines from Cretaceous System in Table 1 (Collins, 1975). The concentration of subsurface brine often related to evaporation during deposition of shallow restricted marine environments such lagoons, pans and subkhas (Collins, 1975), or due to compaction and membrane filtration of clay sediments (Chilingarian & Rieke, 1969 in Collins, 1975). Parker (1969 in Collins, 1975) had studied brines and waters from five aquifers of Cretaceous age in the East Texas Basin. He found that the composition of the waters in the older, more deeply buried aquifers was modified more than waters in younger, less deeply buried formations. The exceptional lower average value of the sulfates (1184 ppm) as compared to seawater value (2701 ppm) is believed to be related to inorganic reduction of sulfate, anaerobic reduction or hydrocarbon reduction of anhydrite (Bush, 1970 in Collins 1975). The relative lower concentration of the subsurface brine of the Mauddud reservoir as compared to the other Cretaceous reservoirs of southern Iraq may be related to dilution by surface water percolated through the master fault deeply intersect the Khabbaz Structure (Figure 1). It is also noticed that despite the high concentration of the Mauddud reservoir brine, it has comparatively, lower total dissolved salts (TDS) as well as most of the analyzed elements than the Cretaceous reservoirs of southern Iraq as shown in Table 1 (Awadh *et al.*, 2018; Awadh *et al,* 2019). It is noticeable that the chemical analysis of the water sample from Kz-7 show relatively low concentration of TDS and other cations and anions compared to the other studied wells, seawater composition, as well as the Cretaceous reservoirs of southern Iraq (Table 1). The exceptional low concentration of the subsurface brine at well Kz-7 as compared to the other wells, and the low values of the TDS and other cations and anions of the Mauddud reservoir, as compared to other Cretaceous reservoirs may be related to the dilution of the subsurface brine. A process can be developed by surface water percolating down through the master fault which is deeply intersect the Khabbaz Structure at the southeastern plunge (Figure 1).

3.1. Classification of Oilfield Waters

The classification of subsurface water depends on the dominant mineral ions present in solution. The Russian geochemist classification widely used in this context like Sulin (1946, in Collins, 1975). His classification of the subsurface hydrochemical system based upon various combinations of dissolved salts in the waters. The classification revealed four basic water types each one refers to different environments from natural water distribution (Table 3):

1- Terrestrial conditions refer to the genetic type of such sulfate waters as "*sulfate-sodium*".
2- Continental conditions refer to the sodium bicarbonate waters formation. The genetic type is "*bicarbonate-sodium*".
3- Marine conditions allow to formation "*chloride-magnesium*" water type.
4- The deep subsurface conditions within the earth's crust allow to formation of a "*chloride-calcium*" water type.

The first two types are reflected meteoric and/or artesian waters properties, while the third one belongs to marine environments and evaporite sequences, the fourth type represents deep stagnant water conditions.

Sulin's (1946) system was modified by Bojarski (1970 in Collins, 1975). The modification emphasized the redefinition of Sulin's (1946) classification of water types and reinterpretation the environment of each water types as follow:

1- The "*bicarbonate-sodium*" Water type occurs in the upper horizon of sedimentation environment, under hydrodynamic conditions, which promotes to preservation of petroleum and natural gas deposits.
2- The "*sulfate – sodium*" water type, indicates to the sodium reaction with the chloride or sulfate.

Table 1. Formation Water Geochemical Analyses in Khabbaz Oilfield. Comparison with Seawater and Other Cretaceous Brines is Given Below for the Sake of Evaluation (Castro & Huber, 2019; Awadh et al., 2019; Awadh et al., 2018; Collins, 1975).

Wells No.	TDS ppm	Ca^{+2} ppm	Mg^{+2} ppm	Na^{+1} ppm	SO_4^{-2} ppm	Cl^{-1} ppm	HCO_3^{-1} ppm	NaCl ppm
Kz-3	130137	6006	1091	43008	1239	77823	1832	109317
Kz-4	151310	4830	1840	46998	1059	84909	1220	119461
Kz-7	27580	662	458	6302	1654	10295	1220	16018
Kz-23	127937	26588	13220	811	641	86380	Nil	2061
Average	109241	9521	4152	24279	1148	64851	1068	61714
Seawater (1)	35000	416	1295	10752	2701	19345	145	_
Zubair (2) Reservoir	215625	14674	3542	59200	417	123679	137	_
Mishrif (3) Reservoir	221660	12196	3091	68779	673	131751	223	_
Cretaceous (4) System	_	7000	900	31000	280	62000	260	_

Table 2. Formation Waters Geochemical Analysis Data of the Khabbaz Oilfield Converted into epm Values.

Wells No.	TDS ppm	Ca^{+2} epm	Mg^{+2} epm	Na^{+1} epm	$SO4^{-2}$ epm	Cl^{-1} epm	HCO_3^{-1} epm
Kz-3	130137	300	91	1870	26	2192	30
Kz-4	151310	242	153	2043	22	2392	20
Kz-7	27580	33	38	274	34	290	20
Kz-23	127937	1329	1102	35	13	2433	Nil

Waters of the "*chloride – magnesium*" type is characteristic of the transition zone between hydrodynamic areas which is becoming more hydrostatic in the deeper part of the basin.

3- Water of the "*chloride – calcium*" type occurs in deeper zones which is isolated from the influence of infiltration waters, and is hydrostatic.

Large variation in the chemical composition in the chloride – calcium type and subdivided this type was observed by (Bojariski, 1970 in Collins, 1975) as following:

a- Class, **"chloride – calcium I"** with ratio of Na/Cl > 0.85 refers to an active hydrodynamic zone. It is considered as a zone of little prospect for the preservation of the hydrocarbon.

b- Class, **"chloride – calcium II"** with ratio of Na/Cl = 0.85 – 0.75, refers to the transition zone between hydrodynamic zone and stable hydrostatic zone. It is considered as a poor zone for hydrocarbon preservation.

c- Class, **"chloride – calcium III"** with ratio of Na/Cl = 0.75 – 0.65, represents condition for the favorable preservation of hydrocarbon deposits. It is designated as a fairly hydrocarbon preservation environment.

d- Class, **"chloride – calcium IV"** with ratio of Na/Cl = 0.65 – 0.50, represents a complete isolation environment of hydrocarbon accumulation as well as by the presence of residual water. This class represents good zone for hydrocarbon preservation.

e- Class, **"chloride – calcium V"** with ratio of Na/Cl < 0.50, refers to the presence of highly altered residual ancient seawater. This type is one of the most likely indicators for the hydrocarbon accumulation zone.

Table 3. Parameters of Sulin (1946) and Bojarski (1970) Formation Water Classification.

Type of water	Na^{+}/Cl^{-}	$(Na^{+} - Cl^{-}) / SO4^{-2}$	$(Cl^{-} - Na^{+}) / Mg^{+2}$
Sulfate – Sodium	> 1	< 1	< 0
Bicarbonate – Sodium	> 1	> 1	< 0
Chloride – Magnesium	< 1	< 0	< 1
Chloride – Calcium	< 1	< 0	> 1

3.2. Classification of Mauddud Formation waters

The resulted epm data of Table 2 were recalculated in percentage to estimate the Sulin's- Bajoriskki basic hydrochemical parameters used in the classification of the formation water. The calculated parameters represent ratios either between ($\mathbf{Na^{+1}/Cl^{-1}}$)or between ($\mathbf{Na^{+1} - Cl^{-1}}$)/$\mathbf{SO_4^{-2}}$), and ($\mathbf{Cl^{-1} - Na^{+1}}$)/$\mathbf{Mg^{+2}}$) which reflect the chemical composition of the analyzed water, the type, and class of each water samples from each of the studied wells are shown in Table 4.

Table 4. The Mauddud Reservoir Formation Water Type and Classes According to Bojarski (1970) and Sulin's (1946) Classification.

Wells No.	Na^{+1}/Cl^{-1}	$(Na^{+1}- C^{-1})/ SO_4^{-2}$	$(Cl^{-1}- Na^{+1}) /Mg^{+2}$	Water type	Class
Kz-3	0.85	-12.49	3.69	***Chloride calcium***	**II**
Kz-4	0.85	-15.79	2.37	***Chloride calcium***	**II**
Kz-7	0.94	-0.46	0.44	***Chloride magnesium***	**---**
Kz-23	0.01	-179.57	2.27	***Chloride calcium***	**V**

Table 4 shows that three of four analyzed samples are refer to the dominant of "chloride-calcium" type, due to the ratio of (Cl^{-1}-Na^{+1})/Mg^{+2}) which represents value more than one among the three analyzed samples. The dominant type of water from studied wells Kz-3, Kz-4, and Kz-23 represents a hydrostatic deeper zone, which refers to the semi - completely isolated environment may be due to the influence by infiltration waters according to Bojarski (1970). The sample from well Kz-7 revealed "chloride magnesium" type (Cl^{-1}-Na^{+1})/Mg^{+2}), in order to the value of the ratio was less than one which refer to the situation of transition zone between dominated hydrodynamic areas which was became more hydrostatic at deeper part of the environment.

Some variations were detected among "chloride calcium" water type within their Na^{+1}/Cl^{-1} ratios that were analyzed from the three studied wells, therefore, it must be subjected to subdivision within one classis of Bojarski (1970).

The ratio of Na^{+1}/Cl^{-1} obtained from the two (Kz-3 and Kz-4) wells are equal to 0.85. This value according to Bojarski (1970) classification is return to the subdivision of second class (chloride-calcium II) of formation water that is very close to the first class (chloride-calcium I) as well. The value of 0.85 refers to the transition zone between hydrodynamic and stable hydrostatic zones, and this zone is generally representing poor zone for hydrocarbon preservation. Such variation in the result may be due to the sampled wells locations. The wells Kz-3 and Kz-4 are located at the extreme ends of the studied field structure (Figure 1), and thus affected by the transitional nature of the marginal waters of the pool. The Na^{+1}/Cl^{-1} ions ratio obtained in the well Kz-23 was 0.01, this value belongs to the fifth class (chloride-calcium V), which represents a good zone for hydrocarbon preservation.

The location of Kz-23 Well nearest to the central part of studied field (Figure 1) probably represents the typical formation water that associated with the assemblies of oil pool within the studied reservoir of Khabbaz Oilfield. The formation water represents the ancient residual sea water, and most likely represents an area of hydrocarbon accumulation (Bojariski, 1970 in Collins, 1975)

The well Kz-7 revealed ratio of Na^{+1}/Cl^{-1} equals to 0.94, this value return to the class I of chloride-calcium formation water type, and this value close to the value of class III chloride – magnesium formation water type. The interpretation may be probably related to the location of the well Kz-7 which affected by the intersecting a major fault (Figure 1) (Qader, 2008). The fault plays a key role in creating a hydrodymic condition at the well Kz-7 and may cause intermixture of the formation water with other type of water passes through the fault plane.

4. Discussion

The location of studied oilfield within the Low Folded Zone, which is characterize by the domain of intense hydrodynamic effect as a result of the culminating tectonic deformation of the Zagros Orogenic Belt. The intensive fracturing and faulting of the Mauddud reservoir is characteristic in many fields of northern Iraq such as Khabbaz Oilfield (Al-Qayim *et al.*, 2010), Bai Hassan Oilfield (Al-Peryadi, 2002), Jambour Oilfield (Al-Shakiry, 1977), and Miran Oilfield (Rashid *et al.,* 2020). It is conceivable, thus, to see some intermixing of the Khabbaz formation water with other type of water from shallower depth including meteoric water percolating through fractures and faults, namely, the master fault at the southeastern plunge of the structure (Figure 1). The invasion by surface water will lead to dilution of the salinity of the original brine as compared to other Cretaceous formation waters. While the greater resistance to the invasion was existence, multi layers from clay and anhydrite succession above the studied reservoir rocks, which helped the site faraway from hydrodynamic effect and contributed to enhance the close system (Al-Mashadani, 1986). Also due to high pressure reported from the Mauddud reservoir which was reached 4364 psi at depth of 2685m (Reports of Petroleum Engineering Department, 1976-1982), this pressure is indicates to an anomaly situation from hydrodynamic condition when compared with either interstitial fluid pressure or theoretically estimated hydrostatic pressure. The estimated pressure gradient of a formation of 0.48 psi/ft or 1.50 psi/m (Serra, 1986), will be 4028 psi at the same depth (2685m). The resulted relatively high-pressure condition of the Mauddud reservoir represents isolated and close system within the Khabbaz Oilfield. These coincides with the dominant “chloride calcium” water type as inferred by Sulin-Bajoriski classification. This type indicate to the occurrence in the deeper zones which refer to relatively isolated, stagnant, and hydrostatic conditions (Sulin, 1946).

However, the wells with marginal location with respect to reservoir (Kz-3 and Kz-4) of “chloride calcium” type within Class II group are characterizes by the transition zone between an active hydrodynamic and stable hydrostatic zone, which is generally considered as a poor hydrocarbon preservation zone (Bojariski, 1970). Location of the well Kz-23 is on the apex of the structure passing through the central part of the oil zone (Figure 1). The water type of this well is of “chloride calcium” type but of class V group (Table 4). This type of water according to Bojarski (1970) is characterized by the presence of ancient residual seawater, which has been highly altered since original deposition, and considered as one of the most likely areas where hydrocarbons are accumulated.

The noted relatively diluted dissolved salts values of Kz-7 (TDS and other cation and anion) as compared to the other wells and its different water type (chloride magnesium) can be explained in term of location of the well close to the master fault of the structure. Such lower values are seemingly influenced by water infiltration through the fault zone, which is directly diluted its water salinity greater than the other wells.

5. Conclusions

The hydrogeochemical analysis of the formation water of the Mauddud reservoir at Khabbaz Oilfield reveals variable water types dominated by “chloride calcium “group which is in general indicates a relatively deep, isolated, and stagnant subsurface environment of transitional hydrostatic to hydrodynamic conditions. The noticed variability among the details of the analyzed water samples; however, are related to the location of the studied wells with respect to the water pool area (oil zone), and the position of the wells with regard to the master fault of the structure.

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