# PREPARING MINERAL POTENTIAL MAP USING FUZZY LOGIC IN GIS ENVIRONMENT

M. Karimi [a] , M.B. Menhaj [b], M.S. Mesgari [a]

[a] Faculty of Geodesy & Geomatic Engineering, K.N.Toosi University of Technology, 15875-4416, Tehran, Iran - ( mkarimi, smesgari )@kntu.ac.ir
[b] Faculty of Electric Engineering, Amir Kabir University, Tehran, Iran - menhaj@aut.ac.ir

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**ABSTRACT:**

In vector model, the boundary between features is stored and shown categorically in an absolute way, in other words Membership or non-membership of a point in each polygon is known which can be 0 or 1. For showing real world and its projection on map, because of the uncertainty on the border of the boundary between phenomena and spatial data, there is some uncertainty and vagueness in drawing and depicting features. Because of the uncertainty in membership and non-membership amount of each point of factorial map according to the distance from spatial features, fuzzy logic would expose and show the existence vague between phenomena and features, and thereafter a closer result to the real world. So using fuzzy logic could be useful and workable. Attempt of the present study is tend to describe the modelling and storage of real world on digitised map by fuzzy logic, and eventually the approach for maps' integration in GIS by fuzzy logic with application test is presented. In our research three fuzzy operators proposed and using these operators, factor maps are integrated in case study. The result of using these operators comparing with conventional fuzzy operators shows that three proposed fuzzy operators have better result or have equal values with conventional fuzzy operators. In the present work as a case study, mineral potential map of porphyry copper ore of Rigan Bam in Iran is prepared by using of fuzzy logic.

## 1. INTRODUCTION

Spatial data is type of data which related and associated to an especial situation or a restricted location. For obtaining successful decisions which are related to environmental and geographical factors, existence of precise and update spatial data and their optimal management, is necessary.

There are two types of models for presentation and storage of spatial data which are vector and raster models. In vector model the smallest element is a point and in order to show real world; points, lines and polygons are used. In raster model, the smallest element is referred to a unit cell which presents as a pixel. Each pixel has a value. Set of pixel that lay in matrix form chronologically exhibits the spatial features. Satellite photos, scanned maps and etc, are some sample of raster model. Sometimes in the real world, the boundary between phenomena and features is not absolute; therefore there is some uncertainty and vagueness in drawing and depicting features.

In vector model, the polygonal feature border is stored and shown categorically in an absolute way, in other words Membership or non-membership of a point in each polygon is known which can be 0 or 1. In most of real state, the border between polygons is not precise (figure 1); hence determination of the exact border in order to expression the membership or non-membership in a polygon is impractical and impossible ( R. Sunila, 2004).

Polygonal features are made from lines and linear feature are made from points. For showing and storage of linear and pointed features and their factorial maps, the amount of membership or non-membership of every point of map according to the nearest distance from linear and pointed features is also uncertain. Usually at these cases, the amount of membership or non-membership of each point according to the distance from linear and pointed feature is recognized by a membership function. For instance, the possibility of mineralization according to its distance from linear features (Fault) and point features (Mineralization indicator) are mentioned.

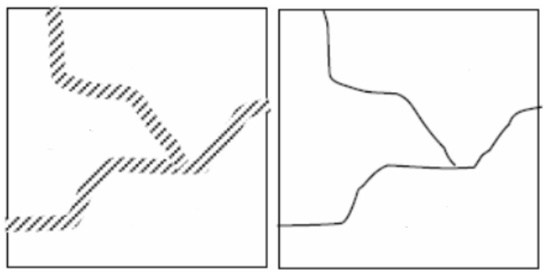

Figure 1. Fuzzy and vague borders between polygons

Fuzzy theory was offered firstly by Iranian scientist professor Askar Lotfizadeh in Berkley University in the USA for operation in uncertain condition. This theory has the ability to provide, present and describe many of concepts, variables and fuzzy systems in an arithmetic form and makes it possible for reasoning, control and makes decision in uncertain conditions.
For showing real world and its projection on map, because of the uncertainty on the border of spatial data, and also uncertainty in membership and non-membership influence of

each point of factorial map according to the distance from spatial features, fuzzy logic would expose and show the existence vague between phenomena and features, and thereafter a closer result to the real world. So using fuzzy logic could be useful and workable.

In the classical theory of sets, membership of component is expressed by zero or one. In fuzzy theory of sets, a fuzzy set is described as a subset of components which their membership is between zero and one. On the other hand if the range {0,1} is converted to the closed base of [0, 1], classic set will change to fuzzy set.

By using fuzzy logic, the provided map could be shown in a way which the value of each point is equal to its fuzzy membership degree. Membership degree is usually express by a membership function. The membership function $\mu(x)$ is a conversion of fuzzy membership of x, in the aforesaid domain of X to the unit base of {0, 1}. Membership function could be expressed in linear, nonlinear, continues, uncontinues and even in numerical tables. The amount of membership of x in $\mu(x)$, measures the amount of allocation accuracy of x in $\mu(x)$.

fuzzy membership function for two Rock units, in which their existence alteration of fuzzy membership degree are different from the border of Rock units. [F R S Moreira 2004]

Attempt of the present study is tend to describe the modelling and storage of real world on digitised map by fuzzy logic, and eventually the approach for maps' integration in GIS by fuzzy logic with application test is presented.

## 2. FUZZY MEMBERSHIP FUNCTIONS IN STORING SPATIAL DATA

At this section those sorts of fuzzy membership functions which are used in storing spatial data will be presented. In conventional map drawing software and GIS software, the border of polygon features are shown and stored categorically (Figure 2-A).

In showing real world, despite of the uncertainty in border of the polygon, it is possible to model existence vagueness in storing and showing polygon border, by using membership degree. Membership degree can be defined by its distance from polygon border line (stored border in vector model). All of the points which are in the same distance from polygon border have equal membership degree.

In geomatics engineering every map has its own specified scale and as a result has specific geometric accuracy. Geometric accuracy of a map is calculated by its scale. For example in 1:5000 scale, maps accuracy equals to 1.5 metres. Thus it is possible to calculate membership degree of each point of map domain (related to distance from polygon line) according to map accuracy.

For instance if the existence vagueness in storing and showing of polygon border presume three times further than map geometric accuracy (4.5 m), three internal buffer and three external buffer from polygon A border in vector model (figure 2-b, the red line) is drawn. If the map accuracy assumed 1.5 metres then (Table 1):

| Set of points which placed in distance (D) from polygon border<br>d = geometric accuracy of map | membership degree |
|---|---|
| D > -3d | 7/7 =1 |
| -3d < D < -2d | 6/7 |
| -2d < D < - d | 5/7 |
| - d < D < 0 | 4/7 |
| 0 < D < + d | 3/7 |
| + d < D < +2d | 2/7 |
| +2d < D < +3d | 1/7 |
| D > +3d | 0/7=0 |

Table 1. membership of each point according of distance from polygon border

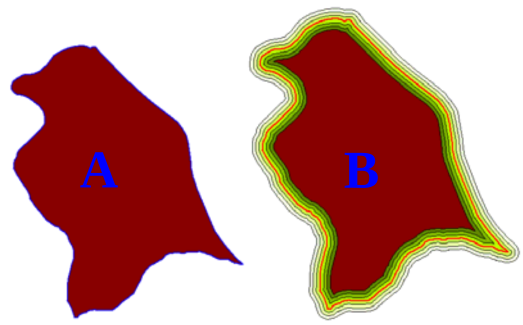


Figure 2. Showing and storing of spatial data categorically A) in vector model B) using fuzzy logic

The fuzzy membership function in figure (2-b) is presented with equation (1) and figure3. In equation (1) the statement $x, y \in \{A - nd \;\text{ to }\; A - (n-1)d\}$ express set of points which are situated in distance $-nd \;\text{ to }\; -(n-1)d$ from polygon border.

$$\mu(x) = \begin{cases} 1 & x, y \in \{A - nd\},\; b = 3,\; n > b \\ \dfrac{b+n}{2b+1} & x, y \in \{A - nd \text{ to } A - (n-1)d\},\; n = \{1,2,\ldots,b\} \\ \dfrac{(b+1)-n}{2b+1} & x, y \in \{A + (n-1)d \text{ to } A + nd\},\; n = \{1,2,\ldots,b\} \\ 0 & x, y \in A + nd,\; n > b \end{cases} \quad (1)$$

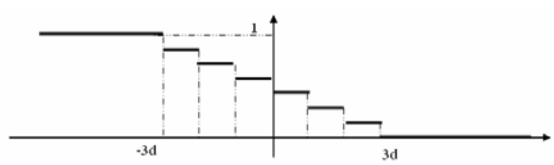


Figure 3. Fuzzy membership function of polygon B with attention equation 1

Sometimes, moreover than storing the existence vagueness in polygon border, preparing of factorial map is also considered. In preparing factorial map, effectiveness radius and manner of effectiveness of each feature should be specified. Manner of effectiveness can be modelled with a membership function. If so, usually two or three internal buffer and lots of external buffer (according to the effectiveness radius) are drawn. For instance in figure5, three internal buffers (b1) and twelve external buffers (b2) in modelling from polygon border have been drawn. (Blue line in Figure4).

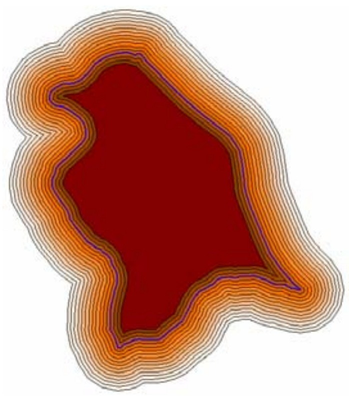

Figure 4. Storing and showing of polygon A and preparing factorial map using fuzzy logic

The fuzzy membership function in figure 4 is presented with equation 2 and figure 5.

$$\mu(x) = \begin{cases} 1 & x,y \in \{A - nd\},\ b1 = 3,\ n > b1 \\ \dfrac{b+n}{b1+b2+1} & x,y \in \{A - nd \text{ to } A - (n-1)d\},\ n = \{1,2,\ldots,b1\} \\ \dfrac{(b2+1)-m}{b1+b2+1} & x,y \in \{A + (m-1)d \text{ to } A + md\},\ m = \{1,2,\ldots,b2\} \\ 0 & x,y \in \{A + md\},\ b2 = 13,\ m > b2 \end{cases} \quad (2)$$

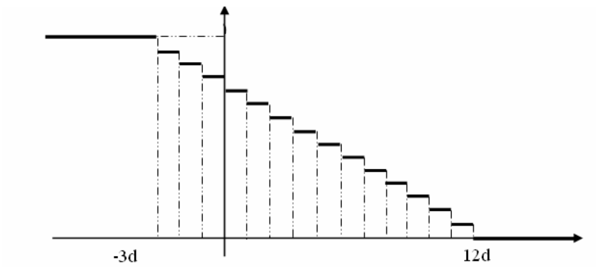


Figure 5. Fuzzy membership function of polygon A with attention equation 2

In order to preparing pointed and linear factorial map, foresaid features should be converted into polygon features. Thereafter according to effectiveness radius and manner of effectiveness, it is possible to model each pointed and linear feature by a membership function. In these cases usually lots of buffer (according to effectiveness radius) are drawn.

The fuzzy membership function a linear feature in vector model (For instance thirty buffers (n)) is presented with equation 3 and figure 6.

$$\mu(x) = \begin{cases} 0 & x,y \in \{A - nd\},\ b = 30,\ n > b \\ \dfrac{b-n}{n+1} & x,y \in \{A + (n-1)d \text{ to } A + nd\},\ n = \{1,2,\ldots,b\} \end{cases} \quad (3)$$

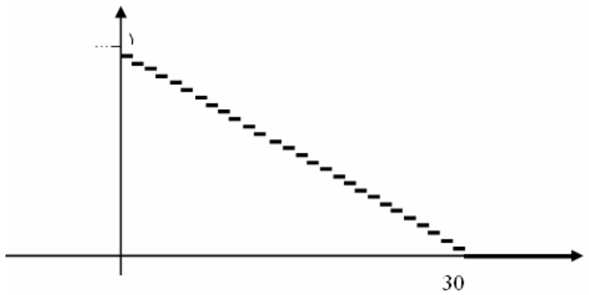


Figure 6. Fuzzy membership function of polygon A with attention equation 3

The above mentioned examples are only useful for layer which contain only one type object. In other words, all of the existence objects in aforementioned layer have similar effectiveness radius and manner of effectiveness. If in a layer two or several types of object with different effectiveness radius and manner of effectiveness are exist, it is necessary to divide layer at one stage, into several layers on the basis of the amount of types of objects. Integration of each layer is scheduled after storing and showing of objects and also preparing of factorial map for each layer individually.

In continuation, various current types of methods for integration of different layer are presented. In the case study (section 5), the storing approach and preparation of factorial map for layers is described by fuzzy logic. In this case study eight layers which were prepared by fuzzy logic and integrated by fuzzy operator.

## 3. INTEGRATION METHODS BY FUZZY LOGIC

(An et al, 1991), (Gitigs and Bultman, 1993), (Right and Bunham Karter, 1998), (Chang and Agterberg, 1999), (Naz and Rabinson, 2000) and (Karanza and Hal, 2000) have utilized fuzzy logic in maps integration. Various types of conventional fuzzy operators which are used in composition of spatial data are presented in table 1.

| Operator equation | Operator name |
|---|---|
| $W = MIN(W_A, W_B, W_C, ...)$ | Fuzzy AND |
| $W = MAX(W_A, W_B, W_C, ...)$ | Fuzzy OR |
| $W = \prod_{i=1}^{n} W_i$ | Fuzzy Algebraic Product (F.A.P) |
| $W = 1 - (\prod_{i=1}^{n} (1 - W_i))$ | Fuzzy Algebraic Sum (F.A.S) |
| $W = (F.A.S)^{\gamma} * (F.A.P)^{1-\gamma}$ | Fuzzy Operation Gamma |

Table 2. Various types of conventional fuzzy operators

In these equations :

a) $W_i$ , $W_A$ , $W_B$ and $W_C$ presents the quantity of fuzzy membership of it's map in an especial situation.

b) In fuzzy AND operator as a t-norm, the weight of compositional layer in the multilayer intersection section, is equivalent of their minimum and for other sections is equal to zero. In fuzzy OR operator, as an S-norm, the weight of compositional layer in the multilayer union section is equal to their maximum and for further sections is zero.

c) In fuzzy algebraic product operator as a t-norm, the weight of compositional layer in the multilayer intersection section is equal to their products and for other sections is zero. Therefore mentioned operator has a decrease effect.

d) In fuzzy algebraic product operator as an s-norm, membership fuzzy amount of output map is always more than or equal to the maximum amount of fuzzy membership amount in matching situations of input maps. Therefore the mentioned operator has an increase influence.

e) Fuzzy operation Gamma is a composition of Sum and Product. In this equation the amount of $\gamma$ is specify between zero and one.

In this research three of new fuzzy operator which can use in composition of spatial data, proposed. Three type of proposed fuzzy operators, presented in table 3.

| | |
|---|---|
| $W = ArcSin(Sin\frac{W_a * \pi}{2} * Sin\frac{W_b * \pi}{2}) * \frac{2}{\pi}$ | Fuzzy Sinus |
| $W = 1 - ArcSin(Cos\frac{W_a * \pi}{2} * Cos\frac{W_b * \pi}{2}) * \frac{2}{\pi}$ | Fuzzy Cosine |
| $W = (\text{Fuzzy sin})^{\gamma} * (\text{Fuzzy cos})^{1-\gamma}$ | Fuzzy SinCos |

Table 3. three types of proposed fuzzy operators

In these equations, $W_a$ and $W_b$ presents the quantity of fuzzy membership of it's map in an especial situation.

In continuation, in the case study, various types of conventional and proposed fuzzy operators which are used in composition of spatial data are investigated and evaluated.

## 4. CASE STUDY

Mineral storage, occurrences, is one or some useful materials which are spread in most areas on the earth. (Bateman, 1951). In most real situation, the border between areas which are good or poor for mineralization is uncertain and therefore fuzzy. Hence it is possible to prepare factorial map with fuzzy logic, and by the aid of fuzzy operations which were introduced in the latter section, integrate factorial maps for obtaining a mineral potential map. In the present work as a case study, mineral potential map of porphyry copper ore of Rigan Bam in Iran is prepared by using of fuzzy logic.

The ore of Rigan Bam territory is situated in 175 kilometres of south-west of Bam County. Iran cooper industry national company has started the comprehensive investigation of cooper sign in 1998 in 1:5000 scale. Regarding to conceptual model of cooper porphyry storage and specific characteristics of the done study in ore of Rigan Bam, the controller mineralization factors for this ore are consist of: micro-granite, mineralized zones, alteration, dyke, a group of micro-granite and dibasic stones, fault, sampling point of geochemistry, sampling point of geomagnetic and sampling point of geo-electric. After factors determination, required information layers were prepared in GIS environment. In figure 7, some of these layers are presented.

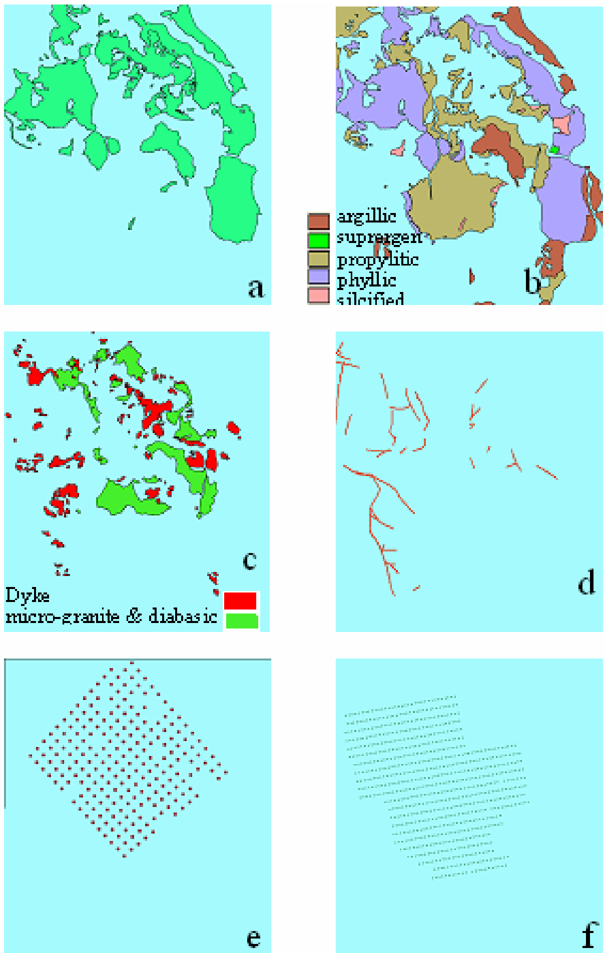


Figure 7. a) granite rock type map, b) alteration map, c) dyke and granite & diabasic rock type map, d) Faults map, f) geochemistry sampling points map g)geo-electric sampling points map

By doing the following processes the foresaid factorial maps were prepared. In maps preparation the following comments were perceived.

a) Intended for factorial map, micro-granite stone unit, phyllic alteration, silica and supergene alteration and prophylitic and argillic alteration, the membership function equation 1 was employed. In this equation b=2 was presumed. The alteration for phyllic, silcified, supergene, prophylitic and argillic has weight parameter chronologically 0.9, 0.8, 0.8, 0.4 and 0.4.

b) Intended for mineralized zones factorial map, the membership function equation 2 was utilized, in this equation b1=2 and b2=100 were presumed.

c) Intended for faults factorial map, membership function equation 3 was employed. In this equation b=300 was presumed.

d) Intended for dykes and a set of micro-granite and dibasic stones factorial map, the membership function equation 4 was use. A set of micro-granite and dibasic stones and dykes role the heat region zone, Thereafter membership degree effectiveness on the above units border, were maximum and by increasing the distance, their effectiveness is reduced.

$$\mu(x)=\begin{cases} 1 & x,y\in\{A-nd\},\ \ b1=2,\ \ n>b1 \\ 0.3+\dfrac{n}{2(2b1+1)} & x,y\in\{A-nd \text{ to } A-(n-1)d\},\ n=\{1,2,\ldots,b1\} \\ 0.5+\dfrac{n}{2(2b1+1)} & x,y\in\{A+(n-1)d \text{ to } A+nd\},\ n=\{1,2,\ldots,b1\} \\ 0.8+\dfrac{241-m}{b1+b2+1} & x,y\in\{A+md\},\ n=\{3,4,\ldots,b2\},\ b2=240 \\ 0 & x,y\in\{A+md\},\ \ m>b2 \end{cases} \quad (4)$$

e) By interpolation of additive indexes (CuZscore + MoZscore), the raster map of compositive hallo (geochemistry anomaly factorial map) was prepared.

f) By the amount of chargeability and point nominal resistance, the amount of metallic factor for points was calculated and with interpolation the amount of metallic factor, anomaly factorial and anomaly geo-electric maps were prepared.

g) Intended for geochemistry, geomagnetic and geo-electric factorial map, fuzzy membership function was calculated using normalized numbers of additive indexes, amount of geomagnetic and amount of metallic factor chronologically.

Prepared factorial map are presented in figure 8.

In order to preparing mineral potential map, aforesaid factorial maps were integrated in an inference network (figure 9). According to the operation of prepared factorial maps, (Fuzzy Algebraic Sum: FAS) operator which has an increase influence was utilized. The weighing manner for factorial maps of ore in Rigan Bam is illustrated on the left of the following figure.

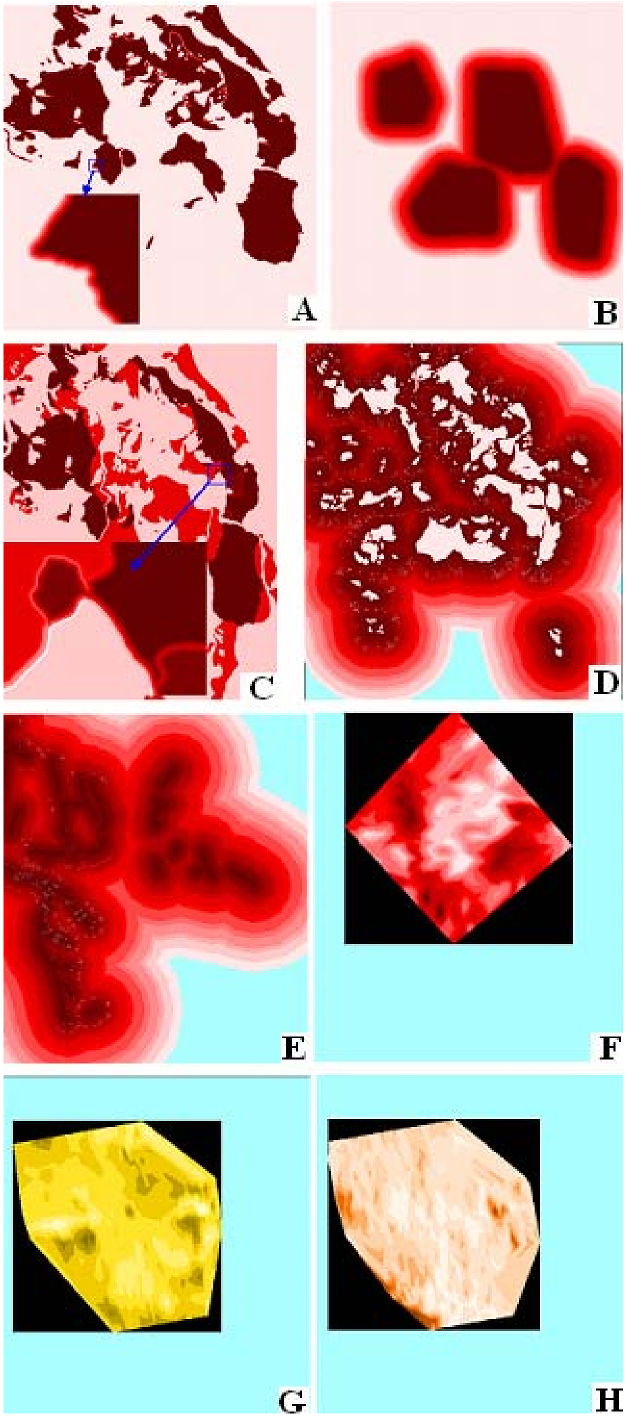


Figure 8. a) Granite Rock units factor map, Mineralization map, Alteration factor map, dyke and granite & diabasic Rock unit factor map, Faults factor map, Geochemical factor map, Geo-Electric factor map and Geomagnetic factor map

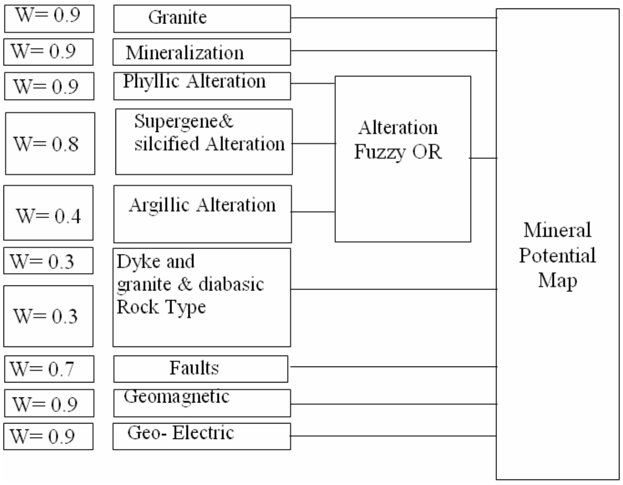


Figure 9. Rigan Bam mineral potential map inference network

At this stage, mentioned mineral potential map was prepared and divided into three classes of anomaly, moderate limit and field limit (Table 4)

| Operator | Class_1 | Class_2 | Class_3 |
|---|---|---|---|
| F.A.P | 0 – 0.12 | 0.12 – 0.50 | 0.50 – 0.95 |
| F.A.S | 0.66 – 0.99 | 0.99 – 0.9993 | 0.9993 – 1 |
| Fuzzy Gamma | 0.01 – 0.16 | 0.16 – 0.31 | 0.31 – 0.38 |
| Fuzzy Sinus | 0.43 – 0.97 | 0.97 – 0.9965 | 0.9965 – 0.999 |
| Fuzzy Cosine | 0.00- 0.01 | 0.01 – 0.04 | 0.04 – 0.09 |
| Fuzzy SinCos | 0.01 – 0.25 | 0.25 – 0.44 | 0.44 – 0.54 |
| Crisp | 0.01 – 0.55 | 0.55 – 0.755 | 0.755 – 0.80 |

Table 4. Domains of three classes in the potential mineral map

In order to appraise the diggings results, cooper grade profile, was depicted in depth for eight discovery wells and the related class was determined for every well. Pixels amounts for eight discovery wells in the potential mineral map were obtained. At this stage, the specified class for each well was compared to its situation.

| **operator** | Dh1 good | Dh2 weak | Dh3 medium | Dh4 medium | Dh5 weak | Dh6 medium | Dh7 Very weak | Dh8 weak | **Satisfying fitness** |
|---|---|---|---|---|---|---|---|---|---|
| F.A.P | 0.48 + | 0.01 + | 0.38 + | 0.01 – | 0.02 + | 0.05 – | 0.00 + | 0.15 – | 62.5 |
| F.A.S | 0.9998 + | 0.996 – | 0.9992 + | 0.9997 – | 0.97 + | 0.99 + | 0.00 + | 0.9992 – | 62.5 |
| Fuzzy Gamma | 0.32 + | 0.13 + | 0.30 + | 0.10 – | 0.13 + | 0.16 + | 0.00 + | 0.26 – | 75 |
| Fuzzy Sinus | 0.041 + | 0.001 + | 0.035 + | 0.001 – | 0.002 + | 0.002 + | 0.00 + | 0.002 – | 75 |
| Fuzzy Cosine | 0.998 + | 0.984 – | 0.997 + | 0.895 + | 0.954 + | 0.997 + | 0.00 + | 0.996 – | 75 |
| Fuzzy SinCos | 0.45 + | 0.20 + | 0.43 + | 0.16 – | 0.21 + | 0.25 + | 0.00 + | 0.38 – | 75 |

Table 5. The comparison of mineral potential mapping (6 map ) with result of drilling

It could be arise from the diggings results that the presented scheme for six wells has a satisfying fitness (75 percent). Potential map of the mentioned scheme is accessible in figure 9.

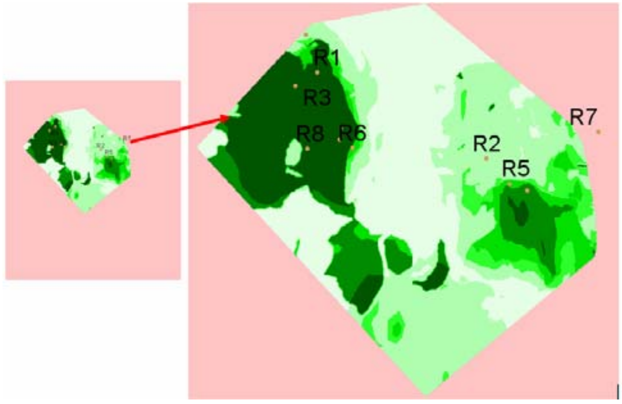


Figure 9. Mineral potential map of porfiry copper ore of Rigan Bam with using Fuzzy SinCos operator

In order to prepare mineral potential maps, those group of maps which features border were stored categorically, were used, and aforesaid maps according to presented inference network in figure (7), were integrated together. The diggings results for four wells show a fair fitness (50 percent).

## 5. CONCLUSION AND SUGGESTIONS

Presenting and showing of the real world and its projection on map has difficulties and problems because of the existence uncertainty between spatial objects border, and also the inaccuracy of membership or non-membership for each point of factorial map according to the distance from spatial objects. Fuzzy logic could be useful and workable in order to prepare a map which shows the existence vagueness between phenomena and features, which is closer to the real world.

In this research, the modelling and storage of real world on digitised map and eventually the approach for maps' integration in GIS by fuzzy logic presented.

With checking of drilling results on 6 wells it is understood that they have good accordance (75 percent). If using maps are stored with crisp boundaries, the results of drilling on 4 wells have suitable accordance (50 present). Consequently, we can say the result of this research with a required variation can be used for other mineral potential areas and site selection of drilling wells

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