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Three-Dimensional Geological Model of the Nahr Umr Reservoir in Al Rafidain Oil Field

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Abstract

The 3D geological model is very important for reservoir characterization, volumetric calculation, reservoir simulation, and setting development strategies. The present paper is dealing with building 3D geological model for the Nar Umr reservoir of Al Rafidain oil field located in southern Iraq.
The data needed to construct the 3D model: contour map, well head, well tops, and computer processing interpretation (*CPI*) data that comprised porosity (Ø), water saturation (*Sw*), and net to gross thickness (*N/G*). The model is built in sequential steps as make units' surfaces, 3D skeleton grids, layering, petrophysical properties arithmetic scale-up, property modeling by the sequential Gaussian simulation (*SGS*) method, and finally volumetric oil reserve calculations by volumetric method.
The Nahr Umr reservoir is classified into three unit zones: A, B, and C. These units are described as shaly-lime, clean sandstone, and shale zones, respectively. The last one is declined in volumetric calculations because it is a shale zone. The volumetric equation provided an initial oil in place (*IOIP*) value as 805.0944 MMSTB. This value is compared with a unique study before the existing one that handled *IOIP* value as 748.48482 MMSTB. The value of IOIP depends upon distributed CPI properties for each grid and reservoir volume. Accurate property modeling led to best estimate of IOIP.

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1. Introduction

The 3D geological modeling is the basic critical component of geological and reservoir studies [1]. It is combining geology and computation to extract the best reservoir representation and data insights and improve reserve estimation and reservoir modeling and development [2]. The development in software has facilitated the fast growth in the process of 3D modeling, which mainly deals with the difficulty of real mapping representation and the geology of topological correlation [3,4]. Structural modeling and petrophysical modeling are the two parts that make up the 3D geological model. Geophysical information as contour maps and seismic data models in structural modeling, while the petrophysical information like porosity, water saturation, permeability, and net pay thickness is simulated with petrophysical modeling [5]. As widely known, this type of model deals with involving a comprehensive analysis of petrophysical, seismic, geological, and engineering data by employing geostatistical approaches, spatial data processing, and volumetric calculations within a virtual 3D environment [6]. Finally, all mentioned necessary data combined to provide a relevant model that is appropriate for volumetric estimations and reservoir simulation [7]. A 3D model is evaluated as good if it completely describes real-world relevant reservoir properties [8].

The construction of the 3D geological model is passing through a number of steps. The structural map is plotted for the target reservoir contour map, which reveals that the reservoir is dominated by an anticlinal feature that plays a critical role in hydrocarbon accumulation. Anticlines represent classic structural traps where hydrocarbons migrate upward and accumulate in the crest of the fold. The crest of the anticline is therefore the most favorable location for reservoir quality and hydrocarbon saturation, while the flanks tend to contain increased shale content and reduced productivity [9]. The 3D grid skeleton was constructed, and petrophysical properties were entered and modeled by one of the geostatistical methods, such as Gaussian sequential simulation (*SGS*). *SGS* is a widely used method that has been utilized in recent years. Simply, flexibility and reasonability are the main features of this method [10]. The volumetric calculation is performed by applying a volumetric equation to estimate initial oil in place (IOIP) [11].

The aim of the present paper is to construct a 3D geological model for the Nahr Umr reservoir of the Al Rafidain oil field located in Nasiriya Governorate, southern Iraq, by performing the following objectives:

1. Construction of a 3D surface model.
2. Making a scale-up for utilized petrophysical properties of the target reservoir.
3. Making property modeling by the SGS method.
4. Making volume calculation for IOIP estimation.

2. Area of Study and Geological Setting

Al Rafidain (Abo Amood) oil field is one of the Iraqi oil fields located in Thi-Qar Governorate in southern Iraq away 250 km from Baghdad and 23 km southwest of the Dujaila field. It has an area approximately 208 km^2 and a structural orientation from northwest to southeast. Longitudes in the area range from 45.30 to 46.30 degrees, with latitudes of 31 degrees, as shown in **Fig.1** [12]. This field has three main reservoirs, Mishrif, Mauddud, and Yamama, and three secondary reservoirs, Nahr Umr, Zubair, and Ratawi. It is rising twenty meters above sea level, and the geography distribution showed flat topography. It was discovered in 1977 and improved by the Iraqi Southern Oil Company [13]. During the years 1973-1976, a seismic survey on the structure was conducted as part of a survey connected to Dujaila. The first exploration well was drilled in July 1980. This drilled exploration well reached a depth 4702 m of Najmah formation that formed in the Jurassic phase [14].

Nahr Umr reservoir formed in the middle Cretaceous age below the Mauddud reservoir and above the Shuaiba that formed in the early Cretaceous as illustrated in **Fig.2** [13]. Based on existing field data and reports, this reservoir has a top below sea level approximately equal to 3025 m in Al Rafidain oil field. The reservoir is stable with no fault; however, faults may be present in the Yamama and Ratawai reservoirs [15]. The Nahr-Umr reservoir consists of shale intersected with limestone rocks and sand in the top portion of the reservoir, which is followed by a layer of sand that is considered the most important part for reservoir properties due to the formation's thickness that is approximately equal to 139 m [16]. The oil is found in the Nahr-Umr reservoir's middle unit (sand layer) in AAM 1, with a net thickness of 13 m and continuity in seismic sections. [17]. To get a structural picture, time, velocity, and depth maps of the top of the Nahr-Umr reservoir were made. These maps supported that the Al Rafidain oil field has a semi-symmetrical structure with an axis that runs NW-SE, and the slope of the NE limb is larger than that of the SW limb. Isochrones and isopach maps were created for the Nahr-Umr reservoir to show its thickness, which progressively grows to the west, *NW*, and *SW* sections of the study region and more gradually increases to the east and *NE* parts of the study area. Seismic characteristics were applied to the research region; these attributes demonstrated the presence of a direct hydrocarbon indication at the Nahr Umr reservoir [12, 18].

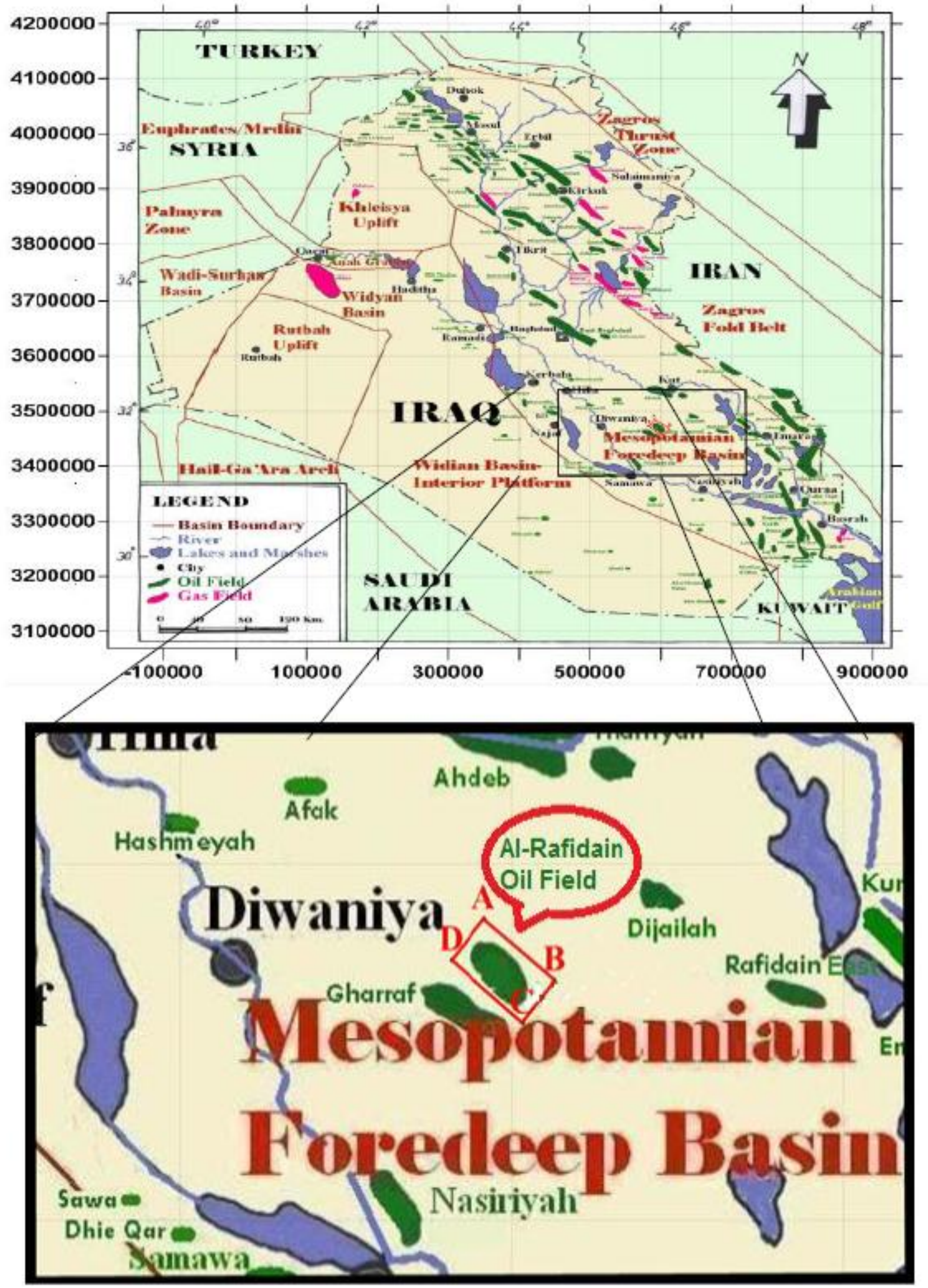

Figure 1: Al Rafidain oil field location on Iraqi fields map [12].

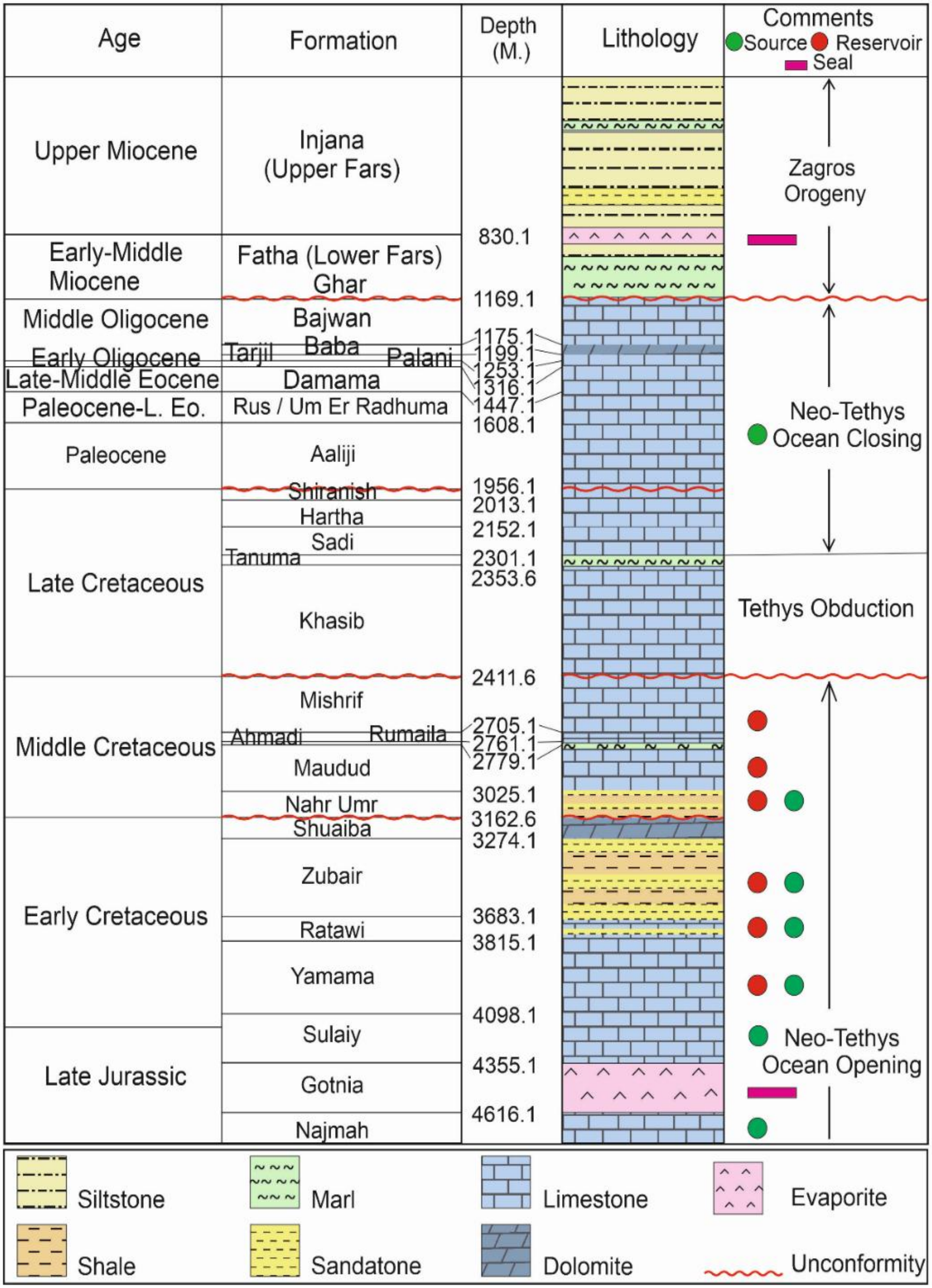

Figure 2: Stratigraphic column of Al Rafidain oil field [13].

3. Methodology and Results

The present paper is performed by using data of five wells. In fact, using data from five wells to build a 3D model could lead to inaccuracies in the distribution of petrophysical properties and consequently in the final 3D model results. However, in this field, there are no more than five drilled wells, and the wells are close together, as shown on the map. This justifies using the data to obtain good results. The used data comprised on contour map of the top of the Nahr Umr reservoir, a computer processing interpretation (*CPI*) of logs that consisted of porosity, water saturation, net to gross thickness, well heads and tops, and water-oil contacts of each zone. The work methodology comprised main four parts: (1) Data preparation, (2) Making 3D surface, skeleton, and polygon, (3) Property modelling as scale-up and petrophysical distribution, and at last (4) Enter the fluid contact and make a volume calculation by the volumetric method, as shown in the following workflow diagram.

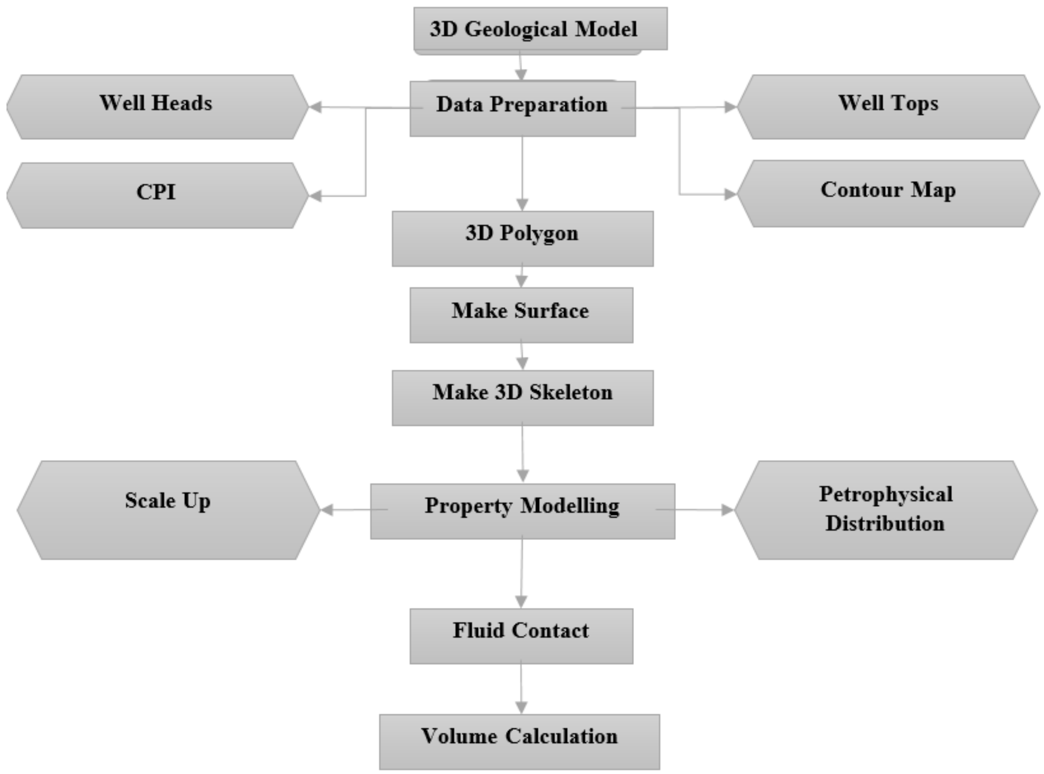

Figure 3. Workflow diagram of constructing 3D geological model.

3.1. Preparing Data

The needed data for constructing a 3D geological model of Nahr Umr reservoir of Al Rafidain oil field comprised five well heads as applied in **Table 1** and well tops as listed in **Table 2**, where the classification of the reservoir into three units A, B and C is based on the evaluation of petrophysical properties. The petrophysical properties porosity (Ø**)**, water saturation (*Sw*) and net to gross (*N/G*) thickness ratio utilized in this paper are summarized and listed in the following **Table 3**.

Table 1. Well head data.

Name	X	Y	KB (m)	MD (m)
AAM 1	614869.6558	3529453.381	19.9	3162.9
AAM 2	608071.7951	3533672.057	18.74	3176.7
AAM 3	613704.1866	3529378.172	17.7	3192
AAM 4	620762.3998	3525642.296	16.95	3196
AAM 5	610704.0801	3532659.712	17.75	3185

Table 2. Well tops data.

Name	Unit	X	Y	MD (m)
AAM 1	A	614869.6558	3529453.381	3025.5
AAM 1	B	614869.6558	3529453.381	3068.1
AAM 1	C	614869.6558	3529453.381	3159.1
AAM 2	A	608071.7951	3533672.057	3040.02
AAM 2	B	608071.7951	3533672.057	3119.1
AAM 2	C	608071.7951	3533672.057	3175.1
AAM 3	A	613704.1866	3529378.172	3046.1
AAM 3	B	613704.1866	3529378.172	3108.1
AAM 3	C	613704.1866	3529378.172	3173.1
AAM 4	A	620762.3998	3525642.296	3061
AAM 4	B	620762.3998	3525642.296	3120.1
AAM 4	C	620762.3998	3525642.296	3134.1
AAM 5	A	610704.0801	3532659.712	3040.21
AAM 5	B	610704.0801	3532659.712	3092.1
AAM 5	C	610704.0801	3532659.712	3167.1

Table 3. Petrophysical properties adopted in present work.

Well	Zone	$Ø_{Min}$	$Ø_{Max}$	Sw_{Min}	Sw_{Max}	N/G
AAM 1	A	0.07	0.45	0.2	0.75	0.351
AAM 1	B	0.06	0.27	0.17	0.7	0.424
AAM 1	C	0.02	0.07	0.22	0.85	0
AAM 2	A	0.08	0.39	0.3	0.85	0.104
AAM 2	B	0.05	0.35	0.3	0.8	0.502
AAM 2	C	0.1	0.25	0.5	0.85	0
AAM 3	A	0.05	0.25	0.25	0.73	0.145
AAM 3	B	0.06	0.35	0.3	0.8	0.745
AAM 3	C	0.08	0.26	0.35	0.7	0.274
AAM 4	A	0.07	0.22	0.4	0.75	0.052
AAM 4	B	0.05	0.23	0.3	0.85	0.46
AAM 4	C	0.08	0.25	0.4	0.9	0.015
AAM 5	A	0.09	0.27	0.3	0.75	0.001
AAM 5	B	0.06	0.35	0.25	0.86	0.452
AAM 5	C	0.07	0.28	0.3	0.77	0.077

3.2. Making 3D Surface, Skeleton, and Polygon

Structure contour maps provide insights into the structural characteristics of reservoirs. The top of Nahr Umr reservoir map was used as a trend to make the surface if the three units A, B, and C. Fig.4 is showing the structural map of A unit with a polygon. These maps will be utilized as a base for property modeling and reservoir simulation. Therefore, accurately digitizing and making the surfaces will produce a more accurate model. The polygon represents the boundary of the reservoir, and only all properties of the reservoir will be distributed on its area within grids. The surface that is bordered by a polygon is classified by the number of grids, so the 3D skeleton will be built as appears in **Fig. 5**. The grids will be used to quantify the rock and fluid properties, and each calculation will be performed for each grid. that has 50 *x* 50 m dimensions.

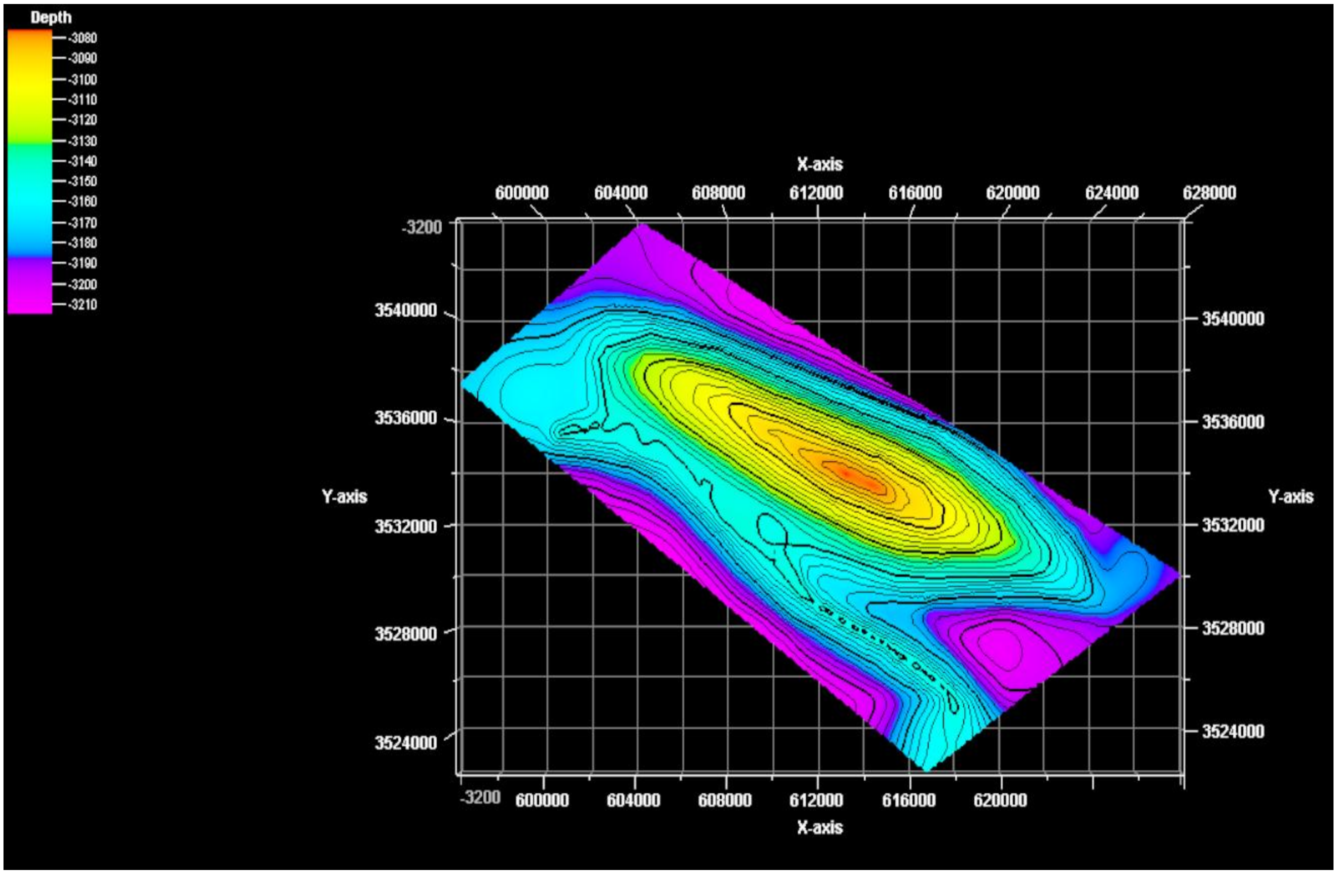

Figure 4. Structural contour map of A unit- Nahr Umr reservoir.

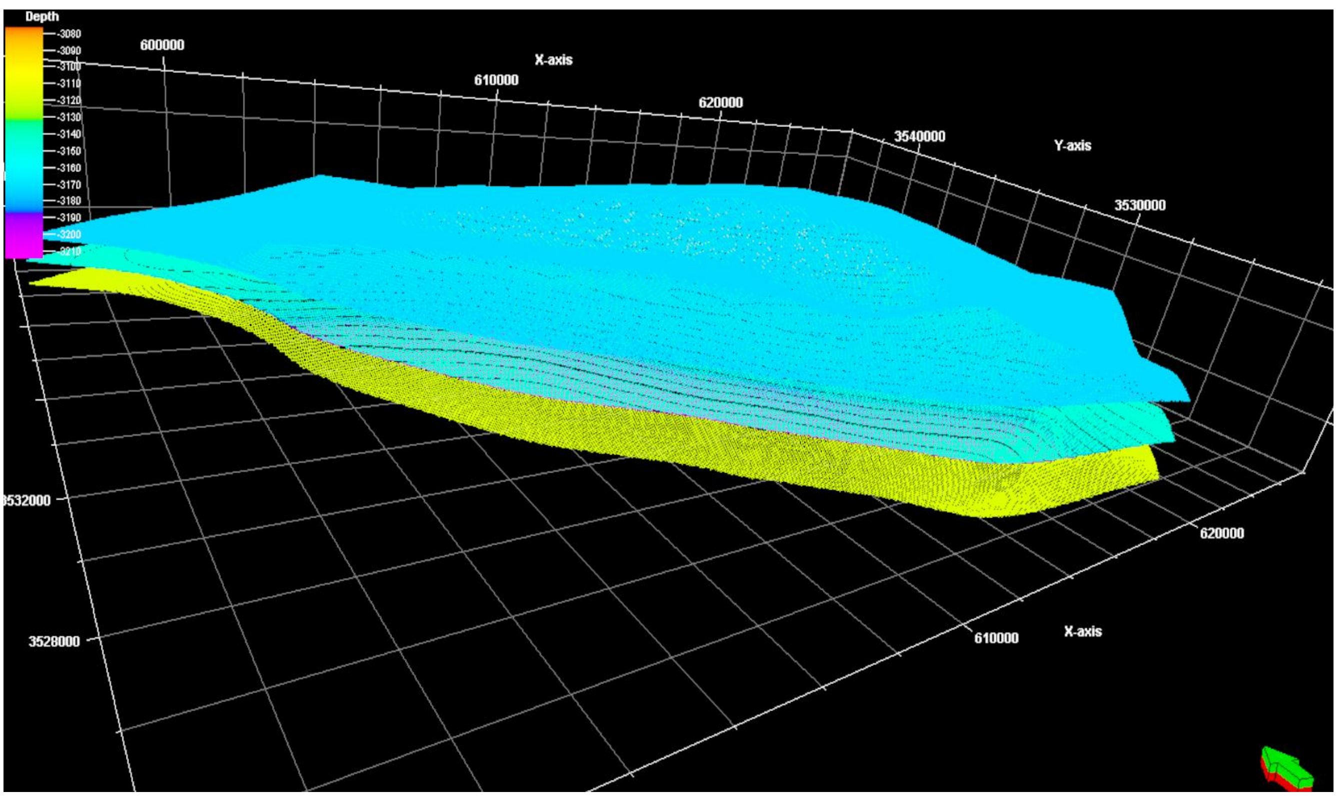

Figure 5. 3D skeleton covered the Nahr Umr reservoir units.

3.3. Property Modelling

Property modelling is the process of quantifying each petrophysical properties in each grid from the entered and scaled up property of wells by using one of the geostatistical methods [19]. So before making this step, the properties need to be processed.

The Nahr Umr reservoir, as showed previously, is classified into three units based on the rock and fluid properties of each unit. Zone A is described as shally-lime zone with some hydrocarbon saturation. Zone B is a clean sand zone that contains a high amount of hydrocarbon in contrast with zone A, while the last zone is shale and totally water saturated. So the A zone classified as 40 multilayers, while the B zone is classified as 50 multilayers and the last C, is neglecting. The C zone neglecting will make the results better with less uncertainty because this zone is shale saturated with water, so the *IOIP* will be decreasing if zone C is considered based on the increasing of *Sw*.

Scale-up of well logs is a process of making averages for adopted petrophysical properties such as arithmetic, geometric, and harmonic methods [20]. The arithmetic method was adopted to make the scale-up for Ø, *Sw*, and *N/G*. As a summary, each one of the multilayer will have a single value of Ø, *Sw*, and *N/G* as applied in the following **Fig.6.**

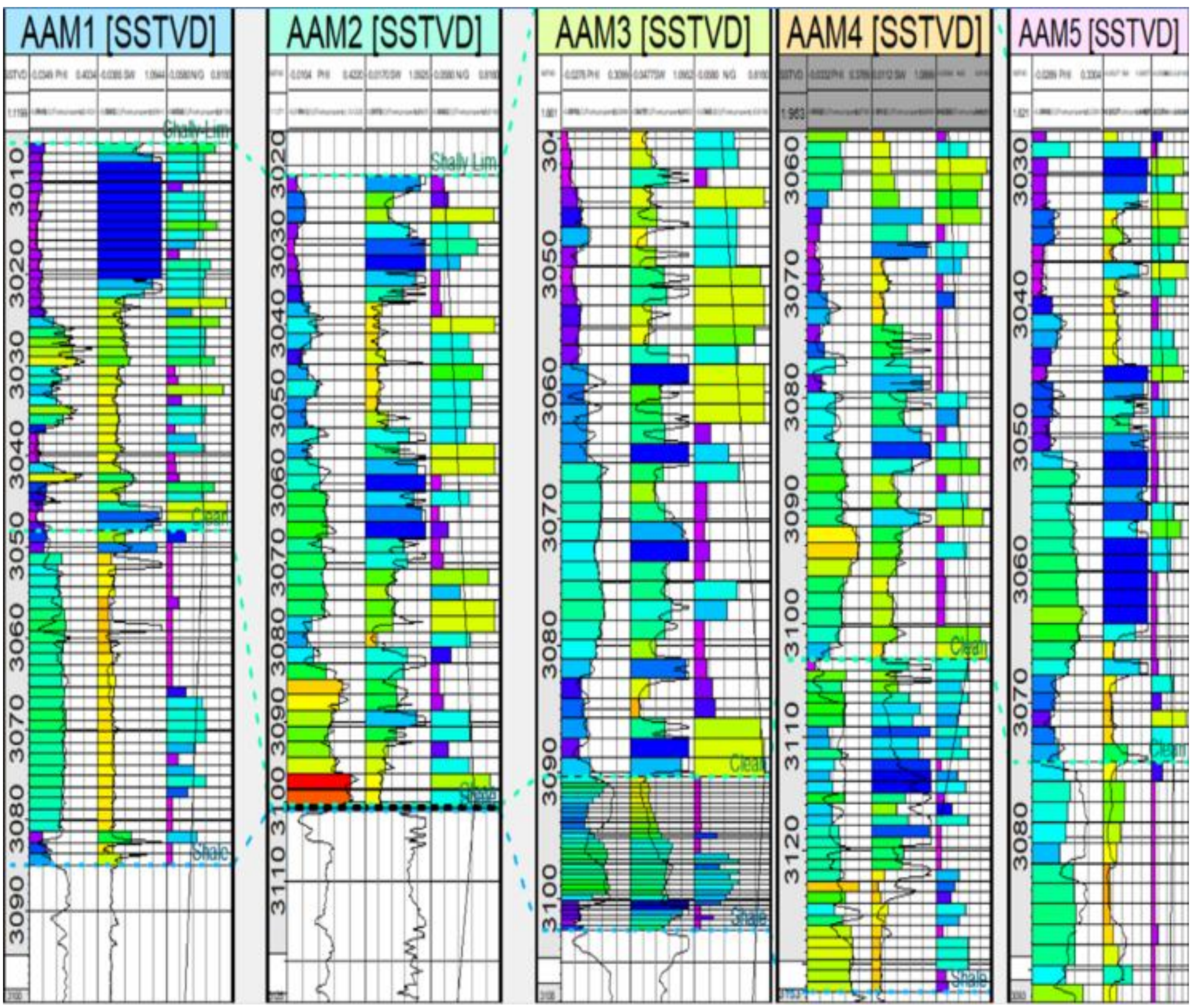

Figure 6. Scale up for Ø, *Sw*, and *N/G* respectively of the five wells.

Petrophysical distribution is the process of distributing each property mentioned previously in each grid cell by utilizing one of the geostatistical approaches such as *SGS*. *SGS* is preferred than over property modelling methods such as Kriging because the latter provides a single forecast that leads to underestimation and extreme property values, while the SGS makes many equally good guesses of petrophysical property values and places, so it is better at catching the natural property variability and risks to be analyzed, finally adopting volumetric calculations based on the constructed 3D model and reservoir simulation. In this approach, a mathematical algorithm is applied to determine the spatial variation of the modelled property; the following figures show the distributed Ø, Sw, and *N/G* for the A zone of Nahr Umr reservoir.

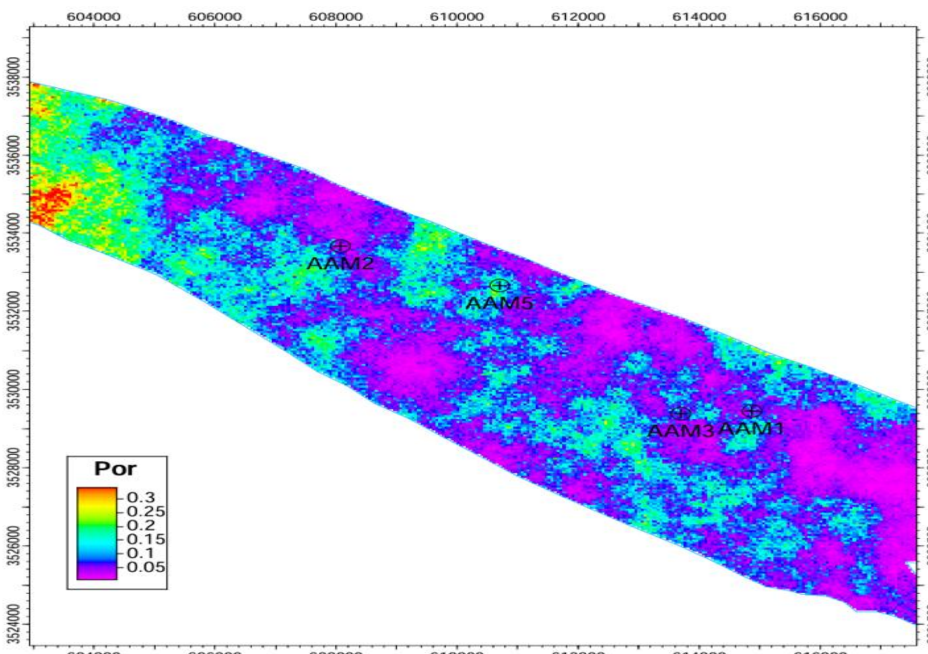

Figure 7. Distributed Ø of A zone.

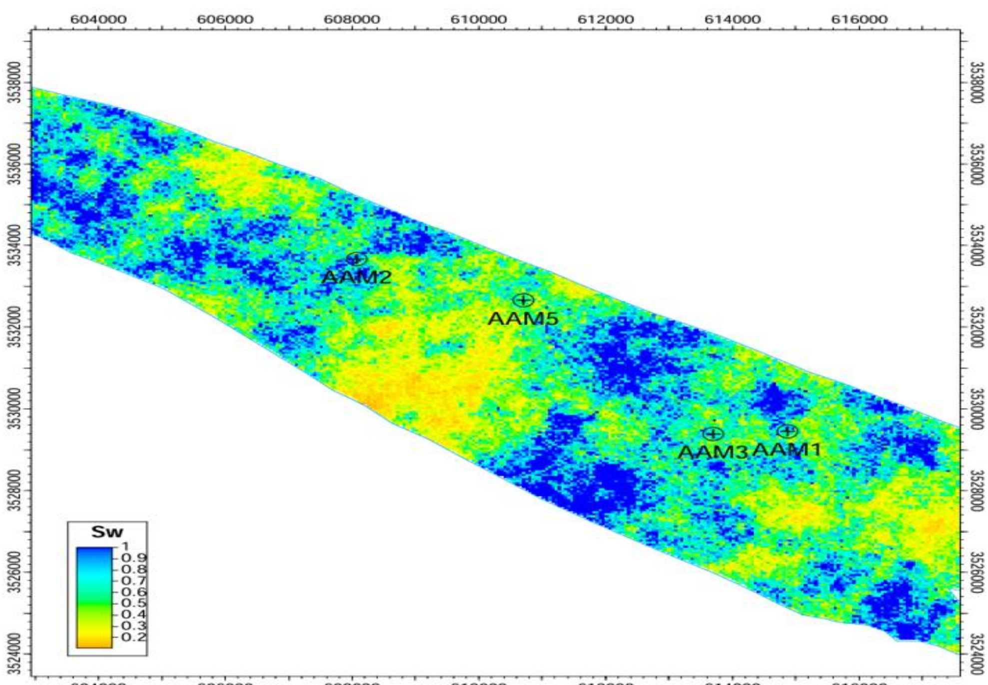

Figure 8. Distributed *Sw* of A zone.

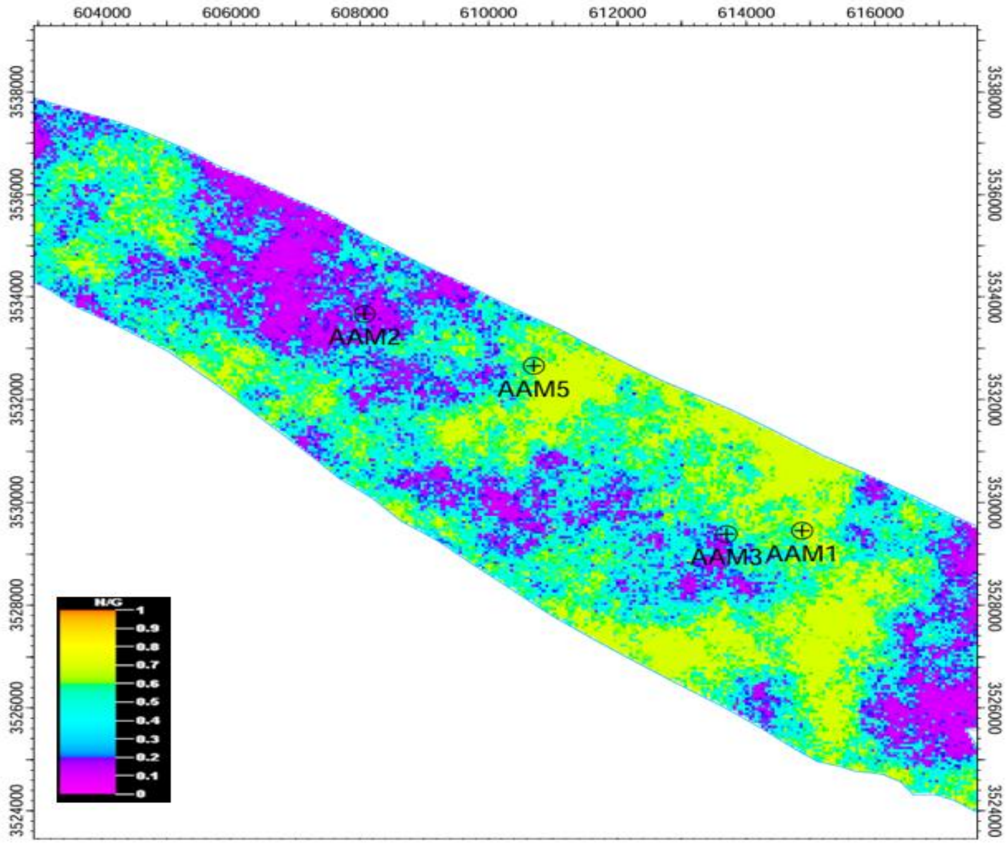

Figure 9. Distributed *N/G* of A zone.

3.4 Fluid Contact

In the present geological model of the Nahr-Umar reservoir, the oil-water contact (*OWC*) was determined at a depth of 3127.96 meters. This was established based on the interpretation of well logs during the formation evaluation process. The defined OWC plays an important role, as it indirectly affects reserve estimation by influencing the delineation of hydrocarbon-bearing zones within the reservoir model. Determining the *WOC* depends on the accuracy of the well logging data used and how it is utilized. Additionally, the accuracy of the formation evaluation model and the petrophysical property calculations all depend on the expertise of the person interpreting the results to derive this value.

3.5. Volumetric Calculation

The initial oil in place (*IOIP*) will be as a result from applying volumetric equation. This equation used the distributed value of properties in each grid and applying the equation for it. Finally, the *IOIP* will be the summation of all calculated grid volumes. The following formula is the volumetric equation [21]:

$$\mathrm{IOIP} = \frac{7758\ x\ \mathrm{V_{bulk}}\ x\ \emptyset\ x\ (1 - \mathrm{S_{wi}})\ N/G}{\mathrm{B_{oi}}} \tag{1}$$

Where:
IOIP: is the initial oil in place (STB).
V_{bulk}: is a bulk volume of reservoir (Acre.ft).
S_{wi}: is the in initial water saturation on each cell (percent)
B_{oi}: is the oil formation volume factor (bbl/STB)

The *IOIP* resulted from applying the **Eq.1** for the Nahr Umar reservoir is 805.0944 MMSTB (128 MMm^3). The details for the zones A and B is listed in the following **Table 4**:

Table 4. Volumetric calculation of Nahr Umr reservoir.

Zone	Bulk volume (MM m^3)	Net volume (MM m^3)	Pore volume (MM m^3)	*IOIP* (MM m^3)
A	7180	2654	312	109
B	1121	230	40	16
Total	8301	2885	352	128

4. Discussion

Accurate construction of a 3D geological model led to excellent estimation of *IOIP*. **Figs. 7, 8, and 9** show the distribution of Ø, Sw, and *N/G* respectively. The approach used for these properties modelling was *SGS* beginning with defining values of univariate distribution, e.g., evaluation of grade values, performing an original score transformation of values to a standard normal distribution, and assuming multi normality of normal scores. So, the distribution is applying high heterogeneity in the A zone and that is expected according to its main two components, shale and limestone. Also the heterogeneity of the target distribution is based on lack wells number, the increasing of wells number and decreasing the distance between wells produce excellent distribution representing the real case existing underneath.

The estimated IOIP from volumetric **Eq.1** shown in **Table 4** is based upon adopting the distributed Ø, *Sw*, and *N/G* of each grid by *SGS*. The bulk volume of the reservoir had been calculated by using contour map data, the net pay thickness was estimated by multiplying each grid thickness by the ratio of *N/G*, and the utilized initial oil formation volume factor (*Boi*) from PVT data was 1.2076 bb/STB at initial pressure value. The value of *WOC* has an indirect effect on *IOIP* value, where it affects *Sw* and the latter inversely impacts on *IOIP*.

The existing paper is providing *IOIP* as 805.0944 MMSTB. There is one study before that dealt with estimating *IOIP* for the same target reservoir of the existing paper, and this study was finding the *IOIP* for the Nahr Umr reservoir equal to 748.48482 MMSTB [22]. The difference in current and past mentioned estimations is approximately 50 MMSTB; this is reasonably based on the dissimilar formation evaluation approach and units' classification as well as the final adopted CPI results. This field needs to drill more wells to get accurate 3D modelling where the distribution and estimation are based on well data and the increasing of the number of wells leads to high-accuracy modelling.

5. Conclusions

1. The 3D surface model constructing needs to accurate digitized contour map and best classification of reservoir units where the entered map will be trained to make other units' surfaces.

2. The scale up process is making the average for the utilized *CPI* data to decrease the number of calculation and processing during run where the scale up values equal the number of sublayers for each unit.

3. The petrophycial properties of well data are distributed using SGS method for each grid and the method connect the wells in hidden lines to guess values in each grid.

4. Knowledge the nature of formation according the determined petrophycial properties and its modelling will enhance the drilling of future wells as well as excellent reservoir modelling, production forecasting and finally accurate IOIP estimation.

Nomenclature

B_{oi}: oil formation volume factor (bbl/STB)
CPI: computer processing interpretation
IOIP: Initial oil in place (STB)
Ø: porosity (percent).
SGS: sequential Gaussian simulation
S_{wi}: initial water saturation on each cell (percent)
V_{bulk}: bulk volume of reservoir (Acre.ft).
WOC: water oil contact (m)

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