IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)

*IBGM (**2025**, Vol 21; Issue 1)* *57-73*

# PETROPHYSICAL CHARACTERISTICS OF THE SHIRANISH FORMATION FROM TWO SELECTED OILFIELDS IN THE KURDISTAN REGION, NORTH EAST IRAQ

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*Type of the Paper (Article)*
*Received: 02/ 08/ 2024*
*Accepted: 14/ 11/ 2024*
*Available online: 27/ 06/ 2025*

## Abstract

Petrophysical characteristics of the Shiranish Formation were analyzed at the Shewashan-2 (SH-2) and Bazian-1 (BZ-1) wells within the selected oilfields. The suggested lithology for the studied formation is limestone and marly limestone. Moreover, at the SH-2 well, the formation tends to have a lower shale content, which gradually increases downward in the well. Meanwhile, in the BZ-1 well, the middle of the studied formation consists mainly of shaly and shale intervals. In addition, it is observed that porosity values generally decrease deeper in the SH-2 wells, with most values being less than 7.0 %. However, there are a few intervals where porosity increases. On the other hand, the BZ-1 well indicates a pattern of higher porosity at the top of the formation, gradually decreasing towards the bottom of the Shiranish Formation. It appears that the studied formation shows a higher porosity in the BZ-1 compared to the SH-2 well. Additionally, the secondary porosity at the top of the Shiranish Formation in the SH-2 well measures around 2.0 to 5.0%. Nevertheless, in the BZ-1 well, it varies between less than 5.0% and 10%. Porosity along both SH-2 and BZ-1 wells is generally greater at the upper part of the Shiranish Formation. Regarding the permeability, it seems that the formation has a poor to fair permeability in the well of SH-2, meanwhile, it shows moderate to good permeability at the BZ-1 well. The Shiranish Formation can be divided into three reservoir units depending on the shale volume, porosity, and permeability. The RU-3 demonstrates the most significant reservoir characteristics in both of the studied wells. Nevertheless, the reservoir quality was found to be the lowest in RU-1 for the SH-2 and BZ-1 wells. Furthermore, a significant majority of the pore spaces in the formation are occupied by residual hydrocarbons.

**Keywords:** Shiranish Formation, Shewashan, Bazian, Porosity, Permeability, Reservoir Unit.



ISSN 1811-4539, EISSN 3005-3714
https://doi.org/10.59150/ibgm2101a04
IBGM: http://ibgm-iq.org/
Academic Scientific Journals: www.iasj.net

## 1. Introduction

The Late Cretaceous Shiranish Formation at the High-Folded Zone in Northern Iraq was first identified and described by Henson in 1940, particularly near a Shiranish Islam village; the formation is composed of thin-bedded, occasionally dolomitic and argillaceous limestones covered with blue marls, within the type setting (Bellen, 1959, Jassim & Goff, 2006).

The formation is a frequently discovered and extensively distributed Late Cretaceous sequence in northern Iraq. The Shiranish Formation has substantial value and is considered by many to be a crucial petroleum reservoir in multiple oilfields in Iraq and the Kurdistan Region. This is primarily due to the presence of secondary and fracture porosity, making it a potential source of hydrocarbon production (Dunnington, 1958, Garland et al., 2010; Awdal et al., 2013).

The Shiranish Formation in NE Iraq is recognized as a distinguished fractured carbonate reservoir that was deposited during the Late Campanian and Maastrichtian cycles (Dunnington 1958). In northern Iraq, the Shiranish Formation has been confirmed to possess hydrocarbon accumulation and production in the Baba-Dome of the Kirkuk Oilfield as well as the Ain-Zalah and Butmah oilfields in Mousl (Dunnington, 1958, Bellen et al.,1959: Awdal et al., 2013).

Furthermore, Garland et al. (2010) stated that at the Taq-Taq Oilfield from highly fractured limestone of the Shiranish Formation, hydrocarbon is extracted through the process of production. Shewashan Oilfield is situated about 18 km East of the Koya district (Figure 1). This field is designated as having around 120 $km^2$ of area inside the Khalakan Block (Mills, 2018). The reservoir intervals were identified within the Cretaceous fractured Shiranish, Kometan, and Qamchuqa formations. The well of Shewashan-2 (SH-2) was the second exploratory well drilled on the Khalakan Block, which is positioned between the Taq-Taq Oilfield and Miran Block. However, the Shewashan-1 well produced light oil in the assessment in 2015 (Mills, 2018; Salih &Yamulki 2020). Besides, the second well that was studied is within the Bazian Field, which is situated northwest of Sulaimani City (Figure 1). To evaluate the hydrocarbon accumulations in the northernmost region of the Bazian Field, the well of BZ-1 was drilled, which is the first exploration well in the field. In addition, the prominent reservoir prospects in the Bazian Field are the Cretaceous strata comprising the Qamchuqa, Kometan, and Shiranish formations, and the formations of the Early Jurassic and Late Triassic are the subsequent objectives of the operation company (Darwesh, 2014; 2020). The core focus of this research is the petrophysical analysis, which involves the assessment of porosity, permeability, lithology, and hydrocarbon saturations in the Late Cretaceous Shiranish Formation along the wells of SH-2 and BZ-1.

### 1.1. Geologic Setting

The studied fields are situated in the NE of Iraq, in the Kurdistan Region, in the Sulaimani Governorate and Koya district. Tectonically, the Bazian Field is at the boundary of High-Folded and Low-Folded Zones, whereas the field of Shewashan is in the Low-Folded Zone (Figure

1). The northeastern Arabian Plate's Cretaceous sequence formed in a geological paleo-depositional environment characterized by stable paleo highs, broad fore-land basins with the thrust-front belt zone, and restricted extensional basins (Kassab, 1975; Buday, 1980; Aqrawi et al., 2010). Deep marine subsidence was the environment of the Shiranish Formation deposition, ranging from the outer-shelf to the higher bathyal zone (Aqrawi et al. 2010). Bellen et al. (1959) proposed that during the Late Campanian and Maastrichtian period, the Shiranish Formation was deposited; depending on where it settles in the sedimentary basin, the thickness of the formation varies from where it is situated (Al-Dulaimi et al., 2023; Karim et al., 2008). From the furthest reaches of the SE to the NW of Iraq, the vast expanse of the Shiranish Formation is revealed throughout the High-Folded Zone (Sissakian & Al-Jiburi, 2014).

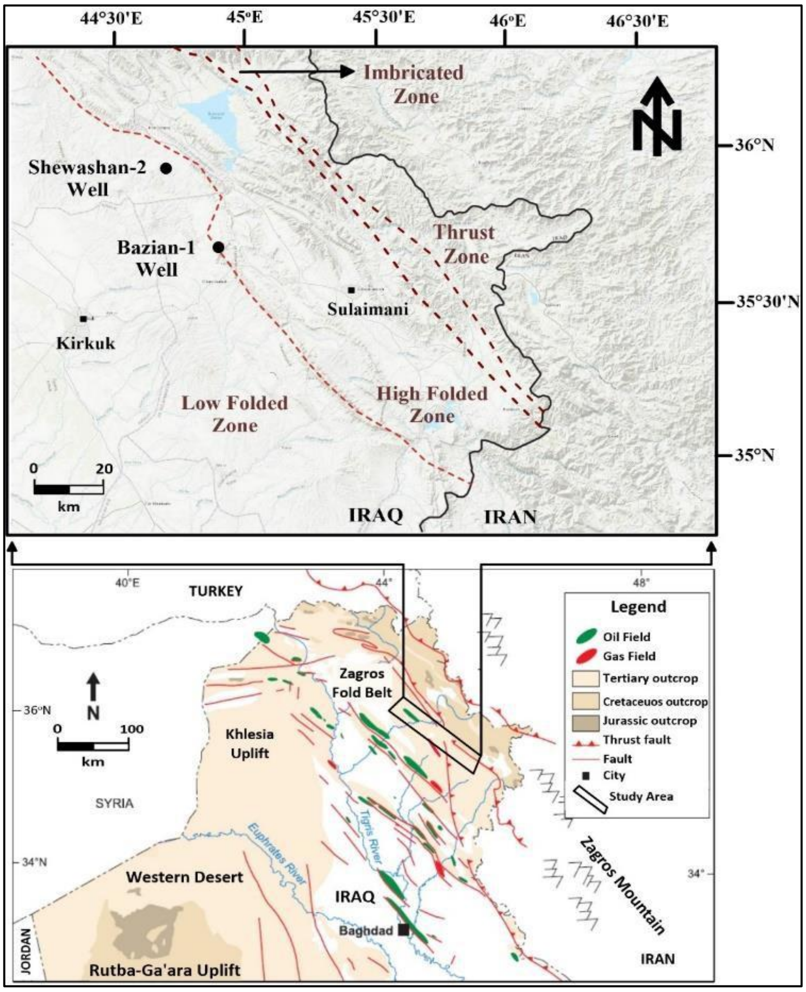


**Figure 1.** The structural subdivisions of Northern Iraq, and study location of the selected wells and fields (modified after Buday & Jassim, 1987).

In certain regions of northern Iraq, there is significant erosion and removal of sedimentary layers, particularly from the anticlines. This erosion predominantly focuses on terminating the advancement of Late Cretaceous deposits in the area. Moreover, excluding a few uncommon deposits, contemporary Maastrichtian formations are frequently absent (Bellen et al., 1959; Jassim & Goff, 2006; Aqrawi et al., 2010) Widespread depression produced an open marine water depositional basin where carbonate rock units were deposited when the foreland basin in N Iraq was formed (Dunnington, 1958). Along the Zagros Fold Thrust Belt, numerous reservoirs with shallow-marine marginal carbonates and detrital limestones have been discovered (Ziegler, 2001).

## 2. Data and Methods

The major sources of data utilized in this research for examining the Shiranish Formation were wireline logs. The data obtained from two boreholes situated within the Bazian and Shewashan fields was sourced from the Ministry of Natural Resources (MNR/KRG) of the Kurdistan Region of Iraq. The petrophysical characteristics of the Shiranish Formation in the investigated wells of SH-2 and BZ-1 were assessed using the available logs. Porosities, permeability, and lithology have been identified using a variety of logs, in particular GR, acoustic (sonic), density, and neutron logs. Data logs of resistivity, specifically the SFL (Spherical Focused Log) and the LLD (Latero Log Deep), were employed to ascertain the saturations of hydrocarbon and water throughout the studied formation. The NeuraLog program was implemented for digitizing the well-log datasets into digital format, and the data were then examined by applying the program of Interactive Petrophysics.

## **3. Results and Discussion**

### 3.1. Lithology Identification Utilizing M-N Crossplot

In order to define the Shiranish Formation's lithology at the wells of SH-2 and BZ-1, the M-N method was implemented. The quantities of N and M parameters can be utilized to distinguish between lithologies (Schlumberger, 1989). The three porosity logs, including acoustic, density, and neutron measurements, are appropriately integrated with the drilling fluid properties and the following log parameters, identifying the M-N crossplot procedure (Bateman, 1985; Schlumberger, 1989; Schlumberger, 1997). A carbonate zone devoid of shale is represented by the lithology triangle made up of dolomite, calcite, and silica in the M-N plot technique; in addition, the distance that exists between the lithology triangle and the points exhibits the degree of secondary porosity forming in regions over the line of calcite, dolomite, and silica (MacCary, 1978; Schlumberger, 2009)The points are depicted in the developing shaly space underneath the triangle owing to the component's shale concentration. The data's displacement is also influenced by rugosity, and this finally indicates a trend toward a larger concentration of shale (Burke et a., 1969; MacCary, 1978). Considering Equations 1 and 2, the variables M and N are obtained (Schlumberger, 1989). Halliburton (2001) stated that under conditions where the formation consists of multiple minerals, particularly dolomite, which has been cemented with sandstone, the cross-plot interpretations may be uncertain.

$$M = [(\Delta t_{fl} - \Delta t_{log}) / (\rho b - \rho_{fl})]\ 0.01 \quad (1)$$

$$N = (ØN_{fl} – ØN_{log})/ (ρb - ρ_{fl}) \quad (2)$$

Where: $\Delta t_{fl}$: Mud filtrate's acoustic transit time (Fresh Fluid = 189 µsec/ft and Brine Fluid = 185 µsec/ft), $\Delta t_{log}$: Acoustic log measurement at available depth in (µsec/ft), ρb: The matrix's bulk density at every given depth in (gm/cc), $\rho_{fl}$: Density of Fluid (Fresh = 1.0 gm/cc and Brine = 1.10 gm/cc), 0.01: The ratio quantity that is employed to adjust the quantities of M parameter, $ØN_{fl}$: Fluid's neutron generally equals 1, and $ØN_{log}$: The matrix's neutron porosity at any given depth.

Besides, some of the points lie within the dolomite area; in general, the impact of the clay material (shale content) or the dolomitization process is typically responsible for the shifts of the points throughout the dolomite region (Figure 2). The prevalence of the depicted results in the calcite region makes it obvious that the Shiranish Formation's predominant lithology at the SH-2 and BZ-1 wells is limestone and marl with limestone (Figure 2). This is consistent with the study of Baban et al. (2020) at Taq-Taq Oilfield.

3.2. Shale Volume

Along the studied Shiranish Formation, the quantity of shale content has been identified by combining Equation 3 and the formula for shale volume computation (Equation 4), considering the digitized data obtained from the GR log (Larionov, 1969; Asquith & Gibson, 1982; Dewan, 1983). The recorded GR data indicate lower values at the SH-2 well than at the well of BZ-1. Furthermore, in the Shiranish Formation, the GR log response is predominantly less than 50 API (Figure 3); at the BZ-1 well, however, the GR record shows higher in the middle and lower intervals of the formation, therefore, the volume of shale content often increased downward. The highest shale concentrations are roughly 40% and 30% for wells BZ-1 and SH-2, respectively; other than certain intervals at the bottom of the formation, which exceeded around 50% (Figure 3).

$$IGR= (GR_{Log}- GR_{Min})/(GR_{Max}-GR_{Min}) \quad (3)$$

$$V_{Shale}= 0.33 (2^{2*IGR}–1.0) \quad (4)$$

Where IGR is the gamma-ray Index, $GR_{Log}$ is the value of GR from the log, $GR_{Min}$ is the value of the lowest GR at a free shale interval, $GR_{Max}$: is the value of the highest GR at a shale interval, and $V_{Shale}$= Shale content volume.

In the studied formation of Shiranish, the categorization of (Ghorab et al., 2008) was utilized to delineate the degree of shale contents within the studied boreholes. With this strategy, a shale zone has more than 35% of the shale volume. Besides, a shaly interval is described as containing between 10% and 35% of the quantity of shale; nonetheless, a clear horizon can be described as having a higher limit of 10% shale constituent. Consequently, the top of the Shiranish Formation is mostly dominated by clean intervals (less than 10%), which have risen downward to form a shaly zone along SH-2's well, extending from 2448 m to the formation's very bottom. Shaly intervals (10 – 35 %), however, are widespread over the BZ-1 well at the middle and lower part of the Shiranish Formation, specifically at depths of 2073 to 2169 m and 2189 to 2251 m, respectively, notwithstanding a few isolated shale zone horizons where shale content is more than 35% (Figure 3). This conclusion is nearly in line with the preceding Shiranish Formation study in Taq Taq Oilfield conducted by Baban et al. (2020).

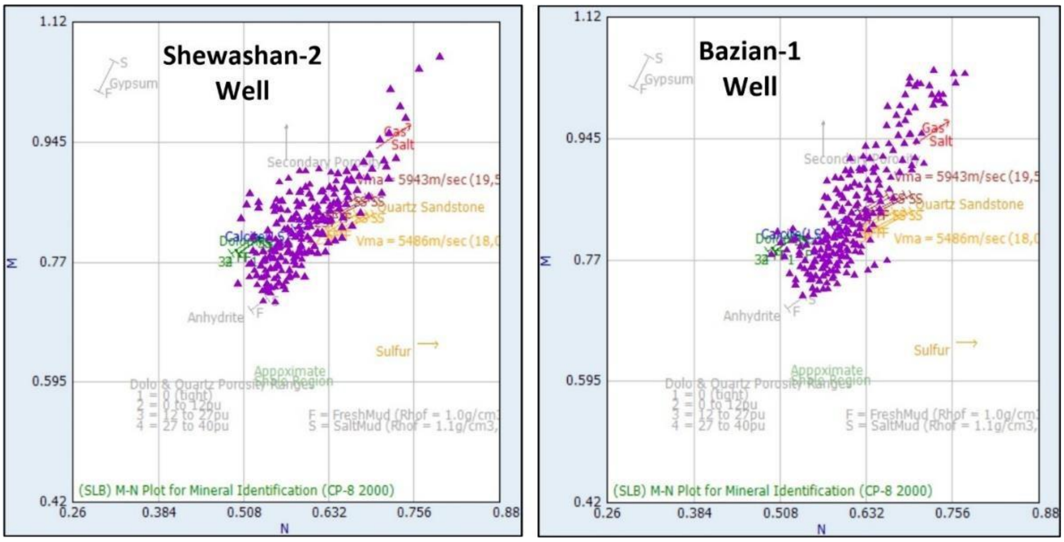


**Figure 2.** The Crossplot of M-N for the Shiranish Formation at the SH-2 and BZ-1 wells.

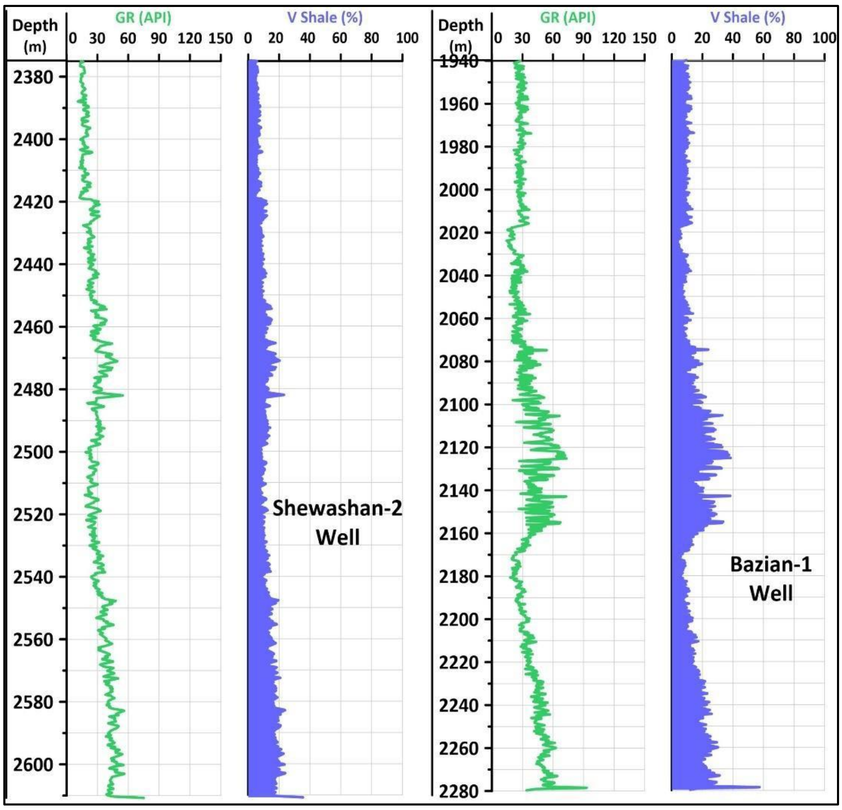


**Figure 3.** Shiranish Formation's GR log and determined shale volume at the studied wells.

3.3. Determination of Total and Secondary Porosities

A key attribute of reservoir rocks that have been associated with the storage capacity of reservoirs is porosity. The entire field of petrophysical examination revolves around the study of porosity (Asquith & Krygowski, 2004). The observed total porosity, which comes from a combination of density-porosity (ØD) and neutron-porosity (ØN), provides an adequate description of the primary and secondary porosities. Figure 4 shows the overall (neutron and density combination) porosity at the studied wells, both before and after the shale impact modification for the Shiranish Formation. Schlumberger (1989) provided the basis for this computation. Typically, the determined porosity declines downward along the studied wells. The Shiranish Formation's average porosity at the SH-2 well is around 7.7%, in contrast to approximately 9.2% in the BZ-1 well. Along the well of SH-2, compared to the other part of the formation, the upper part of it also records a higher average of 10.9% from 2375 m to 2456.4 m; as previously mentioned, porosity reduces, particularly from 2456.4 m to the very bottom of the formation, the porosity almost remains constant. Furthermore, the upper part of the formation at the BZ-1 well is undoubtedly from 1940 to 2030 m, where greater porosity with an average of 12.8% is identified. A few intervals in the middle portion of the formation, including those with horizons of 2073.1 – 2074.7 m, 2093.5 – 2095 m, 2012 – 2014.5 m, and 2122.5 – 2124.3 m, are distinguished by porosity exceeding 10% (Figure 4). As a consequence, the combination of neutron and density porosity reveals that the Shiranish Formation in the BZ-1 well is more porous than the SH-2 well. Moreover, dissolution, fracturing, and reprecipitation are the actions that lead to secondary porosity; nevertheless, diagenesis is the major mechanism that regulates secondary porosity (Choquette & Pray, 1970). Reservoir rocks exhibit variations in petrophysical characteristics resulting from multiple-porosity systems, which reflect most carbonate rocks (Mazzullo & Chilingarian, 1992). The overall amount of porosity can be measured using combination porosity (ØN-D), and primary porosity is often indicated by sonic porosity (ØS). The variance between the two should be exploited to figure out secondary porosity (Asquith & Gibson, 1982).

After that, the secondary porosity for the Shiranish Formation at the studied well has been estimated employing the previously suggested approach, with the outcome shown in Figure 5. Commonly, secondary porosity percentages within the studied formation are between 5.0% and 10%, respectively, at the wells of SH-2 and BZ-1. At the SH-2 well there is comparatively little secondary porosity over most of the Shiranish Formation records, ranging from 1.0% to 5.0%. Except for a few horizons across the SH-2 well where its value records greater, these intervals of 2381.2 – 2382.6 m, 2383.3 – 2326.7 m, 2395.5 – 2397.1 m, 2455 – 2456 m, and 2606 – 2608.2 m are among the horizons that don't surpass 15 meters in total (Figure 5).

On the other hand, the higher secondary porosity at the BZ-1 well typically dominates the formation and varies from 3.0% to 6.5%, particularly at the top of the Shiranish Formation. The next several horizons along the well of BZ-1 are differentiated by higher percentages of secondary porosity at the following intervals corresponding to more than 10 percent, including 1946.1 – 1942.4 m, 1955 – 1957 m, 1964 – 1966.2 m, 1970 – 197.1 m, 2028.5 – 2030 m, and 211.5 – 2112.5 m as indicated in Figure 5. Therefore, the Late Cretaceous Shiranish Formation at well BZ-1, compared to the well of SH-2, has higher secondary porosity. As previously mentioned, the capability to precisely pinpoint the secondary porosity is the main convenience of the M-N technique. Therefore, the plotted results (Figures 2 and 5) indicate that the Shiranish Formation at the BZ-1 well is characterized by higher secondary porosity than in the SH-2 well. This is due to the lower response of density log measurement in fractured formations (MacCary, 1978; Schlumberger, 1989).

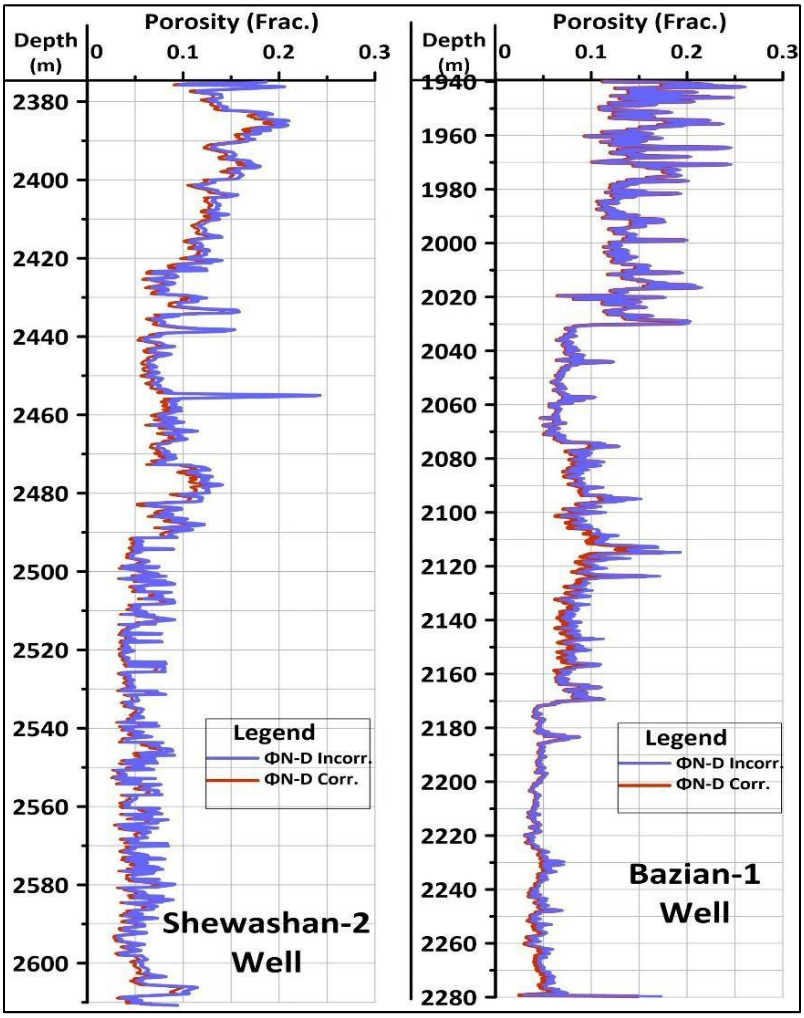


**Figure 4.** Computed combination porosity (ØN-D) together corrected and incorrect from the shale content influence for the studied formation at the SH-2 and BZ-1 wells.

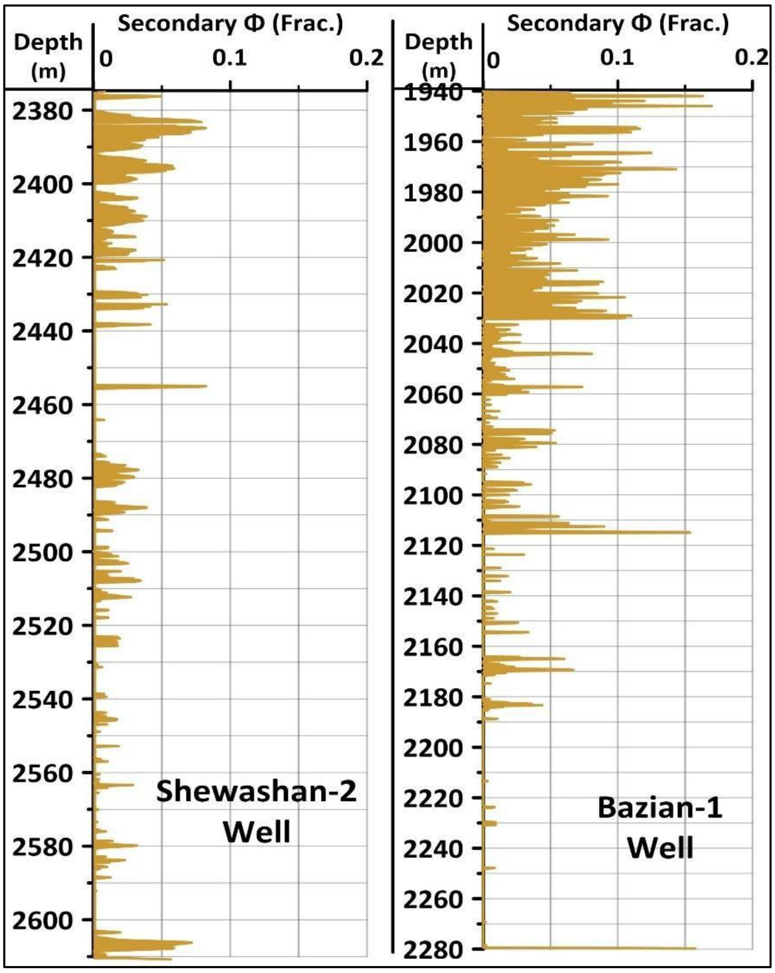


**Figure 5.** Determined secondary porosity at the studied wells for the Shiranish Formation.

3.4. Permeability

Permeability, which describes a porous material's potential to transfer liquids, establishes the quantity of fluid that can flow within a reservoir rock unit. Data on permeability may be obtained from a variety of sources, including the examination of core samples and the assessment of measurements taken in the field during drilling (Schlumberger, 1989; Rafik & Kamel, 2017) In carbonate formation, pore connectivity is the single most significant aspect influencing permeability. Since various diagenetic processes follow the depositional setting, carbonate rock units present variability from a permeability perspective (Selley, 1998). In the SH-2 and BZ-1 wells, the permeability of the Shiranish Formation was ascertained by implementing a numerical approach (Equation 5) that was recommended by Wyllie & Rose (1950). Mohaghegh et al. (1997) found that the MLR (multiple linear regression) is an alternative procedure that provides a more adequate approach for computing the values of permeability from the provided wireline-log data. While the log records are approved as independent data, the permeability-derived logging result is considered dependent. To determine the log's expected permeability of the Shiranish Formation, the MLR technique was adopted in this study. There have been contemporary demonstrations of the technique described by Baban & Ahmed (2021) and Salih & Qader (2023).

$$K = CØ^3/ (Sw_{Irr.})^2 \quad (5)$$

Where K: Calculated Permeability, C: Constant for (dry-gas=79 and oil=250), Ø: Combination of neutron-density porosity (corrected), and $Sw_{Irr}$: Irreducible saturation of water.

To describe permeability at the wells of SH-2 and BZ-1, along with determining the optimal correlation between the dependent and log-data permeabilities, two basic concepts of the MLR technique were employed to define permeability inside the Shiranish Formation. The neutron porosity, bulk density, sonic transit time, and GR log data are all utilized in the first method. In addition to the previously indicated factors, the data of latero-log deep/LLD is related to the second premise, check Equation 6 for LLD (Mohaghegh et al., 1997; Taghavi, 2005; Rafik & Kamel, 2017). Figure 6 indicates the estimated log-data permeability at the SH-2 and BZ-1 wells for the Shiranish Formation. It has been defined by the strongest relationship between log-data and dependent permeabilities employing Equations 6 and 7 at the wells of SH-2 and BZ-1, respectively (Mohaghegh et al., 1997; Rafik & Kamel, 2017).

$$K = 1958.81+ (-21.5*GR) + (3.8987*DT) + (-6.715*\rho b) + (1.616*ϴN) \quad (6)$$

$$K = 737.546+(-0.06217*GR)+(2.0945*DT)+(-2.168*\rho b)+(0.12184*ϴN)+(0.067*LLD) \quad (7)$$

According to the computed MLR permeability, the Shiranish Formation was relatively dominated by greater permeability as compared to the BZ-1 well, specifically in the middle and upper part of the formation (Figure 6). In general, the predicted permeability of the Shiranish Formation dropped in almost the same manner as the porosity declined (Figures 4 and 6) towards the lower part of the formation. This is because the MLR permeability is dependent on the values of the well-log data (Taghavi, 2005; Rafik & Kamel, 2017).

At the well of SH-2, the formation's permeability normally varies from 0.1 to 15 mD, particularly at the top of the formation between 2375 and 2467.5 m depth, while the middle and lower sections of the Shiranish Formation are virtually less than 3.0 mD. In contrast, the upper part of the Shiranish Formation (from 1940 m to 2029 m) is distinguished by a greater permeability of almost 5.0 to 100 mD, with the exception of limited minor horizons of less than 1.0 mD in the BZ-1 well. Moreover, the permeability of the investigated formation varies from 0.1 mD to 10 mD between 2029 m and 2185 m depths. The bottom section is then dominated by less permeability, concerning < 2.0 mD. Consequently, the log-derived permeability of the Shiranish Formation indicates that poor to fair permeability predominates in the SH-2 well, while it is comparatively moderate to almost good at the BZ-1 well (North, 1985).

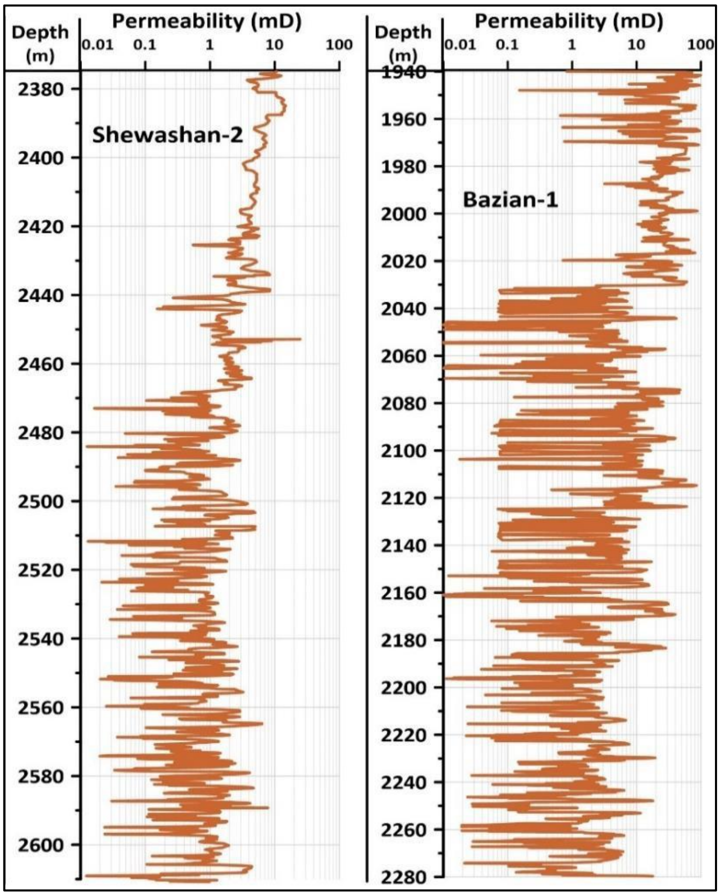


**Figure 6.** Determined log data derived permeability for the Shiranish Formation in the studied wells.

3.5. Reservoir Units

To distinguish between rock units according to various reservoir characteristics, the determined essential rock parameters of shale content, porosity, and permeability along the Shiranish Formation were employed, irrespective of what type of fluid accumulated within the formation. In addition, all three previously described factors were implemented for separating the reservoir units of the Shiranish Formation at the SH-2 and BZ-1 wells. According to these variations, three reservoir units (RU) have been identified for the Shiranish Formation in the studied wells, and the results are demonstrated in Figure 7. A Summary of the average, least, and highest values for depth ranges, thickness, shale volume, porosity, and permeability of each detected reservoir unit is given in Table 1. According to the data, the RU-3 has the most outstanding reservoir property along the Shiranish Formation in the wells of SH-2 and BZ-1, since the lowest shale volume, together with the highest average values of porosity and permeability, are dominated in this reservoir unit. In contrast, as a consequence of the permeability and porosity levels remaining the smallest and the volume of shale proved the largest, the RU-1 within both of the studied wells appeared to possess the fewest reservoir attributes (Figure 7 and Table 1). Therefore, it implies that the reservoir's overall quality is defined along the SH-2 and BZ-1 wells as downward declining.

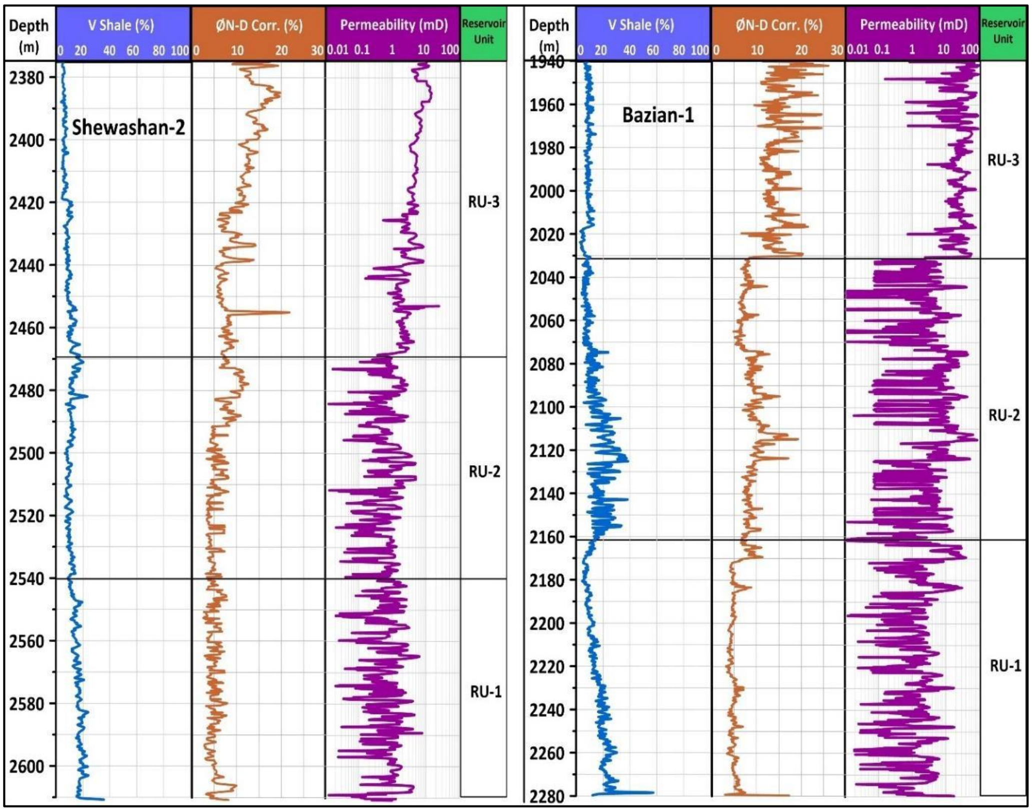


**Figure 7.** The designated reservoir units for the Shiranish Formation within the SH-2 and BZ-1 wells are determined by porosity, permeability, and shale content.

**Table 1.** Thickness and depth in the wells of SH-2 and BZ-1, together with numerical parameter descriptions along recognized reservoir units of the Shiranish Formation.

| SHEWASHAN-2 WELL | | | | | | |
|---|---|---|---|---|---|---|
| **Reservoir Units** | **Depth Interval (m)** | **Thickness (m)** | **Statistics** | **Shale Volume (%)** | **Porosity (%)** | **Permeability (mD)** |
| RU-3 | 2375 – 2469.5 | 94.5 | Minimum | 1.1 | 5.2 | 0.15 |
| | | | Maximum | 17.7 | 21.3 | 25 |
| | | | Average | 8.0 | 9.4 | 4.6 |
| RU-2 | 2469.5 – 2540.2 | 70.7 | Minimum | 6.2 | 3.0 | 1.2 |
| | | | Maximum | 23.2 | 12.7 | 5.1 |
| | | | Average | 10.9 | 6.3 | 1.0 |
| RU-1 | 2540.2 – 2610 | 69.8 | Minimum | 9.0 | 2.5 | 1.2 |
| | | | Maximum | 35.5 | 10 | 7.8 |
| | | | Average | 16.4 | 5.1 | 1.1 |
| **BAZIAN-1 WELL** | | | | | | |
| **Reservoir Units** | **Depth Interval (m)** | **Thickness (m)** | **Statistics** | **Shale Volume (%)** | **Porosity (%)** | **Permeability (mD)** |
| RU-3 | 1940 – 2030.4 | 90.4 | Minimum | 2.6 | 6.5 | 0.14 |
| | | | Maximum | 14.4 | 25.6 | 99.8 |
| | | | Average | 8.26 | 12.8 | 32.3 |
| RU-2 | 2030.4 – 2160.2 | 129.8 | Minimum | 3.9 | 4.8 | 0.06 |
| | | | Maximum | 38.5 | 19 | 90.3 |
| | | | Average | 14.6 | 8.7 | 7.7 |
| RU-1 | 2160.2 – 2280 | 119.8 | Minimum | 4.2 | 2.9 | 0.01 |
| | | | Maximum | 54.7 | 17.3 | 42.7 |
| | | | Average | 15.2 | 5.1 | 3.3 |

### 3.6. Saturations of Water and Hydrocarbon

The well-log data can be exploited to estimate the degrees of reservoir fluids' saturation and potential areas of interest, together with the depth of the formation rock units (Brown, 2002). Assessments of reservoir rocks are strongly impacted by water saturation; moreover, any reservoir hydrocarbon saturation is often computed based on reservoir storage and capacity, porosity, and water saturation (Asquith & Gibson, 1982). Archie's calculation, capillary pressure evaluations, and instantaneous examination of core samples are all approaches that can potentially be performed to identify water saturation for any reservoir rock (Asquith & Gibson, 1982; Rider, 1996). The cementation factor represented a critical element of the water saturation assessment at reservoir units utilizing Archie's formula, found through the Pickett cross-plot and reported as 1.31 and 1.23 individually for the SH-2 well and well of the BZ-1 procedure (Figure 8).

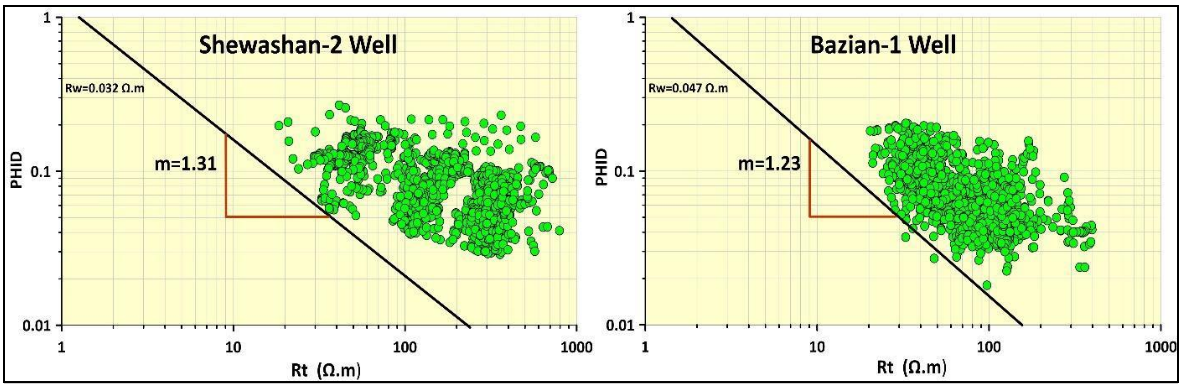


**Figure 8.** Determination of cementation factor (m) for the Shiranish Formation from Pickett cross-plot in the SH-2 and BZ-1 wells.

Additionally, the respective values of shallow resistivity ($R_{xo}$) and true formation resistivity ($R_t$) have been obtained by analyzing data from the resistivity log instruments, which consisted of the (SFL) and the (LLD), respectively. Along the Shiranish Formation in the selected wells, the methodologies of Rider (1996) and Asquith & Krygowski (2004) were implemented in order to identify water saturations in the flushed and uninvaded zones, as well as hydrocarbon saturations (moveable and residual). Next, the saturation values within the pore spaces can then be visualized and represented as a percentage by multiplying the specified parameters by the total corrected porosity (Serra, 1984; Rider, 2002). The distribution of the computed saturations within the Shiranish Formation porosity is manifested in Figure 9.

Regarding water saturation, the well of BZ-1 was dominated by the lowest volume, although the SH-2 well presented a further percentage. Furthermore, from the saturation of the hydrocarbon perspective in both SH-2 and BZ-1 wells, an obvious fraction of movable oil can be seen along with all of the specified reservoir units of the studied formation. However, the residual component made up a significant portion of the hydrocarbons (Figure 9). As was pointed out relating to reservoir condition, the finest reservoir quality has been identified in the

RU-3; however, the lowest quality was defined with the RU-1 (Table 1). Therefore, RU-3 of the Shiranish Formation possesses the greatest percentage of mobile hydrocarbons, whereas RU-1 has the lowest concentration. This conclusion applies to both wells of the study. As a result, the saturation of residual oils predominated in the pores of the Shiranish Formation along both of the studied wells. The relationship between relatively high porosity and large proportions of residual hydrocarbon saturations suggests the presence of isolated pores and numerous confined spaces along the Shiranish Formation at the studied wells (Baban & Ahmed, 2021; Salih & Qader, 2023).

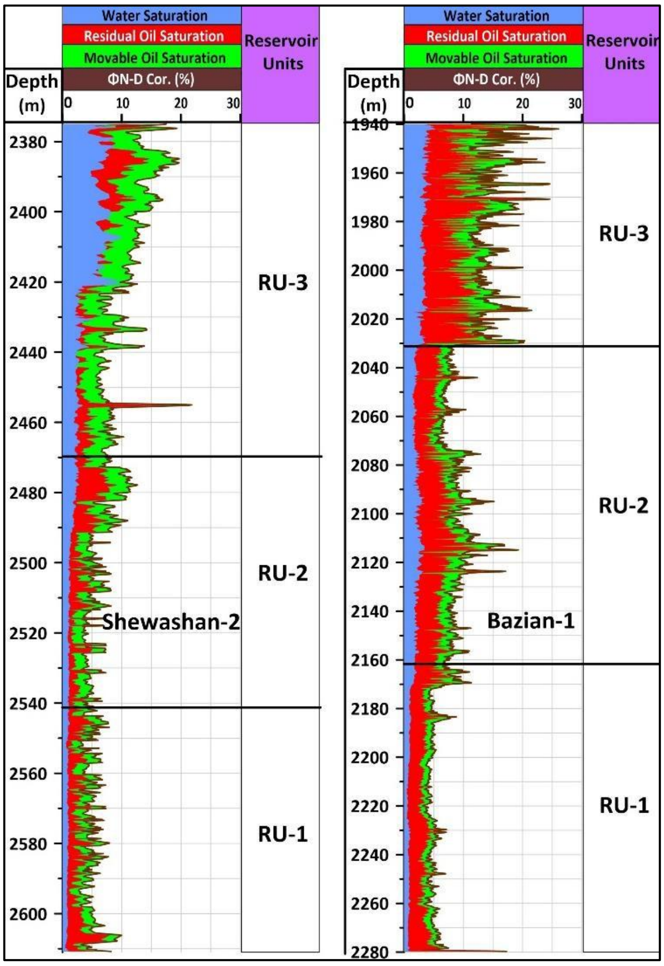


**Figure 9.** Moveable and residual oil saturation together with water saturation of the studied formation in the wells of SH-2 and BZ-1.

## 4. Conclusions

The Shiranish formation is predominantly made up of limestone and marly limestone in the studied wells of SH- and BZ-1. In the upper part of the Shiranish Formation along the studied wells, the shale content is often characterized by a lower value, whereas once it descends to the bottom of the holes, the value increases. Other than a few areas in the middle of the BZ-1, where the shaly zone predominates. The total average porosity at the very top of the Shiranish Formation is around 7.0% and 12% at SH-2 and BZ-1, respectively; however, it gradually declines downward, excluding the few intervals where the porosity records higher values, particularly at the BZ-1 well. In addition, secondary porosity suggested that the Shiranish Formation was characterized by greater secondary porosity at the BZ-1 well than at the well of SH-2. According to permeability data, at the BZ-1 well, the Shiranish Formation has comparatively moderate to almost good permeability, whereas poor to fair permeability predominates in the SH-2 well according to the categorization of North (1985). Three reservoir units were identified for the Shiranish formation in both of the selected wells; RU-3 demonstrated the most effective reservoir condition, while RU-1 had the lowest reservoir quality along both the SH-2 and BZ-1 wells. A large portion of the Shiranish Formation's pore spaces is made up of the remaining hydrocarbons. All reservoir units may possess a quantifiable volume of recoverable hydrocarbons. Compared to the BZ-1 well, the Shiranish Formation in the SH-2 well is more saturated with water.

## Acknowledgments

The Ministry of Natural Resources in the Kurdistan Region of Iraq (MNR/KRG) is acknowledged and appreciated by the authors for supplying the data utilized for this study.

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