Geostatistical Evaluation of Oil Shales existence and their Potential Economic importance through Wadi Ad Dharwa Area-Jordan

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Abstract In this study, geostatistical methods were carried out to estimate the oil contents in Wadi Ad Dharwa oil shale as pre-feasibility stage and economic potential. The oil shale contents have been evaluated based on samples taken from 37 boreholes and wells. A total of 937 chosen samples were used to check for the type of distribution of the oil content. The mining industry parameter given a value of β = 3.23% as empirical estimation that have been depleted from Jordan oil shales, most probably due to their nearness to the surface. Wadi Ad Dharwa taken as an example for Grade-tonnage relationships were then studied at different cut off grades. It has been found, for example, that above a cutoff grade 7% the average grade would be 8.8% and that 22.96 % of the total studied deposit would be having this concentration. The economic potential of the studied oil shales was then discussed in terms of the following factors: geologic aspects, energy rating, mining aspects, break-even price of the oil and price of conventional oil, Energy Returned on Energy Invested (EROEI), Climate, Infrastructure, and the environment of the surrounding areas of the deposit. Based on the pre mentioned aspects.

Key words: Oil shale, Geostatistical methods, Cutoff grade, Wadi Ad Dharwa-Jordan

1 Introduction

P Jordan has a limited conventional energy sources, therefore the evaluation of the presented oil shales in Jordan has a great importance for the local and international companies which are interested in oil shale field technologies. The oil shales are found in almost all the areas covered with cretaceous and tertiary sedimentary deposits. The average organic matter concentration in the Yarmouk basin does not exceed 14% in compared with the same formations in the Central Jordan area. There are 24 known surface and subsurface occurring deposits of oil shale, among these are eight occurrences located in west central Jordan within 20 to 75 km east of the Dead Sea are of large and relatively high-grade organic content (Jaber et al, 1997; Hamarneh, 1998). These are: Jurf Ed Darawish, Sultani, Wadi Maghar, El Lajjun, Attarat Umm Ghudran, Khan Ez- Zabib, Siwaqa, and Wadi Thamad deposits. A number of these deposits are in Grabens such as the Wadi Maghar deposit, which is now considered to be the southern extension of the Attarat Umm Ghudran deposit (Hamarneh, 1998). Wadi Ad-Dharwa area in the eastern part of Jordan is focus on as a case study for its oil shale economic potential. Exploration in this area has commenced with the intension of drilling 50 boreholes with different lengths. Core samples at 3 m intervals were collected from already drilled 37 boreholes to carry out this study. Alnawafleh (2007) revealed local and lateral variability of relatively high oil content in Central Jordan. But El Hasan (2008) found that the Upper Cretaceous oil shale's trace elements of Central Jordan have no covariance with the total organic (TOC), but have a positive covariance with sulfur. Al-Harahsheh et al. (2011) found by experiment that Kerogen can be isolated from raw oil shale by sequential HCl and HCl/HF digestion. Abed, et al. (2009) reported the most important characteristics of some Jordanian oil shales and developed a tentative model regarding their genesis. The geostatistical techniques applied on a total of 937 core samples (3 m in length) taken from 37 drilled boreholes, so far, were analyzed. The assessment of the shale oil grade tonnage relationships were carried out depended mainly on the total oil content % and the survey data including X, Y, and Z coordinates. The other variables were used to account for the economic potential of the studied oil shales at Wadi Ad Dharwa.

2 Location and Climate

Wadi Ad-Dharwa area is located approximately 175 km southeast of Amman at 1047000-1065184 N and 293500-331518 E covers 722 km², the area lies between 718 m to 936 m above sea level (Figure 1).

The climate is primarily of Mediterranean climate type recognized by seasonal variations in both temperature and precipitation. Summer is dry hot and starts around Mid-May while winter is cool and wet starts around Mid-November. The mean rainfall is about 101 mm. The mean temperature values in summer are 25.5 C^0 and 8.9 C^0 in winter, The mean percentage relative humidity value in summer is 45% and in winter 69%, ,the prevailing winds are north westerly in summer and westerly to south westerly winds in winter.

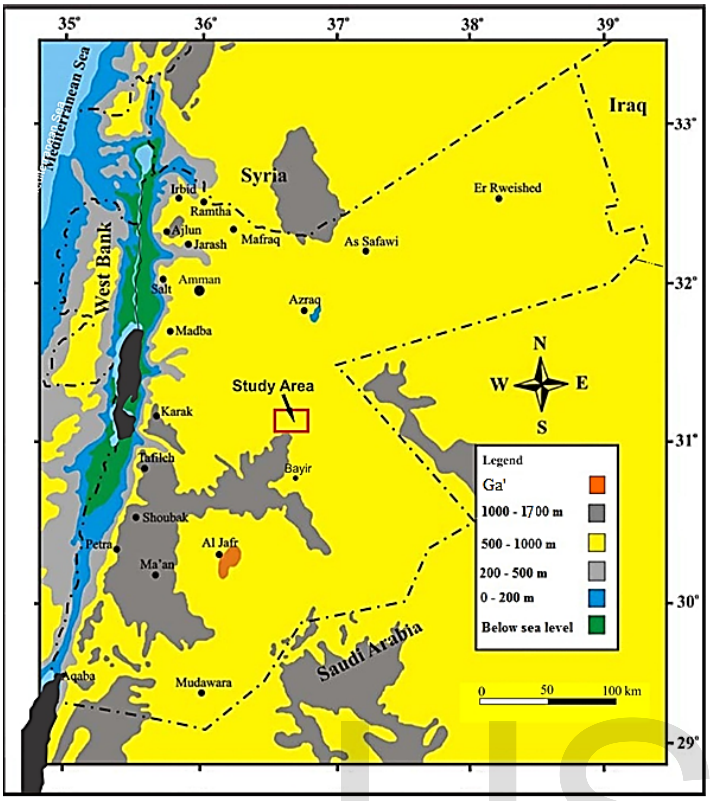

Figure 1, Location of the study area.

3 Geology and Boreholes Location

Wadi Ad Dharwa oil shales are brown, gray, or black colored, formed of the marine Chalk-Marl Unit, which is underlain by phosphatic limestone and chert of the Phosphorite Unit. Their age is Late Cretaceous extends to the Paleocene – Eocene Epochs. The stratigraphic unit's thicknesses through the drilled boreholes ranges from 141 m to 259 m represented the Belqa Group, which comprises the Um Ghudran, Amman Silicified Limestone (ASL) / Al- Hisa Phosphorite (AHP), Muwaqqar Chalk Marl (MCM), Umm Rijam Chert Limestone Formations (URC), and Wadi Shallala Chalk (WSC).

The general dip trend is towards NE with about 34 degrees, where a monocline fold is exposed. Faults in the study area strike in NW-SE and NE-SW directions, and are largely concealed by superficial sediments. The Quaternary deposits comprise superficial, fluvial-lacustrine gravels, sands, clays and conglomerates intercalated with some chert and flint. The maximum penetrated thickness of these deposits is 1 m to 3 m and was reported in almost all of the drilled wells in the area.

Uplift is associated with the formation of the Dead Sea Transform. However, there are evidences that the uplift in Jordan seemed to have started sometimes in the Late Eocene. This uplift process led to the migration of the Neo-Tethys and the complete exposure of Jordan from the Oligocene onwards. Tilting is associated with uplifting. The whole of Jordan is tilted to the east and north that is why SW Jordan contains the highest mountains in the country. It also explains the relatively lower relief of eastern Jordan compared with the west.

Muwaqqar Chalk Marl is consisting of bituminous marl and bituminous chalky marl (oil shale) exhibit low permeability caused by fine grain nature of its material. This formation consists of soft, thick-bedded chalky marl, marl, and chalky limestone, with harder beds and nodules of microcrystalline limestone and chert. The color of the beds is yellow-pink-tan and the formation is typically pale grey-white. The thickness of this formation varies from 20 to 130m.

The oil shale thicknesses in the penetrated area ranged from 60m to 196m with an average thickness of the bituminous strata of about 136 m, and the oil bearing part is about 48 m in thickness, with around 4.7% average oil content. The underlain upper part of AI Hisa Phosphorite formation consists of inter-bedded chert, marl, chalky marl; it has a thickness of 5 to 20 m. This formation is slightly bituminized.

The spatial distributions of the studied boreholes are listed in table 1.

Table 1, Oil shale boreholes coordinate, and the corresponding.

ID	Easting X	Northing Y	Elevation Z
WDH1	307503	1064862	823
WDH2	304660	1064794	846
WDH3	298046	1064002	886
WDH4	298760	1061586	918
WDH5	298580	1058628	890
WDH8	297478	1049863	918
WDH9	297223	1047763	900
WDH10	301195	1047668	896
WDH11	304671	1046650	908
WDH12	305804	1061911	826
WDH13	305032	1060035	879
WDH14	305388	1056647	880
WDH15	305455	1052881	844
WDH16	305716	1050512	833
WDH17	302006	1049970	840
WDH18	300979	1053197	850
WDH19	302423	1062511	870
WDH20	301509	1056799	896
WDH25	298889	1052503	936
WDH26	309874	1064395	803
WDH27	307966	1060513	828
WDH28	308318	1057191	816
WDH29	307905	1053839	844
WDH30	307951	1051014	855
WDH31	308002	1047994	875
WDH32	311080	1047472	847

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WDH33	311107	1051073	843
WDH34	310995	1055009	833
WDH35	310522	1058778	793
WDH36	312604	1062160	778
WDH37	314211	1064878	769
WDH38	316449	1064517	745
WDH39	316950	1062187	745
WDH40	313912	1059396	788
WDH41	314000	1056000	798
WDH42	316000	1053000	768
WDH47	318000	1060000	748

4 STATISTICAL INVESTIGATIONS

The presented data in table 2 were manipulated statistically and geostatistical using the software packages: GS+, Rockworks 15, and Stat Soft.

A total of 37 vertical boreholes were drilled during the exploration and prospecting of the Wadi Ad Dharwa all of these were drilled recently by NRA. Core samples taken from the 37 drilled holes with more than 90% recovery provided lithological, facies and chemical information. The treated variables are overburden, thickness, oil content (wt. %), calorific values and survey data including X, Y, and Z coordinates (Table 2).

Table 2: Statistically treated variables (OB= Overburden, OST= Oil shale thickness, SR= Stripping Ratio).

Table 2: Statistically treated variables (OB= Overburden, OST= Oil shale thickness, SR= Stripping Ratio).

ID	OB (m)	OST(m)	SR	Total Oil %	Cal Val/ g Cal	Samples No.
WDH1	81	127	0.64	4.85	713.71	45
WDH2	69	112.2	0.62	4.26	633.08	37
WDH3	66	96	0.69	5.21	797.1	30
WDH4	69	99	0.7	3.23	439.45	33
WDH5	66	129	0.51	4.22	586.3	44
WDH8	33	171	0.19	6.2	736.51	53
WDH9	39	177	0.22	5.3	603.25	61
WDH10	30	186	0.16	5.31	832.15	63
WDH11	33	170	0.19	4.17	551.98	57
WDH12	115	60	1.92	6.16	859.15	20
WDH13	59	178	0.33	5.72	933.83	63
WDH14	68.5	126.5	0.54	4.13	634.96	43
WDH15	48	167	0.29	4.93	613.51	47
WDH16	68	140.7	0.48	4.93	366.4	49
WDH17	41.5	189.5	0.22	5.37	776.42	12
WDH18	40	178	0.22	5.67	852.17	60
WDH19	59	165	0.36	6.97	1084.3	8
WDH20	60	146	0.41	4.72	684.2	49
WDH25	57.8	195.5	0.3	4.02	517.9	10
WDH26	61.5	130	0.47	6.2	937.86	7
WDH27	58	150	0.39	3.92	497.63	8
WDH28	45	129	0.35	5.57	815.75	8
WDH29	54	186	0.29	6.06	910.36	11
WDH30	55.5	145.5	0.38	3.88	402.67	8
WDH31	59	190	0.31	4.98	702.64	11
WDH32	60	176.3	0.34	5.07	720.05	11
WDH33	84	122	0.69	3.89	482.78	9
WDH34	66	152	0.43	5.35	701.69	12
WDH35	62	139	0.45	6.11	884.83	11
WDH36	54	128	0.42	6.61	823.82	11
WDH37	71	109	0.65	6.01	785.33	9
WDH38	74	105	0.7	4.61	570.33	9
WDH39	62	73	0.85	3.00	439.00	6
WDH40	75	70	1.07	3.85	434.00	5
WDH41	75	80	0.94	3.98	483.17	5
WDH42	78	76	1.03	2.54	366.86	6
WDH47	68	91	0.75	2.60	287.29	6

5 GEOSTATISTICAL CALCULATIONS

The grade tonnage calculations manage for requests regarding the tonnage of the shale oil above a certain cutoff grade or a set thereof, the average grade of that proportion of the resource above the given cutoff, whether enough samples have been taken or not, the effective drill spacing that would yield results that are acceptable at a certain significance level, i.e., the minimum number of boreholes to be drilled that would yield acceptable results with minimum financial costs. The oil shale contents question can be solved by assuming that the histogram of the shale oil contents represent the whole deposit accurately and represents a set of samples from the whole deposit and as such contains some random variation from the population distribution (Clark, 1979, and Rendu, 2008). The constructed histograms concerning the grade tonnage calculations for the available 937 measurements from the 37 drilled boreholes indicate that the shale oil content approximates the lognormal distribution Figure 2 and Figure 3.

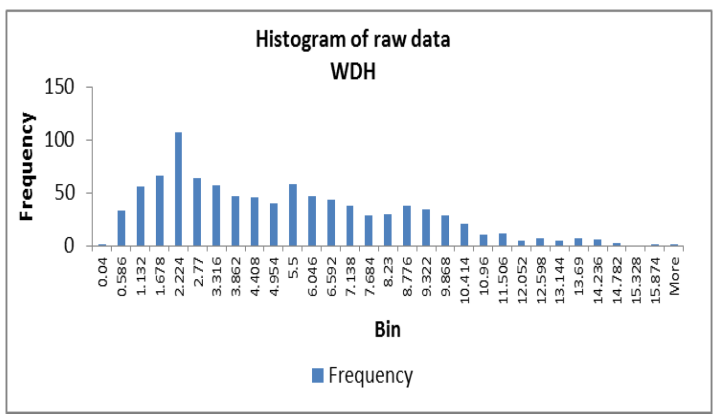

Figure 2: Histogram of Wadi Ad Dharwa shale oil raw values

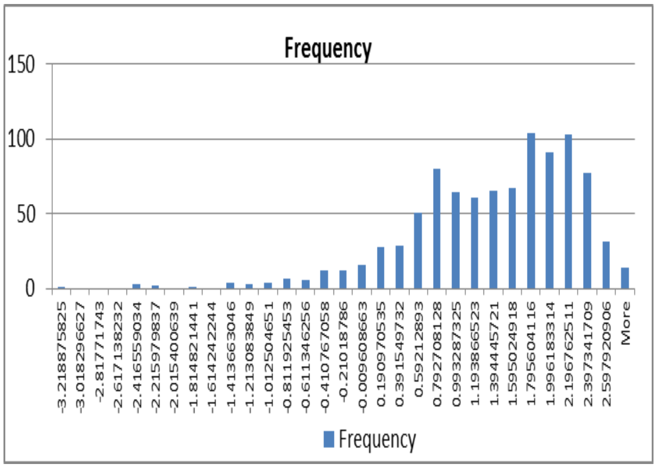

Figure 3: Histogram of Wadi Ad Dharwa shale oil in transformed values

To validate the assumed log normality of the measured shale oil contents, a frequency table of the original data having category limits with exponential relationships was constructed (Table 3).

Table 3: Raw data frequency table with upper category limits having exponential relationships

Bin	Frequency	Cum F	Cum F%
0.2	8	8	0.85
0.4	14	22	2.35
0.8	31	53	5.66
1.6	90	143	15.28
3.2	231	374	39.96
6.4	278	652	69.55
12.8	264	915	97.76
25.6	21	937	100
More	0		

The upper category limits versus cumulative relative frequencies were then plotted on lognormal probability paper. The inference that can be made from figure 4 is that the shale oil values exhibit a three parameters lognormal distribution as the line bends downward at its lower limit (Rendu, 1978).

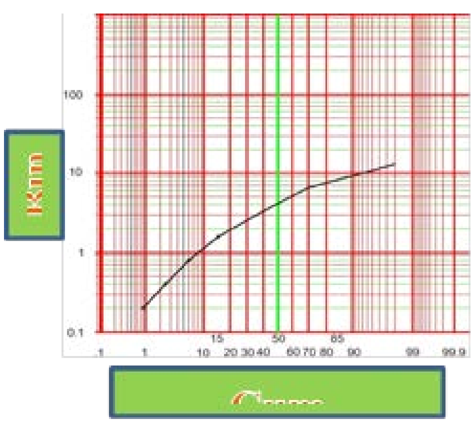

Figure 4, plotted data from table 3.

Accordingly a certain value should be added to straighten the line. The calculation of this value (β) can be carried out as follows:

β = (m² – f1f2) / (f1 +f2) – 2m ……… (1)

Where m is the sample value corresponding to a 50% cumulative frequency, and f1 and f2 are the sample values corresponding to 15% and 85% cumulative frequencies. From Figure 5, we can read m = 4.2, f1 = 1.6 and f2 = 8.2. Hence β= 3.23. The geometric mean ($\hat{y}$) of (x_i+β) equals the mean of the logs of the values of (x_i+β), accordingly the average sample value is then estimated by:

$\hat{m}$ = exp ($\hat{y}$) - β ………… (2)

After that, the amount of 3.23 has been added to the original shale oil values, and a new frequency table, with exponential upper limits, has been constructed (Table 4).

Table 4: $x + \beta$ frequency table with upper category limits having exponential relationships

Bin	*Frequency*	*cum f*	*cum f%*
4.0	52	52	5.56
5.6	225	277	29.60
7.8	217	494	52.78
11.0	242	736	78.53
15.4	172	907	96.90
21.5	29	937	100

Hence ($\hat{y}$) = 2.01, accordingly $\hat{m}$ = 7.48 – 3.23 = 4.25. This was done to check graphically whether the addition of the βconstant straighten the line or not, or in other words, whether the cumulative distribution of x + β is lognormal. This resulted in a dotted straight line on (Fig 5).

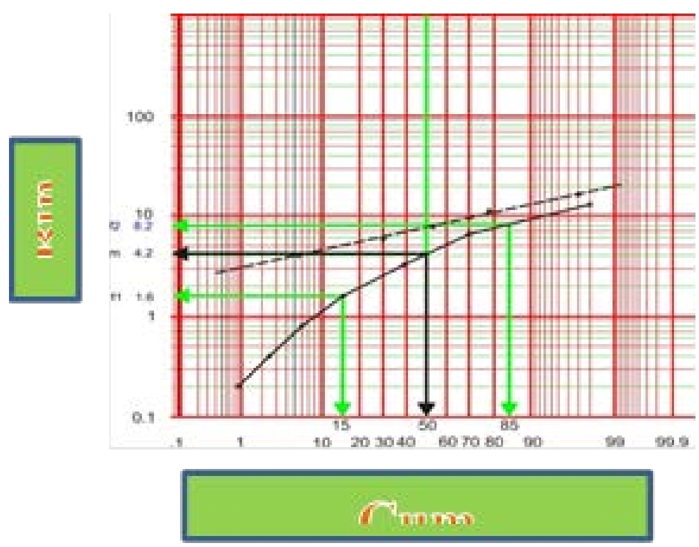

Fig 5: Data from Table 4 plotted on lognormal probability paper

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Procedure B of Clark 1979 will be followed to determine the Grade Tonnage Relationships, thus, if we write y for the logarithm of the grade, then the mean and standard deviation of the y values are given by:

$s_v^2 = log_e\,(s^2/\bar{g}^2 + 1)$ ……..... (3)

$\bar{y} = log_e\bar{g} - 0.5s_v^2$ …………. (4)

Once these parameters have been calculated, then the following may be evaluated:

………………… (5)

Where c is the cutoff grade, y is the mean of the in transformed data, and sy is the standard deviation of the in transformed data.

The proportion (p) of the distribution which is above cutoff grade c can be evaluated from the tables that are widely available for the standard normal distribution which lies below a given value z. the normal table will give us Φ(z), which is the probability of lying below the cutoff, so that:

P = 1 – Φ(z) ……..………… (6)

Where, P is again the proportion of the ore above economic cutoff.

The average grade above a certain cutoff grade is found by the following process:

$\bar{g}_c = Q/p\ \bar{g}$……..……………. (7)

Where, Q = P = 1 – Φ (z - sy).

To apply this procedure we have to calculate the mean and standard deviation of the natural logarithmic data, and to carry out the calculations according to the pre mentioned procedure we have to calculate the geometric mean ($\bar{g}$) of the original data which is in our case the antilog of $\bar{y}$. This gives $\bar{g}$ = 3.6.This is listed in (Table 5).

Table 5 : Summary statistic of the natural logarithms of shale oil values

Summary statistic of the natural logarithms of shale oil data			
Mean ($\bar{y}$)	1.28	Kurtosis	1.97
Standard Error	0.03	Skewness	-1.12
Median	1.47	Range	6.02
Mode	0.68	Minimum	-3.22
St. Deviation(sy)	0.89	Maximum	2.80
Sample Variance	0.80	Sum	1201.76

The items described in equations 3, 4, and 5 were evaluated. The results of the evaluation using a set of cutoff grades (c =4, 5, 6, 7, 8, and 9) are listed in (Table 6).

Table 6: Wadi Ad Dharwa shale oil grades above certain cutoff grades

Possible cutoff (c)	% resource above c (p)	Average grade above c ($\bar{g}_c = 3.61$)%	Average grade above c ($\bar{g}_c = 4.25$)%
4	45.62	6.19	7.29
5	35.94	7.05	8.30
6	28.43	7.94	9.35
7	22.96	8.80	10.36
8	18.67	9.67	11.38
9	15.39	10.52	12.38

To verify the results the original data were also filtered for values above the chosen cutoff grades. Their percentages and averages were also calculated and listed in (Table 7). The applied statistical techniques yielded fairly similar results. Both results will be used later in calculating the reserves at the different cutoffs.

Table 7: Wadi Ad Dharwa shale oil grades above certain cutoff grades as calculated from the filtered data

Possible cutoff (c)	**% Resource above c (*p*)**	**Average grade above c ($\bar{g}_c$)%**
4	52.56	7.44
5	44.23	8.01
6	34.4	8.73
7	26.06	9.47
8	20.08	10.05
9	13.03	10.87

It might be figured out that the done simple statistical grade tonnage calculations and are not sufficient as far as it says how much shale oil there is, but it does not reflects where it is, thus to locate where these quantities are the following steps are to be done:

1- Model the spatial variability of shale oil values by constructing and fitting a Semivariograms that would account for its spatial distribution in the investigated area.
2- Cross validating the model to check whether it would reproduce the spatial variability or not. In our case it turned out to be an exponential model without nugget effect (Figure 6).

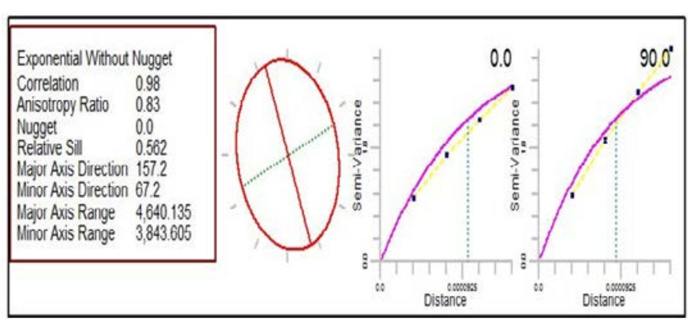

Figure 6: Fitted experimental Semivariograms for WDH shale oil values

A careful examination of Figure 7 shows that shale oil values greater than 6% occur in an E-W trending zone in the northern part of the study area. Having delineated such an area the reserve estimates can be constrained to it.

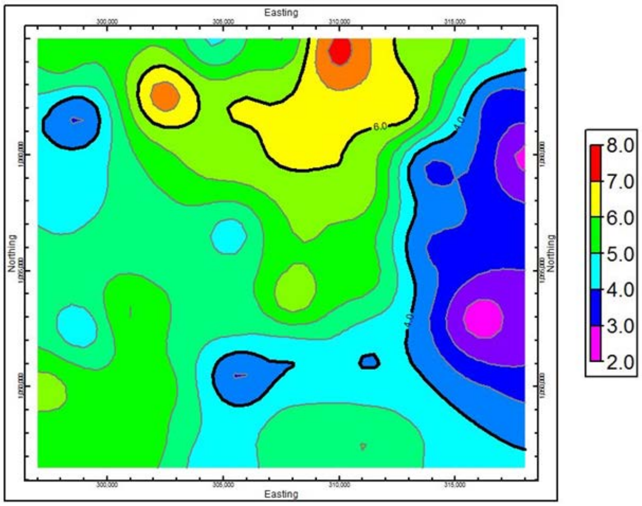

Figure 7: Contoured kriged WDH shale oil values

On the other hand, which shows the variability of shale oil accumulation, indicates also that the payable part of the study area is the NE – SW trending zone. Figures 8 – 11 give an idea about the spatial variability of, calorific values, over burden, and oil shale thicknesses.

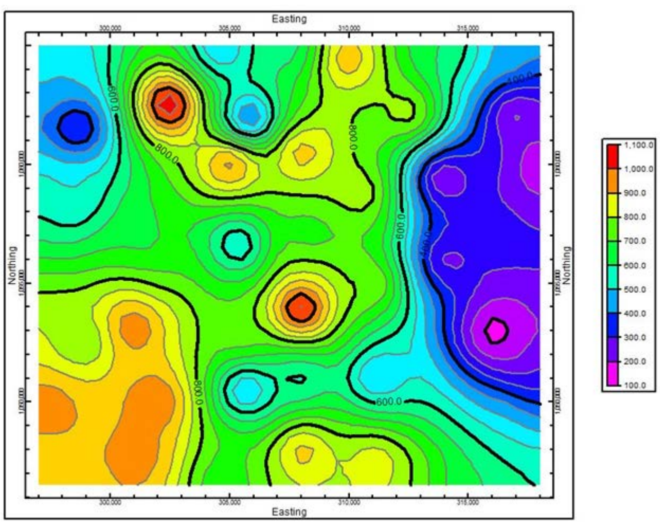

Figure 8: Contoured kriged WDH shale oil accumulation values (Shale thickness * Tot. Oil %)

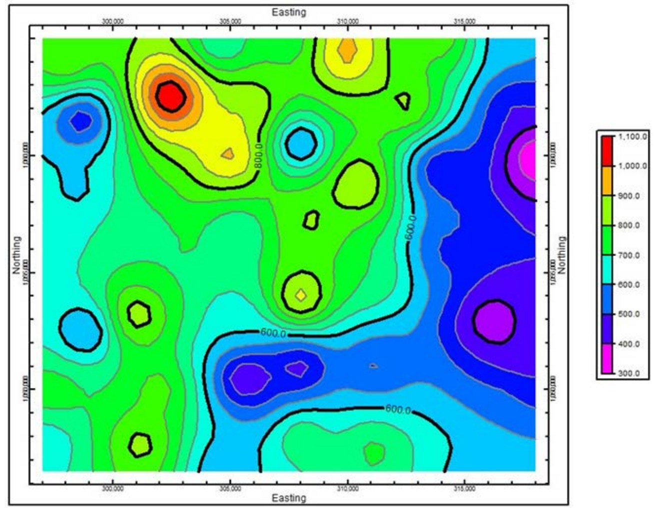

Figure 9: Contoured kriged calorific values of WDH oil shale.

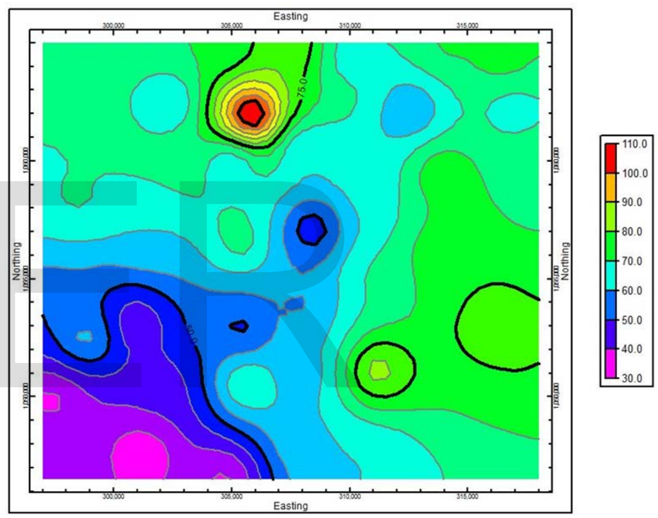

Figure 10: Contoured kriged over burden values.

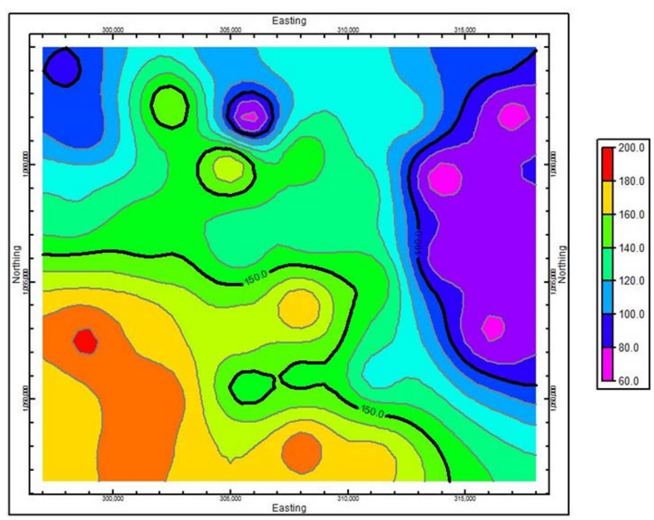

Figure 11: Contoured kriged oil shale thicknesses

The total tonnage of a deposit is given, as already known, by

T = V x D .... (8)

Where V is the volume of the studied oil shale deposits and will be calculated using Delunauy method and D is the specific gravity of the deposit. The volume was calculated based on the area delineated from Fig 12 and was found to be 318.8 km2, and D = 1.7. From this value only the relative resource percent and its corresponding grade above the given cutoff will be taken into consideration.

Volume = 44,268,316,886.6 m3 Total tonnage = V*D = 75,256,138,707.22

It is recognized that estimates of exploration information, Mineral Resources, and Mineral Reserves, being predictions of what will occur in the future based on imperfect knowledge of the present, are inherently forward-looking statements, and will be inaccurate to some degree.

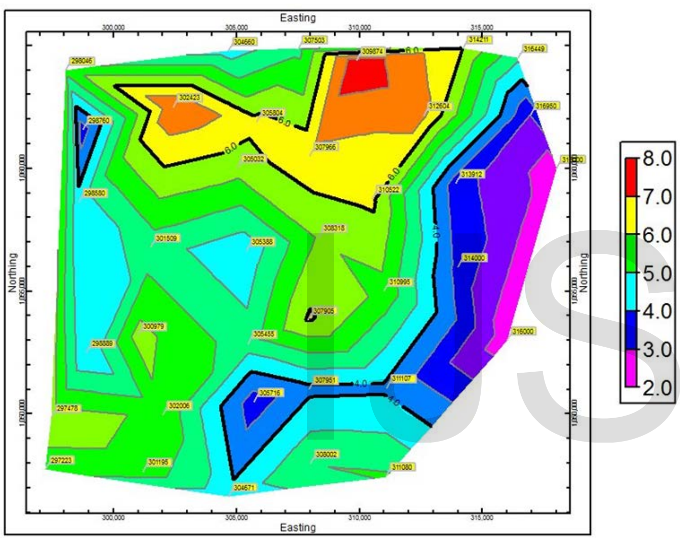

Figure 12: Area used in reserve estimates equals 318,798,246.5 m2 or roughly 318.8 km2

6 Conclusions

1-The calculated Wadi Ad Dharwa shale oil volume using the given geometric parameters of 318.8 km2, and D = 1.7 indicated that the total volume equal to 44,268,316,886.6 m3.

2-The total tonnage is estimated to equal 75,256,138,707.22 metric tons.

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