Integration Based GIS Weighted Linear Combination (WLC) model for Delineation Hydrocarbon Potential Zones in Ayad Area (Yemen) Using Analytic Hierarchy Process (AHP) Technique

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Abstract

Exploration of hydrocarbon resources is a highly complicated and costly process where different geological, geochemical and geophysical element are improved then combined together. It is highly important how to plan the seismic data acquisition survey and locate the exploratory wells since inaccurate or imprecise locations lead to waste of time and money during the operation. The goal of this study is to locate high-potentially oil and gas province in Ayad Area to reduce both time and costs in exploration and development processes. In this observe, 8 maps were developed using GIS functions for factors including: basement structure (BDM), Bouguer gravity anomalies (GAM), pre rift isopach map (PRIM), syn rift isopach map (SRIM), salt depth map (SDM),subsurface faults system(SFS), Lower pre rift Isopach map (LPRI),and Upper pre rift Isopach map (UPRI) . To model and to integrate maps, this study employed Weighted Liner Composition(WLC) and Analytic Hierarchy Process (AHP) methods to locate high-potential zones of hydrocarbon prospects. the hydrocarbon potential map was classified to five classes from very low to very high potential. The classes of hydrocarbon potential map were checked against the distribution of the exploration wells and oil fields in Ayad area. The final favorable potential map suggested new promising areas for hydrocarbon accumulations which were found in agreement to the validated ground truth data.

Keywords-*GIS , WLC , AHP , Hydrocarbon Potential , Ayad area.*

I. INTRODUCTION

The extraordinary growth in the usage of Geographic Information System (GIS) technology in oil exploration studies has become the most sought-after natural resource by the humanity due to tremendous pressure on fuels demand to cover the increasing industrial growth. In exploration or development process of an oil province, different geological, geochemical and geophysical factors are developed and combined together. Today, potential-positioning procedures are generally done through GIS environment [1]. Geographic Information System (GIS) allows gathering, storing, retrieving, managing, processing and displaying spatial and descriptive data to support decisions made based on spatial data. GIS generates new information by combining different data layers using different methods with different views [2].Application of GIS in oil exploration is almost new. Using a set of analytical tools, an efficient GIS can integrate data and make it possible for users to overlap and change data sets as a map to analyze the potential or development of existing fields. This would reduce exploration time and cost. In general, data integration models in GIS are divided into two general categories as data-driven and knowledge-driven models [3],[4].knowledge-driven models include multi-criteria evaluation, fuzzy logic, Dempster-Shafer, and index overlay[5].The methodology has been incorporate with two methods, namely; the analytical hierarchy process (AHP) and Weighted Linear Combination (WLC) for representation the possible hydrocarbon potentially zones in the central part of Sabatayn Basin which situated in AyadArea.AHP has been applied in the analysis of location, resource allocation, outsourcing, evaluation, manufacturing, marketing, supplier selection, finance, energy, education and risk analysis, [6]. This process allows giving numerical values to the judgments provided by people, which is also able to measure how each element contributes to each level of the hierarchy. Furthermore, the process is based on a well-defined structure consisting of arrays, and the ability of the eigen values to generate values or to approximate weights of each criterion, [7],[8],[9].The weighted linear combination (WLC) model is one the most extensively used GIS-based decision rules ([10], [11], [12], [13], [14]). The process is often appropriate in land use/suitability analysis, site selection, and resource appraisement problems ([15]) ,[16], [17]). The primitive reason for its popularity is that the process is very comfortable to accomplish within the GIS environment using map algebra operations and cartographic modeling [18]. The process is also easy-to-perceive and intuitively appealing to decision makers ([19], [20]). However, GIS implementations of WLC are often used without full knowing of the assumptions underlying this approximate. In addition, the process is often applied without full insight into the meanings of two critical elements of WLC: the weights assigned to attribute maps and the procedures for deriving commensurate attribute maps. The structural framework of the Sabatayn Basin was established in Kimmeridgian-Tithonian times when the major period of rifting occurred. The rift system is oriented generally west northwest-east southeast as shown in Fig.1. This orientation corresponds to the Late Proterozoic 'Najd Trend' ([21]; [22]) which probably exerted some control on the orientation of the Jurassic rift.The rift widens considerably in the Shabwa area, and important north-south Hadramaut Trend lineaments,as shown in Fig.1 .This trend may be inherited from an underlying Proterozoic arc terrane suture ([23]; [24]).The main objective of this study is to design and implement a GIS-based model employing Weighted LinearCombination (WLC)using Analytic Hierarchy Process (AHP) Technique to locate hydrocarbon potential zones for further developing operations .

II. MATERIALS AND METHODS

A. Study Area

Ayad Area is located within the onshore oil rich Sabatayn basin, it is bounded to the south by Block 70, to the west by Block 69, to the north by Blocks 86/S2 and to the east by Block 3,the studyarea covers around 1998 km^2.Geographically,the study area lies between (15° 10′ 30″N ,46° 30′ 00″E- 14° 49′ 30″ N ,46° 50′ 00″ E) ,as shown inFig.1.SabataynBasin Opening in Kimmeridgian -Tithonian times, the rift system is orientated WNW-ESE parallel to 'Najd Trend' some NE-SW transfer faults parallel to 'Gulf of Aden' faults, major basement depocenters lay in the adjacent hanging walls, salt tectonic affects post salt formations. Sabatayn basin shows half-graben feature elements. The main structural elements in the Ayadarea are relatively parallel to Basin orientation. three main basement highs (Trends) Central Basin High, Ayad&Amal High ,as shown in Fig.1 .

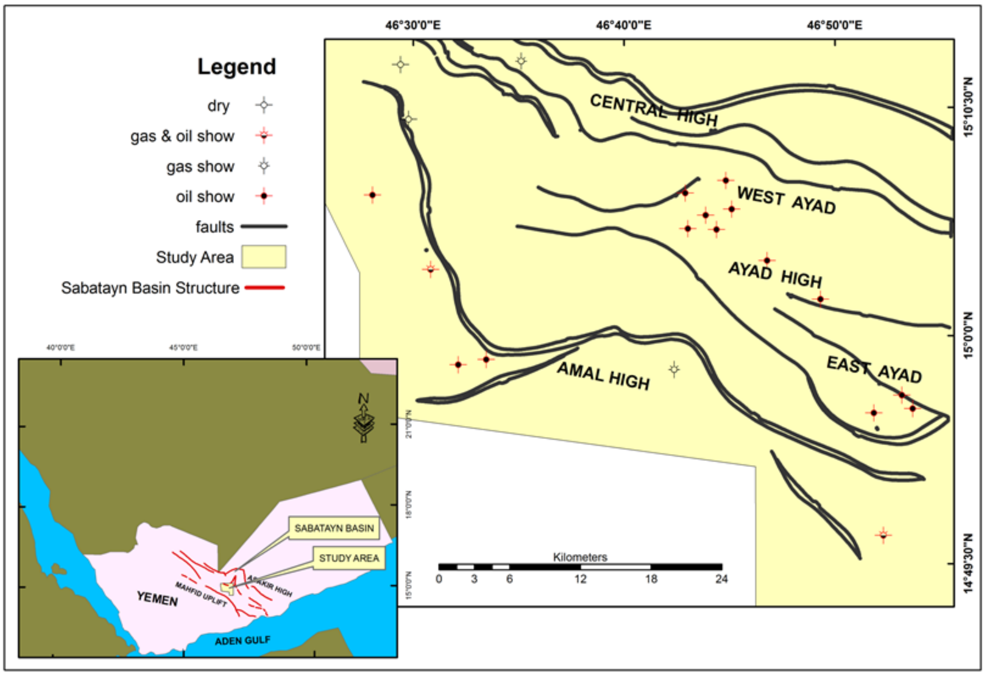


Fig1: The Location Map of Study Area with the Geological Structural Elements.

B. Factors Affecting Hydrocarbon Potential

The thematic maps have the relationship with oil-gas reservoir at distinct levels. The factors recognized were narrated to Basement abundance map (BDM),Gravity anomalies (GAM) , Pre Rift Isopach Map(PRIM), Syn Rift Isopach(SRIM), Salt depth map (SDM) ,Subsurface Faults System (SFS),Lower Post Rift Isopach (LPRI) , and Upper Post Rift Isopach(UPRI). These maps were provided from PEPA (Petroleum Exploration and Production Authority in Yemen) as hard copy contours isoclines , which were scanned and digitized using GIS software package ArcGIS 9.3 , around eight thematic periphery layers were fid and geo-referenced to the Universal Transverse Mercator (UTM) coordinate system WGS 1984 zone 38N.the flow chart of the methodology that used in this research illustrated in, Fig.2 .

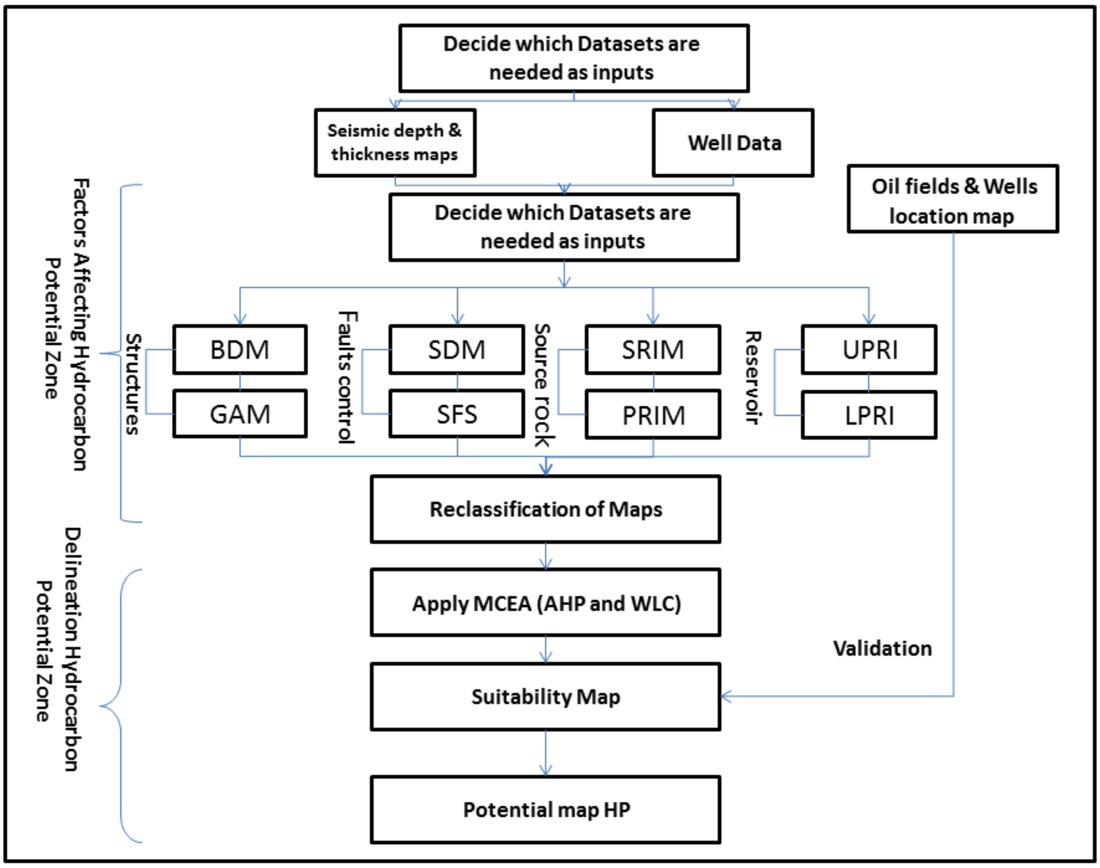


Fig 2:The Methodology Flow Chart of the Research Study.

1) *Basement Depth Map(BDM)*

The (BDM) shows that the major depocentres lie in the adjacent hanging walls of the basin margin faults and are parallel to the margins. Smaller depocentres occur on either flank of the Central Ayad High. A structural consequence of this symmetric half-graben pattern is that some central parts of the rift were completely isolated from provenance areas during early rift times. On the regional scale, Structural highs of Precambrian basement are the preferred targets for oil and gas exploration and still new hot target in Sabatayn Basin. Structure of (BDM) can beused to determine the preferred hydrocarbon zones in a basin. Previous researches also have shown out the correlation between the oil-gas reservoir and basement structure, thehydrocarbon migration is basement controlled. Therefore, the knowledge of composition ,structure and depth of basement is crucial to any analysis of oil-gas resource. Previous studies showed that the traps are mostly concentrated on the basement highs and steep flank of basement highs ,[25].Here, basement surface is determined via subsurface seismic and Well data,as shown in Fig.3.a. The (BDM) is interpreted and classified, based onits slope, into three primary classes: a- on top of basement structural high; b- in steep and faulted flanks of basement structural highs; c- basement structural lows ,as shown inFig.4.

2) *Gravity Anomaly Map (GAM)*

Gravity anomalies (GAM),as shown in Fig.3.b. act an essential role in discovering sedimentary basins and local structures with high oil-gas potentiality. Gravity anomalies caused by mass of density anomalies related to oil-gas reservoirs can be find out by means of gravity data analysis. Gravity highs typically appear over ranges where basement rocks are near the surface; gravity lows appear over basins filled with young, low-density volcanic and sedimentary deposits. Interpretation of gravity anomalies of possible oil-gas reservoirs is often capture out at the initial duration of the exploration. The (GAM) was interpreted and classified, based on its data gradient, into three primary classes: a- High; b- Moderate; c- and Low , as shown in Fig.4 .

3) *Pre Rift Isopach Map(PRIM)*

The Pre-Rift deposits includes Lower to Middle Jurassic carbonates and clastics overlying the Precambrian Basement , [26]. Well data indicates that the Pre-Rift deposits corresponds to the Kohlan Formation, the Shuqra Formation reservoirs and a thin mudstone informally termed the Shuqra Shale source rock Marker, so called due to the ease with which it can be identified on wireline logs. The (PRIM) was interpreted and classified as shown in Fig.3.c., based on its thickness data range favorability, into three primary classes: a- High; b- Moderate; c- and Low ,as shown in Fig.4.

4) Syn Rift Isopach(SRIM)

The Syn-Rift deposits includes Oxfordian to Tithonian carbonates, clastics and minor evaporites. Clastics dominate against basin margins whilst carbonates are better developed remote from major faults. The Syn-Rift deposits contains a wide variety of both clastic and carbonate lithofacies. For nomenclatural simplicity only two formation names are utilized; the thick, clastic-rich, generally turbiditic units are referred to the Lam Formation reservoir and the deep-marine carbonates to the Madbi Formation source rock [27].The (SRIM) was interpreted , and classified, based on its thickness data range favorability, into three primary classes: a- High; b- Moderate; c- and Low ,as shown in.Fig.3.d., Fig.4.

5) (Salt) Depth Map (SDM)

Following minor fault reactivation, rifting stopped in the mid-Tithonian. Carbonate deposition (Ayad Formation) in early post-rift times was rapidly followed by isolation of the basin from the open ocean to the southeast. As a result an extensive salt basin (Sabatayn Formation developed throughout the Sabatayn system). However the salt basin was short-lived and marine carbonate deposition was re-established by late Tithonian times. Initially these carbonates were very clean (Lower Naifa Formation) source rock but the clastic component gradually increased (Upper Naifa Formation) reservoir before sedimentation abruptly stopped in the Berriasian.The Ayad, Sabatayn, Lower Naifa and Upper Naifa formations comprise Post-Rift deposits. The (SDM) was interpreted,as shown in Fig.3.e. and classified, based on its depthvalue range favorability, into three primary classes: a- High; b- Moderate; c- and Low ,as shown in Fig.4 .

6) Subsurface Faults System (SFS)

The subsurface faults system are interpreted from gravityanomalies and seismic data. Correlation between subsurface (SFS) andsubsurface oil and gas reservoirs were investigated. There is a strong association both in orientation and location between the linear features and the subsurface reservoirs. The faults analysis can be used for delineating oil and gas reservoirs in the area ([28], [29]).The main developed direction of the faults is northwest. The oil and gas potential zone in the area will be likely associated with the northwest(SFS), as shown in Fig.3.f.

7) Lower Post Rift Isopach (LPRI)

Sedimentation resumed in the Barremian Post-Rift thickness with the deposition of mixed marine clastics and carbonates of the Qishn Formation.Sediment loading at this time mobilised the salt which flowed up dip and formed a series of elongate ridges overlying the footwall crests of major fault blocks. As a result, Qishn clastics were deposited in a series of discrete, elongate salt withdrawal basins. Paralicclasticsprograded eastwards into the accommodation space left by retreating salt. The Qishn Formation shows dramatic west-east thickness and facies variation within Ayad area .In the west a series of elongate depocentres contain up to 1,000 m of sandstones with minor siltstones and mudstones. Palaeo environmental data indicate that these are dominantly marine sediments though there is a strong terrestrial component, and deltaic and estuarine influences are recognized. The sandstones have immature textures suggesting short transport distances. To the east the interval is generally less than 200 m thick and contains limestones and calcareous mudstones with a marine fauna. The sandstones of the Qishn Formation are of excellent reservoir quality, and the presence of intra-formational shales make this a potential target horizon. Thus far, though, no discoveries have been made at this level in the block. The (LPRI) was interpreted,as shown in Fig.3.g. and classified, based on its thickness data range favorability, into three primary classes: a- High; b- Moderate; c- and Low as shown in Fig.4 .

8) Upper Post Rift Isopach (UPRI)

The most distal basins were initially starved and contain condensed limestones. These basins were infilled by Tawilah Group fluvial sandstones which constitute the upper part of Post-Rift deposits.TheTawilah Group comprises mainly sandstones with minor mudstones. The sandstones containplant roots and exhibit cross-bedding and ripple marks. Some beds contain a marginal marine fauna but most of the unit was deposited in fluvial or aeolian conditions. The (UPRI) was interpretedas shown in Fig.3.h and classified, based on its thickness data range favorability, into three primary classes: a- High; b- Moderate; c- and Low ,as shown in Fig.4 .

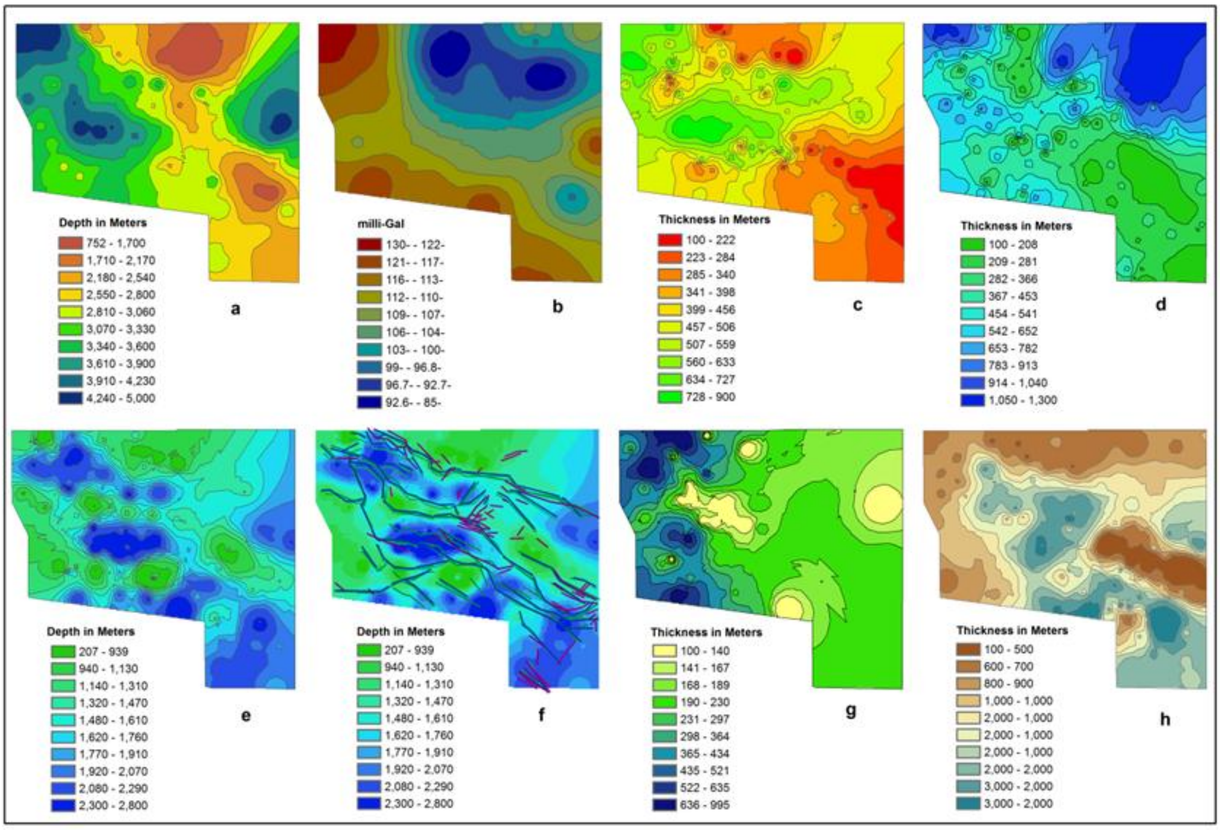


Fig3:The favorable Factors for the Hydrocarbon Potential Target , a.) BDM, b. GAM , c.) PRIM , d.) SRIM , e.) SDM , f.) SFS , g.) LPRI , h.) UPRI.

C. Delineating Hydrocarbon Potential Zones

The instant process begin with the identification of parameters required for hydrocarbon efficacious zone. All these parameters have been recognized based on the related information about targeting hydrocarbon potential zone has also been reviewed from the international practices. The hydrocarbon potentiality is a function of these thematic maps :HP = f(BDM,GAM, PRIM, SRIM, SDM,SFS, LPRI,UPRI)Where HP: hydrocarbon potentiality.The HP in the area was evaluated for each thematic map on the basis oftheory and real conditions in combination. The thematic maps were converted to raster data and reclassified for new field values and ranked into a scale of (1 to 10)depending upon their suitability to oil-gas concentration. The different thematicmaps were weighted scores ranges (1-9)depending on their own properties In this research, specific weighing scheme was adopted as Analytic Hierarchyprocess(AHP).The thematic layers identified for weighted overlay analysis were (BDM,GAM, PRIM, SRIM, SDM,SFS, LPRI,UPRI) Subclasses in every thematic layer were derived through reclassification method which is based on natural breaks in data as shown in Fig.4. Relative importance of each individual class within the same thematic map was compared with each other by pair wise comparison method using continuous rating scale developed by,[30].Using Pairwise Comparison Matrix (PWCM), factor weights were suited by comparing two factors together. The PWCM were applied using a scale with values from 9 to 1/9 introduced by [31]. A rating of 9 infer that in relation to the column factor, the row factor is more essential. On the other side, a rating of 1/9 infer that relative to the column factor, the row factor is less important,[32]. In cases where the column and row factors are equally important, they have a rating value of 1. Since the matrix is symmetrical, only the upper triangle truly necessarily to be filled in. The remaining cells are then simply the reciprocals of the upper triangle as shown in Table I.

Table I : Saaty's 1-9 Scale of Relative Importance

importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong
9	importance

After the pair wise comparison matrix was computed as shown in Table II then priority vector was computed, which is then ormalized Eigen vector of the matrix ,Table III . The normalized principal Eigen vector is also called priority vector. Since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the things that we compare. The AHP captures the idea of uncertainty in judgments through the principal eigen value and the consistency index ,[33]. Principal Eigen value ,λmax, is obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix, TableV. Saaty gave a measure of consistency, called Consistency Index (CI) as deviation or degree of consistency using the following equation(1):

$$CI = \frac{\lambda max - n}{n-1} \quad (1)$$

where λmax is the Principal Eigen value of the pair wise comparison matrix and n is the number of classes. Consistency Ratio (CR) is a measure of consistency of pairwise comparison matrix and is given by equation(2):

$$CR = \frac{CI}{RI}(2)$$

where RI is the Ratio Index. The value of RI for different n values is given in Table.4.If the value of CR is smaller or equal to 0.1, thein consistency is acceptable. If CR is greater than 10% ,we need to revise the subjective judgment .The CR was determined as(0.08) hence, it is acceptable. Further, different units of each theme were assigned knowledge-based hierarchy of ranking on the basis of their significance with reference to HP, where 1 denotes very low potential and 9 denotes very high potential prospects. The final weigh tages and rank of thematic layers and its individual features areshowniTableVI.

Table II: Pairwise Comparison Matrix

	BDM	GAM	PRIM	SRIM	SDM	SFS	LPRI	UPRI
BDM	1	3	1	3	6	3	6	6
GAM	1/3	1	1/3	1	3	1	3	3
PRIM	1	3	1	1/3	3	3	3	3
SRIM	1/3	1	3	1	6	1	3	3
SDM	1/6	1/3	1/3	1/6	1	1/3	1	1/3
SFS	1/3	1	1/3	1	3	1	6	3
LPRI	1/6	1/6	1/3	1/3	1	1/6	1	1
UPRI	1/3	1/3	1/3	1/3	3	1/3	1	1
Column	3.67	9.83	6.67	7.17	26.00	9.83	24.00	20.33

Table III: Normalized Score Table

	BDM	**GAM**	**PRIM**	**SRIM**	**SDM**	**SFS**	**LPRI**	**UPRI**	**∑**	**Eighen**	**%**
BDM	0.286	0.305	0.15	0.4186	0.2308	0.31	0.22	0.295	2.213	0.28	28%
GAM	0.095	0.102	0.05	0.1395	0.1154	0.1	0.22	0.148	0.973	0.12	12%
PRIM	0.286	0.305	0.15	0.0465	0.1154	0.31	0.11	0.148	1.466	0.18	18%
SRIM	0.095	0.102	0.45	0.1395	0.2308	0.1	0.11	0.148	1.378	0.17	17%
SDM	0.048	0.034	0.05	0.0233	0.0385	0.03	0.04	0.016	0.281	0.04	4%
SFS	0.095	0.102	0.05	0.1395	0.1154	0.1	0.22	0.148	0.973	0.12	12%
LPRI	0.048	0.017	0.05	0.0465	0.0385	0.02	0.04	0.049	0.303	0.04	4%
UPRI	0.048	0.034	0.05	0.0465	0.1154	0.03	0.04	0.049	0.414	0.05	5%
Total	1	1	1	1	1	1	1	1	8		

Table IV: Saaty's Ratio Index for Different Values Of N

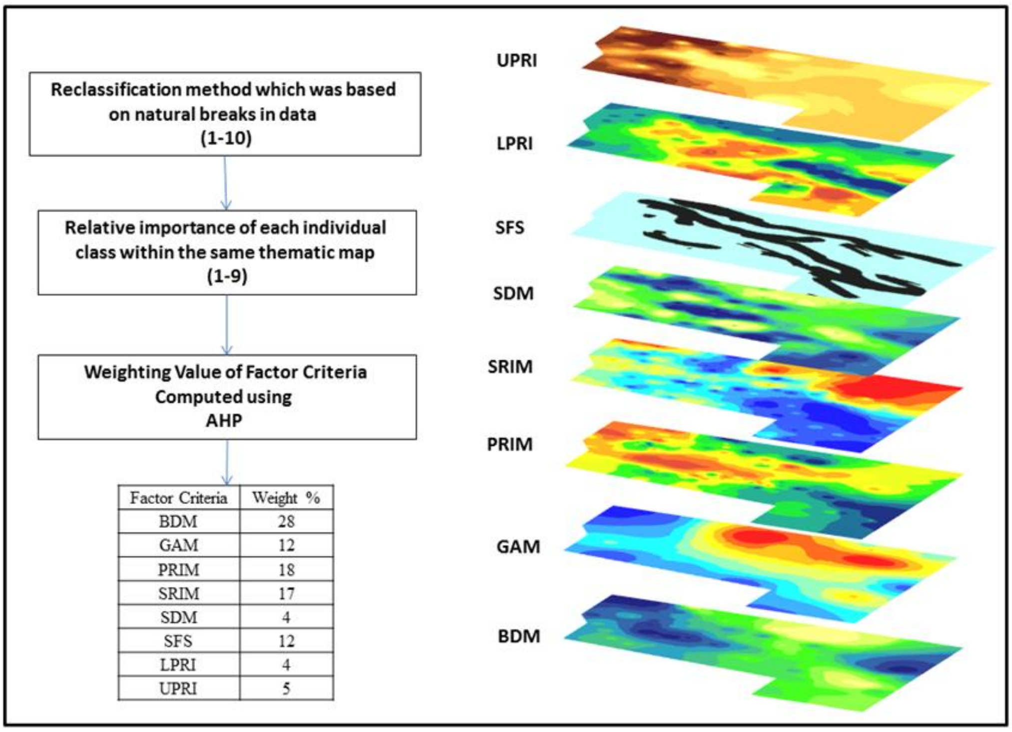
n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45

Table V: Calculation of Principal Eigen Value

Thematic Map	Σ of Column Matrix(1)	Eighen	(1) x (2)
BDM	3.67	0.28	1.03
GAM	9.83	0.12	1.18
PRIM	6.67	0.18	1.20
SRIM	7.17	0.17	1.22
SDM	26	0.04	1.04
SFS	9.83	0.12	1.18
LPRI	24	0.04	0.96
UPRI	20.33	0.05	1.02
Principal Eigen value, λ max			8.82

Table VI: Weighting Value of Factor Criteria Computed using Ahp

Factor Criteria	Weight %
BDM	28
GAM	12
PRIM	18
SRIM	17
SDM	4
SFS	12
LPRI	4
UPRI	5



Factor Criteria	Weight %
BDM	28
GAM	12
PRIM	18
SRIM	17
SDM	4
SFS	12
LPRI	4
UPRI	5

Fig 4: The weighing Value of Factors Criteria using AHP Analysis.

After arriving the above weightages and ranks, HP zones are possess using Weighted Overlay Tool of Spatial Analyst Extension. Weighted Overlay is a technique for applying a common measurement scale of values to distinct and heterogeneous inputs to produce an amalgamated analysis. Finally, WLC process was attach to compute the suitability index value of the potential areas based on the following equation (3) :

$$Š = \sum_{i=1}^{n}(Wi \times Xij) \qquad (3)$$

Where ;Š= Weighted score for an area object in the final map,Wi = is the relative importance weight of theithmap,Xij = is the score of jthclass of theith map,n = is the total number of criteria.maps.

Based on the weights created using the AHP method, the (WLC) model for evaluation of (HP) can be achieved. Hence, weighted layers Integrated into GIS the field calculator the raster calculator (grid data).as shown in equation (4), below.

WLC =([BDM] * 0.28)+ ([GAM] * 0.12) + ([PRIM] * 0.18)+ ([SRIM] * 0.17)+([SDM] * 0.04) + ([SFS] * 0.12) + ([LPRI] * 0.04)+([UPRI] * .05) ------------ (4)

The output map thus arrived by cumulating weightage factors of all the themes shown in nine class influential zones. To avoid more number of sub categories, several inconsiderable provinces are recoded and are incorporated to the nearby expanded potential zones. The decisive map has shown with five influential zones such as Very High, High, Moderate, Low and Very Low was shown in Fig.5 .

III. RESULTS AND DISCUSSIONS

The contributing map for HP, recognized by weighted overlay (WLC) using spatial analyst tools in ArcGIS 9.3, shown in Fig.5 . The measured area available to each propitious set was as follows: Very High Potential 171.73 sq.km , High Potential 301.24 sq.km , Moderate 644.42 sq.km , Low 556.26 sq.km and Very Low 293.76 sq.km. which represent 9%, 15%, 33% and 28 % and 15% of the area respectively. The area of Very High Potential characterized by basement structure high (BDM) around 2500-3000 meters depth , Bouger anomaly values of (GAM) between(-115 to -95) m.Gal, (SDM) salt depth between (1300-1750)meters related to the Ayad, Sabatayn, Lower Naifa and Upper Naifa formations , the pre rift isopach layer(PRIM) shown thickness ranges between (170-430) meters related to the reservoirs Kohlan and Shuqra Formations and Shuqra Shale source rock , the Syn rift isopach layer (SRIM) shown thickness ranges between (150-350) meters related to the reservoir Lam Formations and Madbi Formation source rock , the Lower pre rift isopach (LPRI) shown thickness ranges between (250-450) meters related to the sandstones of the Qishn Formation of excellent reservoir quality, and the Lower pre rift isopach (UPRI) shown thickness ranges between (1000-2000) meters related to the Tawilah Group. These values was in agreement with those considered in the literature. The evaluation of the hydrocarbon potentiality map was checked against the distribution of the exploration (dry, gas shows, oil shows)wells, and the produced oil & gas fields, which reflects the overview of hydrocarbon potential. The HP zones match with these indicators for the hydrocarbonoccurrences,Fig.6. Most of the oil & gas fields and the exploration(gas shows, oil shows) wells were located at zones ofhigh to very high HP while most of the dry exploration wells were located at zones of Low to very Low HP. The final potential map has a high degree of confidence especially it adds new locations for hydrocarbon exploration.

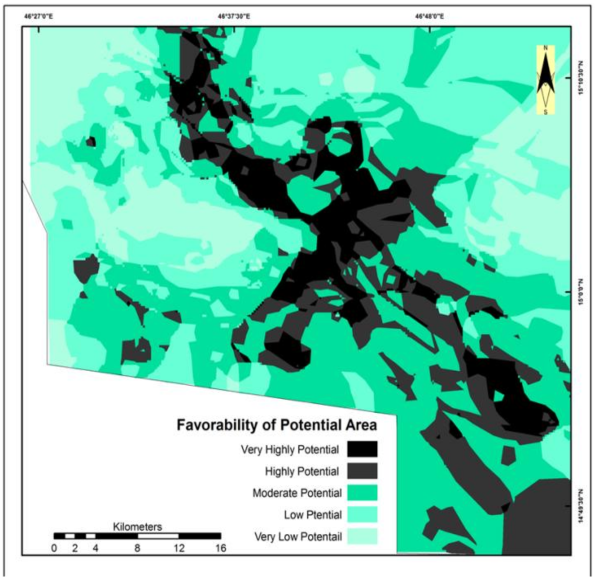


Fig 5 :The HP Map Resulted from (WLC) .

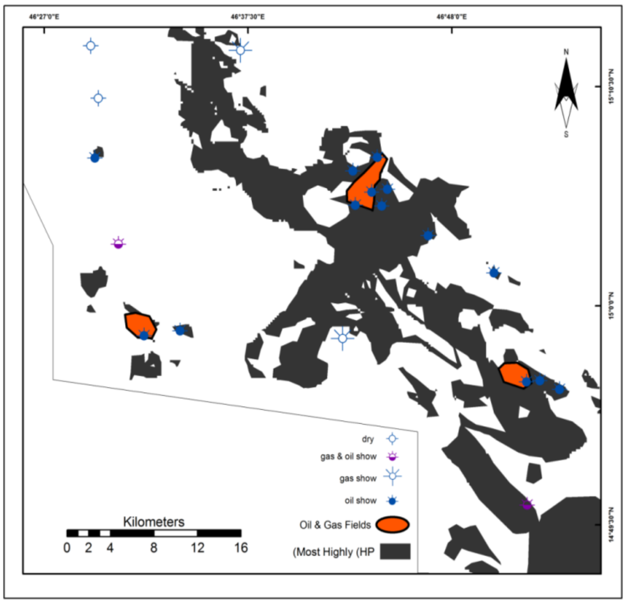


Fig 6:The Locations of Oil Fields and Exploration Wells Overlaid Over the Final HP Map for the Validation of Resulted Model.

IV. CONCLUSION AND RECOMMENDATIONS

The Ayad area indispensably reevaluation for hydrocarbon possibility reservoirs. Several thematic layers were adapted in the current study to determine the propitious zone of hydrocarbon occurrences. These layers BDM,GAM, PRIM, SRIM, SDM,SFS, LPRI, and UPRI. These layers were prepared from distinct data sources include seismic profiles ,gravity anomalies and boreholes data. These data were outgrowth using distinct GIS techniques Finally, all thematic layers wereassigned different ranks and their classes assigneddifferent weights according to their importance for hydrocarbon potential occurrences. The weights and ranks of thedifferent thematic maps were derived based on the weights created using the AHP method, the weighted layers Integrated into GIS using (WLC) model. The finalfavorable potential map suggested new promising areasfor hydrocarbon accumulations which were found in agreement to the validated ground truth data and matched with the subsurface faults (WNW-ESE) direction .

REFERENCES

[1] Carranza, E. M.,Ruitenbeek, F. A., Hecker, C.,Meijde, M. V. &Meer, F.D., 2008- Knowledgeguided data-driven evidential belief modeling of mineral prospectively in Cabo de gata, SE Spain ,International Journal of applied Earth Observation and Geoinformation, 10:374-387.

[2] Malczewski, J. (1999). GIS and multicriteria decision analysis. John Wiley & Sons.

[3] Bonham-Carter G.F. 1994: Geographic information systems forgeoscientists: modeling with GIS ,Pergamon Press, Ontario, Canada.

[4] Nikravesh, Masoud, Lotfi Asker Zadeh, and Fred Aminzadeh, eds. Soft computing and intelligentdata analysis in oil exploration. Vol. 51. Elsevier, 2003.

[5] Bonham-Carter G.F. 1994: Geographic information systems for geoscientists: modeling with GIS, Pergamon Press, Ontario, Canada.

[6] Islam R., Abdullah N.A., Management decision-making by the analytic hierarchy process: a proposed modification for large-scale problems, Journal for International Business and Entrepreneurship Development, 2006, 3, 18-40.

[7] Saaty T.L., The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, McGraw Hill International, New York, United States, 1980.

[8] Saaty T.L., Axiomatic Foundations of the Analytic Hierarchy Process, Management Science, 1986, 32, 841-855.

[9] Saaty T.L., Vargas L.G. Decision Making in Economic, Social and Technological Environ-ments, RWS Publications, Pittsburgh, United States, 2006.

[10] Hopkins L 1977Methods for generating land suitability maps: a comparative evaluation. Journal for American Institute of Planners 34: 19±29.

[11] Tomlin C D 1990 Geographical Information Systems and Cartographic Modeling. Englewood Cliffs, NJ, Prentice-Hall.

[12] Carver S J 1991 Integrating multi-criteria evaluation with geographical information systems International Journal of Geographical Information Systems 5: 321±339.

[13] Eastman J R, Kyem P A K, Toledano J, and Jin W 1993 GIS and Decision Making. Geneva UNITAR.

[14] Heywood I, Oliver J and Tomlinson S 1995 Building an exploratory multi-criteria modeling environment for spatial decision support. In Fisher P (ed) Innovations in GIS 2. London, Taylor and Francis: 127±36.

[15] Hopkins L 1977Methods for generating land suitability maps: a comparative evaluation. Journal for American Institute of Planners 34: 19±29.

[16] Herzfeld U C and Merriam D F 1995 Optimization techniques for integrating spatial data Mathematical Geology 27: 559±86.

[17] Lowry Jr. J H, Miller H J and Hepner G F 1995 A GIS-based sensitivity analysis of community vulnerability to hazardous contaminations on the Mexico/U.S. Border. Photogrammetric Engineering and Remote Sensing 61: 1347±59.

[18] Berry J K 1993 Cartographic modeling: The analytical capabilities of GIS. In: GoodchildM, Parks B and Stewart L (eds) Environmental Modeling with GIS. Oxford, Oxford University Press: 58±74.

[19] Hwang C-L and Yoon K 1981 Multiple Attribute Decision Making: Methods and Applications Berlin, Springer-Verlag.

[20] Massam B H 1988 Multi-criteria decision making (MCDM) techniques in planning. Progress in Planning 30: 1±84.

[21] Greenwood, W.R., R.E. Anderson, R.J. Fleck and R.J. Roberts 1980. Precambrian Geologic History and Plate Tectonic Evolution of the Arabian Shield. Saudi Arabian Directorate General Mineral Resources Bulletin 24, 35 p.

[22] Husseini, M.I. 1989. Tectonic and Deposition Model of Late Precambrian-Cambrian Arabian and Adjoining Plates. American Association of Petroleum Geologists Bulletin, no. 73, p. 1117-1131.

[23] Beydoun, Z.R. 1991. Arabian Plate Hydrocarbon Geology and Potential - A Plate Tectonic Approach. American Association of Petroleum Geologists Studies in Geology No. 33, 77 p.

[24] Seabourne, T.R. 1996. The Influence of the SabataynEvaporites on the Hydrocarbon Prospectivity of the Eastern Shabwa Basin, Onshore Yemen. Marine and Petroleum Geology, no. 13, p. 963-972.

[25] Integrated geophysics corporation. “Footnotes on interpretation”. IGC Foodnotes series.

[26] J. Brannan,G. Saota , Keith D. Gerdes, Jonathan A.L. Berry,1999. Geological Evolution of the Central Marib-Shabwa Basin, Yemen. GeoArabia, Vol. 4, No. 1, 1999 .Gulf PetroLink, Bahrain.

[27] Ellis, A.C., H.M. Kerr, C.P. Cornwell and D.O. Williams 1996. A Tectono-Stratigraphic Framework for Yemen and Its Implications for Hydrocarbon Potential. Petroleum Geoscience, no. 2, p. 29-42.

[28] GenliangGuo, Stephen A. George, 1999. An analysis of surface and subsurface lineaments andfractures for oil and gas exploration in the mid-continent region. Topical Report, PetroleumTechnologies, Inc. Tulsa, Oklahoma.

[29] Tran Tuan Dung et al, 2006. Some features on fault tectonics from interpretation of gravity anomaliesin Vietnam southeast continental shelf. Vietnam Journal of Marine Science and Technology ,vol. 2, 124-133.

[30] Saaty, T. (1977). A scaling method for priorities in hierarchicalstructures. Journal of Mathematical Psychology, 15, 234-281.

[31] Saaty, T. L., (1980), The Analytic Hierarchy Process, McGraw-Hill.

[32] Mustafa AA, Man S, Sahoo RN, Nayan A, Manoj K, Sarangi A, Mishra AK (2011Land suitability analysis for different crops. A multi criteria decision making approach using remote sensing and GIS. Indian Agricultural Research Institute, New Delhi-110 012.

[33] Saaty T L (2004), Fundamentals of the analytic networkprocess–multiple networks with benefits, costs , opportunities and risks; J. Systems Science and SystemsEngineering 13(3) 348–379.