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Performance of Spatial Distribution Quality by Ordinary Fuzzy Kriging for Soil Properties under Uncertainty

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Abstract

This research studies the spatial distribution quality of spatial interpolation methods. The research aims first to obtain unbiased estimator parameters based on regionalized variables in the study field. We used kriging techniques (called Local spatial interpolation) to rely on the variogram function with a fuzzy inference system, where fuzzy kriging is an extension of ordinary kriging. The second objective of this work is to estimate parameters of covariance models based on real data of soil chemicals, the data adopted in this research is taken from (100) real data for each soil chemical (Mg, Cl, and No3). These data are from Mosul Quadrangle in Mosul city in Iraq. After applying kriging techniques and a fuzzy inference system, we show the minimization of the estimation variance to choose the sentimental under uncertainty. We get the Smallest standard cross-validation of errors. Covariance models are described by exponential, and spherical model. With the best fitting models by the constraint of weights we note that the performance of the interpolation method is better by compared to the fuzzy system. In conclusion, the improvement does not rely on the statistical methods, but rather higher quality and large data of soil variables should be used to improve the prediction process. All programming computations are carried out in Matlab Language.

Keywords:
kriging, fuzzy logic, variogram function, soil data.

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I. INTRODUCTION

There are many spatial interpolation methods that are used to find the best performance of a spatial distribution based on the theory of regionalized variables. Kriging techniques are the most important to prediction values in the study area, later on, Georges Matheron, which to the first scientific approach to the kriging method. The main purpose of spatial data analysis is to obtain the best estimate of the values of a particular phenomenon in the study area with minimal variance errors through kriging techniques such as universal kriging [7]. Spatial variability of the studied data has an accurate prediction of covariance for any application (such as mining field, level of groundwater, environmental sciences, soil data, pollution, …, etc.). Various statistics and analysis numerical approaches to the best model have been introduced. Multivariate techniques have proven to be effective in the spatial prediction of landslides using a high degree of accuracy [11], [12]. Many studies dealt with the fuzzy system starting to know the fuzzy logic, fuzzy numbers, and the membership model [16], [18]. Other studies took the prediction using an application of the analytical hierarchy process. [1], [2]. And also, the fuzzy inference system interest other scientists such as [4], [5], [6].

This paper describes a method of fuzzy kriging depending on the variogram function. Kriging specifically explains the subject of uncertainty about the empirical variogram. This work demonstrates how to "fuzzy spacing", which achieves variance kriging. Fuzzy kriging interests soil scientists, it assumes that the reader is familiar with the basic ideas of fuzzy theory [13], [15].

2. Material and Methods

2.1 Interpolation methods

Geostatistical techniques include kriging to interpolate the value of regionalized variable theory. Geostatistics is applied in different fields such as (depth, soil science, hydrology, groundwater, environmental sciences, …, etc.) [12].

2.2 The variogram function

The variogram function is defined in spatial statistics of the stochastic process $\{z(v), v\epsilon R^d\}$. For each pair of points in the sample data, the variogram function is defined by Matheron as a measure of the half mean-squared difference between their values at locations or with at the distance (lag h).

$$2\gamma(h) = \frac{1}{N(h)}\sum_{i=1}^{N(h)}[z(v_i) - z(v_i + h)]^2 \qquad (1)$$

$2\gamma(h)$ is the variogram function, $z(v)$ regionalized variables containing a point (v). Cressie defined variogram as the variance $2\gamma(v_{1_1}, v_2) = var(z(v_1) - z(v_2))$ also, we can write the variogram also function as the expectation .

$$2\gamma(v_1, v_2) = E[z(v_1) - z(v_2)]^2$$

and under stationary process, semi-variogram defined by Cressie:

$$\gamma(v_1, v_2) = \gamma(v_1 - v_2)$$

$z(v)$ is second-order stationarity with mean μ a covariance $C(h)$

i) $E[z(v)] = \mu, \quad \forall\ v \in D$

ii) Covariance function *depends*epend on the distance of h

$$z(v) = Cov((z(v), z(v+h)) = E(z(v), z(v+h)) - \mu^2$$

And the d in case of isotropic

$h = \|v_2\|$, $\gamma(v_1, v_2) = \gamma(h)$

The scientists (Chilled, and Wachanagel) give the properties of variogram function as the following:

i) $\gamma(v_1, v_2) \geq 0$ (non ngative)

ii) $E[z(v_1) - z(v_2)]^2 = 0 \quad at\ distance\ (0)$

iii) $\sum_{i=1}^{N}\sum_{j=1}^{N} w_i\, \gamma(v_i, v_j)\, w_j \leq 0 \quad where\ \sum_{i=1}^{N} w_i = 0$

when we describe the curve of the variogram function by the vriogram parameters as the following:

- Nugget effect denoted as (C_0) defined as the discontinuity at the origin point (or measurement with error).
- Sill ($C+C_0$) defined the limit of function to infinity, where C is partial sill [17],[18].
- Range denoted as (a), is the distance on X-axis at which the variogram levels off to the curve stable. (see Figure (1))

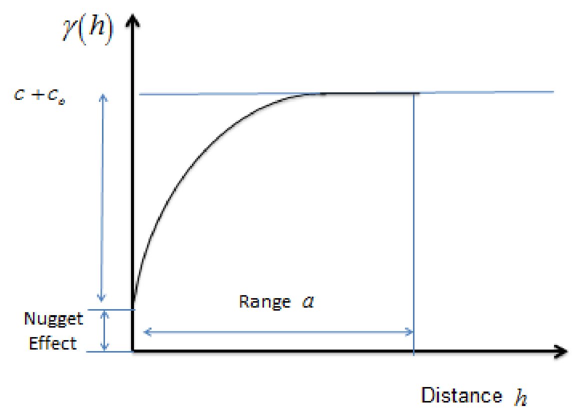

Figure (1): parameters of variogram

- if we have the set of sample $z_1, \dots, z_k$ at locations $v_1, \dots, v_k$ where v_k denoted of $z(v_i)$,
- $i = 1, \dots, k$ and the empirical variogram function can be written as:
- $2\gamma(h) = \frac{1}{N(h)}\sum_{(i.j)\in N(h)}|z_i - z_j|^2 \qquad (2)$
- where $N(h)$ is the pairs of observations [8].

2.3 Fuzzy Theory

The published research" Fuzzy sets" is the first research of the professor and head of the Department of Electrical Engineering at California university at Berkeley Lotfi A. Zadeh which was published in 1965. This scientist is considered the first to sudy " The Fuzzy " after identifying it and linking it with Probability theory to get the mathematical logic. Zadeh used the membership of classical binary logic and developed it for a set of mathematical principles to represent the membership degrees of multivalued fuzzy Logic rather than the classical set. The first introduces some concepts of fuzzy set theory after Zadeh [2], [3], [9]. The fuzzy set A is defined as a set of pairs of elements and the corresponding membership degrees less than or equal to 1 denoted by $A = \{(x, \mu_A(x)),\ x \in X\}$ where X is a collection of element numbers $x; \mu_A: X \to [0,1]$ called the membership function of set A, [10]. If we have two fuzzy sets A and B then the intersection of A and B denoted by $A \cap B$ is :

$A \cap B = \{(x, \mu_{A\cap B}(x)), x \in \sup(A) \cap \sup(B)\}$

membership function $\mu_{A\cap B}(x) = \min(\mu_A(x), \mu_B(x))$

Let M and N, fuzzy subsets of sets X and Y with $\mu_M(x)$ and $\mu_N(y)$ then a furry subset of $M \times N$ has $\mu_{M\cap N}(x,y) = min\{\mu_M(x), \mu_N(y)\}$.

2.4 Fuzzy kriging procedure

Parameter values, whether accurate or inaccurate, at certain points where the parameters are to be estimated these values are the inputs of fuzzy kriging. The estimated value for any location represents the outcome of the fuzzy kriging. The experimental variogram is used as the best tool to find the theoretical variogram function. Fuzzy kriging can be calculated by taking fuzziness and fitting a variogram curve [14], [17].

2.5 The Hypothetical Fuzzy Variogram

The experimental variogram function is defined

$$2\gamma(h) = \frac{1}{N(h)} \sum_{(i.j)\in N(h)} [z(v+h) - z(v)]^2 \qquad (3)$$

Corresponding, the fuzzy variogram for fuzzy $\check{A}$ is defined as $2\gamma_{\check{A}}(h)$ and for the formula:

$$\gamma_{\check{A}}(h) \triangleq \int_{R^P} [\mu_{\check{A}}(v_I + h) - \mu_{\check{A}}(v_J)]^2 dp \qquad (4)$$

From equations (3), and (4) we write:

$$2\gamma_{\check{A}}(h) = \frac{1}{N(h)} \sum_{k=1}^{N(h)} [\mu_{\check{A}}(v_I + h) - \mu_{\check{A}}(v_J)]^2 \qquad (5)$$

[19]

2.6. Ordinary Kriging

The kriging technique is used to estimate a value at a point of real spatial data of the study area. The variables satisfice the second-order stationarity. In ordinary kriging, we want to estimate a value of (v_0) using the data values from neighboring sample point (v_0). The predictor of ordinary kriging linearly with weights can be written as:

$$\hat{z}_{ok}(v) = \sum_{i=1}^{n} \lambda_i * z(v_0) \qquad (6)$$

$where\ \lambda_i, i = 1,2,\ldots,h$ is the weights, the estimate variance is defined by $\sigma_E{}^2$:

$$\sigma_E{}^2 = -\gamma(v_i - v_j) \sum_{i=1}^{n}\sum_{j=1}^{n} \lambda_i\lambda_j\gamma(v_i - v_j) + 2\sum_{i=1}^{n} \lambda_i\gamma(v_i - v_0) \qquad (7)$$

By minimizing the estimate variance with condition on the weight, the ordinary kriging system:

$$\begin{pmatrix} \gamma_{(v_1-v_1)} \cdots \gamma_{(v_1-v_n)} \cdots 1 \\ . \qquad . \\ . \qquad . \\ \gamma_{(v_n-v_1)} \cdots \gamma_{(v_2-v_n)} \cdots 1 \\ 1 \qquad \ldots \quad 0 \end{pmatrix} \begin{pmatrix} \lambda_1 \\ . \\ . \\ \lambda_n \\ \mu_{0k} \end{pmatrix} = \begin{pmatrix} \gamma_{(v_1-v_0)} \\ . \\ . \\ \gamma_{(v_n-v_0)} \\ 1 \end{pmatrix}$$

Where μ_{0k} is the Lagrange parameter and λ_i are the weights also the ordinary kriging system can be defined in the form:

$$\begin{Bmatrix} \sum_{\alpha=1}^{n} \lambda_i \gamma_{(v_i-v_\alpha)} + \mu_{0k} = \gamma_{(v_1-v_0)}, i = 1,2,\ldots n \\ \sum_{\alpha=1}^{n} \lambda_\alpha = 1 \end{Bmatrix} \qquad (8)$$

The estimate variance $\sigma_{0k}{}^2$ is defined as:

$$\sigma_{ok}^2 = \mu_{0k} - \gamma_{(v_0-v_0)} + \sum_{\alpha=1}^{n} \lambda_\alpha \gamma_{(v_\alpha-v_0)} \qquad (9)$$

Where v_0 is location of the real data , then $\hat{z}(v_0) = z(v_\alpha)\ if\ v_0 = v_\alpha$. [5], [8].

2.7 Cross validation

- In order to obtain effective a prediction we used The value of G measures by using sample mean.

$$G = \left[1 - \frac{\sum_{i=1}^{n}[z(v_i) - \hat{z}(v_i)]^2}{\sum_{i=1}^{n}[z(v_i) - \bar{z}(v_i)]}\right] \qquad (10)$$

where $z(v_i)$ are the observations of the variables, $\hat{z}(v_i)$ the predictor values and are $\bar{z}$ the sample mean, to evaluate the complete prediction G is equal to 1 , while the prediction is less accurate when G is a negative value, while if G is a positive value that means a more positive prediction and G is zero refer to the sample mean should be used.

- By using the kriging variance, we can define the accuracy of prediction mean square error (MSE) and calculated by:

$$MSE = \left[\sum_{i=1}^{n} \frac{[z(v_i) - \hat{z}(v_i)]^2}{\sigma_{ok}^2}\right] \qquad (11)$$

3. Results and Discussion

3.1 Study Area

This research adopted the soil data from Mosul city in Iraq. These data contain (100) values of each soil data (Mg, Cl, and NO3).

Table (1): data statistics of soil data (Mg, Cl, and NO_3)

Soil Data	Min	Max	Median	Mode	Standard deviation
Mg	0.200	29.5	7.6500	3.7	6.0881

Cl	**3**	**38**	**16**	**6**	**11.4193**
NO_3	**0.400**	**8.600**	**1.810**	**1.700**	**1.8813**

Table (1) show the statistics of soil data for (Mg, Cl, and NO3) including (min, max, median, mode, and standard deviation

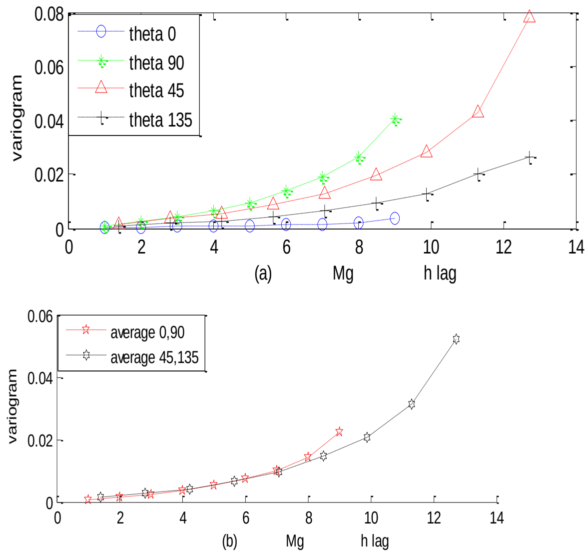

Figure (2): results of variograms for Mg data

Figure (2) describes the curves of the variogram function in figure (a) shows the results of the variogram for all theta of the compass (θ=0°,90°,45°, and 135°). Where the curves of variograms in all theta are curves that behave similarly in all directions of the compass. While figure (b) describes the average of (0°,90°) as it takes the same distance of h (represent red curve), and the average of 45° and 135° have the same lag of h (black curve). Plots of Figure (1) rely on the results of the variogram function in Table (2) below.

Table (2): results of the variogram function for Mg

G11	G22	G33	G44
0.0004	0.0011	0.0017	0.0001
0.0005	0.0025	0.0035	0.0019
0.0006	0.004	0.0054	0.0028
0.0007	0.0067	00.0089	0.0044
0.0010	0.0096	0.0127	0.0065
0.0012	0.0138	0.0195	0.0096
0.0015	0.0187	0.0261	0.0127
0.002	0.0262	0.0427	0.0199
0.0037	0.0408	0.0778	0.0265

Table (2) show results of variogram function (G11, G22, G33, and G44) is results of thetas (0°,90°,45°, and 135°) respectively. And by the same way, we getting the results of the variogram function in follow Figure.

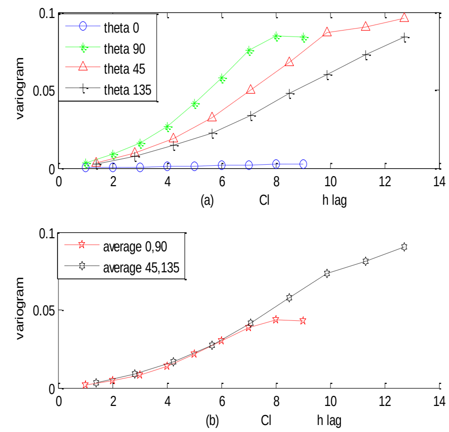

Figure (3): results for Cl data of variogram: (a) for all theta, (b) average of each two thetas.

Figure (3a) illustrates the curves of the variogram function for (Cl data) for all theta between the distance (or lag h) on the x-axis and the variogram on the y-axis. Figure (3b) shows the curves (red) the average of thetas (0^o,90^o) and the black curve for two thetas (45^o, 135^{o}).

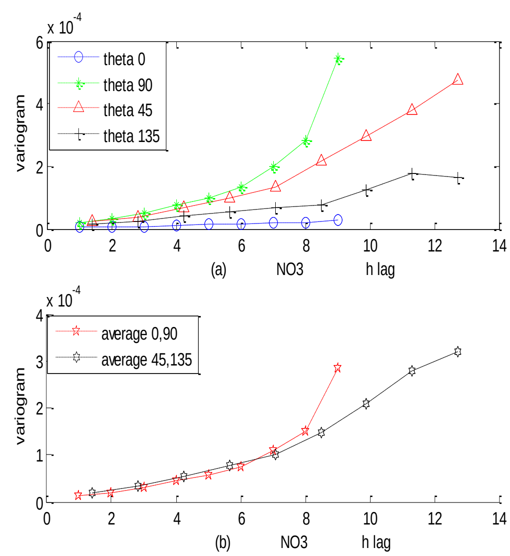

Figure (4): results of variogram function for NO3 data (a) in all theta, (b) average of variogram

Figure (4) above describe the curves of variogram function (a) in all theta of compass, and (b) the curve of average of variogram function rely on the distance.

Table (3): results of parameters of variogram function.

Data	Mg		Cl		NO_3	
Theta	0°, 90°	45°, 135°	0°, 90°	45°, 135°	0°, 90°	45°, 135°
Nugget Effect	0.000734	0.001348	0.001703	0.00303	1.212e-005	1.212e-005
Sill	0.02225	0.0522	0.04354	0.0901	0.0002858	0.0002858
Range	8	1.31	8	11.31	8	8

Table (3) describes the results of the variogram parameters for Mg, Cl, and NO3 in all thetas, these parameters represent the nugget effect, sill, and range. The parameters of the variogram function are defined on the assumption of uncertainty. Property as: nugget effect (C_0), sill (C_0+C) and partial variance (C). the kriging variance $\sigma_E{}^2$ after prediction of points of regionalized variables.

By using the fuzzy of triangular membership function with parameters, where $T(x|a,b,c)$ defined as:[20]

$$T(x|a,b,c) = \begin{cases} 0 & x \le a \quad or \quad x \ge c \\ 1 & x = b \\ \dfrac{x-b}{b-a} & a < x < b \\ 1 - \left(\dfrac{x-b}{c-b}\right) & b < x < c \end{cases} \qquad (12)$$

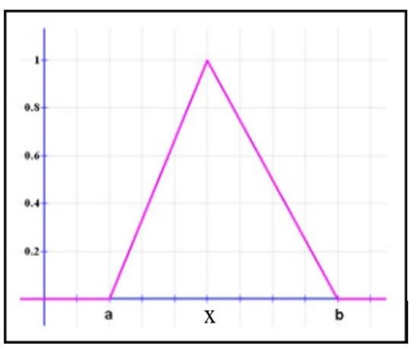

Figure (5): Triangular membership function

Where $a \le b \le c$, let v_1 is fuzzy set, then the membership of a spherical variogram (μ_{Mg}) in $v_i$is given as:

$$\mu_{v_1} = min\{T(c_0|0.0004,0.0011), T(c_0|0.0017,0.001) \qquad (13)$$

Where $T(a|w_m, w_m, w_m)$.

The ranges used to define triangular membership functions for the nugget effect and partial variance of Mg or (No3) Then μ_c, and μ_c can be defined as:

$$\mu_c = T(x|0.0215,005055)$$

The furzy variogram for soil NO_3 in this field with μ_{N03} Thus the membership is

$$\mu_{NO_3} = min\{\mu_0(a), \mu_0(c_0), \mu_c(c)\} \qquad (14)$$

These variograms are described by exponential, spherical, or Gaussian parameters range, nugget effect, and partial variance

$$\left[\begin{array}{l} a_{(sp)} = 3a(Exp) = \sqrt[2]{3}a(gaussian) \\ c_{(sp)} = c_0(Exp) = c_0(gaussian) \\ c_{(sp)} = 0.95(Exp) = \sqrt[2]{3}a(gaussian) \end{array}\right.$$

The step of defuzzification gave the approach the set of the fuzzy spacing by computing the fuzzy mean value:

$$\frac{\int x\,\mu(x)\ dx}{\int \mu(x)\ dx} \qquad (15)$$

where $\mu(x)$ is the membership of the set fuzzy [5], [18].

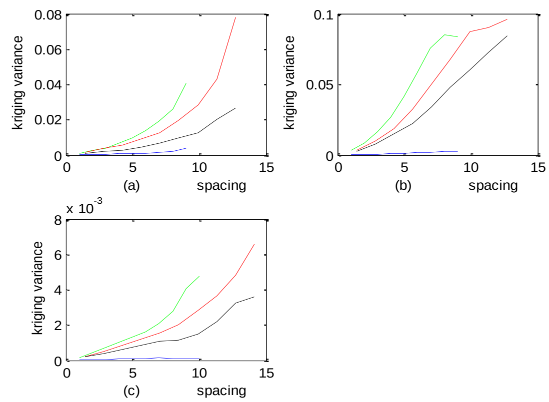

Figure (5): curves of soil data between spacing and kriging variance (a) for Mg data, (b) for Cl Data.

Figure (5) illustrates the curves of soil data (a) for Mg data, (b) for Cl data, and (c) for NO3, showing a plot between the spacing on the x-axis and kriging variance on the y-axis. When we compare the curves of all data we show the similar behavers between the variogram function results with the parameters (nugget effect, sill, and range)

Table (6): results of prediction for (Mg, Cl, and No3).

Soil	Locations of prediction	$\hat{z}(v_0)$for	σ_{ok}^2	MSE	G
Mg	(23.5 , 9.1)	2.15	0.1134	0.133	1.005
	(12 , 10.7)	4.25	0.0224	−0.434	0.901
CL	(11 , 5.7)	6.49	0.056	−0.470	1.012
	(3.6 , 17)	5.68	0.009	−0.100	0.908
No3	(0.9 , 8.9)	4.67	0.103	0.029	0.969
	(5.5, 7.9)	5.50	0.111	0.324	1.102

Table (6) shows a comparison between soil data of Mg, Cl and NO3 of prediction used for six random locations by applying equation (6), compute in these locations to get the accuracy of prediction process. and using kriging variance σ_{ok}^2according equation (9). Most of the values of kriging variance are very small and also we used G measure according to equation (10) and obtained mean square error (MSE) according equation (11). These results in Table (6) proves the accuracy of the kriging technique and, likely, supplies a good prediction. Also, most of the G values are closer to 1 of ordinary kriging technique. In addition, that the weights are equal to one $\sum_{\alpha=1}^{n} \lambda_\alpha = 1$ (condition of unbiased predictor).

Conclusions

Soil data are applied in this work to describe the spatial distribution of several parameters or properties by variogram function beside the fuzzy variogram. The kriging variance could be fuzzification for crisp information and the variance of kriging is very small. A fuzzy variogram was obtained by applying the process models with soil data. The fuzzy variogram function can be made wider, by changing the value we get the organic function of the regionalized variables The results obtained indicate small differences in the prediction. The weights are close to one, we obtained the closest data contains the largest weights, while the further data contains the smallest weights. The variograms are described by exponential, and spherical models. Fuzzy systems appear from applications in soil data is still a developing field through information about soil differences. In addition, the uncertainty they represent by kriging anisotropy. To conclude, the variogram gave the fuzzy specification to derive a fuzzy set of spacing with kriging variance. Fuzzy kriging spacing gave an ideal method for determining sampling composition.

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أداء جودة التوزيع المكاني بواسطة كريكنك الضبابي الاعتيدي لخصائص التربة في ظل عدم اليقين

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تاريخ الاستلام: **تاريخ القبول:**

الملخص

يدرس هذا البحث جودة التوزيع المكاني لطرق الاستكمال المكاني. والهدف من البحث هو اولا الحصول على افضل مقدر خطي غير متحيز بناءً على المتغيرات الإقليمية في مجال الدراسة. استخدمنا تقنيات كريكنك (تسمى الاستكمال المحلي المكاني) بالاعتماد على دالة الفاريوكرام ا لتجريبية مع نظام الاستدلال الضبابي. الهدف الثاني هو تقدير معلماتت نماذج التباين المشترك او التغاير بالاعتماد على البيانات الحقيقية للمواد الكيميائية للتربة والبيانات المعتمدة في هذا البحث مأخوذة من (100) قيمة حقيقية من (Mg ، Cl، No3) . ماخوذة من مدينة الموصل في العراق. بعد تطبيق تقنيات كريكنك مع نظام الاستدلال الضبابي على هذه البيانات نلاحظ من خلال النتائج التي تم التوصل اليها

تقليل تباين التقدير إلى أدنى حد لاختيار افضل مقدر في ظل عدم اليقين. نحصل على أصغر معيار للتحقق من صحة الأخطاء للتباين المشترك مع أفضل النماذج الملائمة مع قيود الأوزان نلاحظ أن أداء طريقة الاستكمال يكون أفضل بالمقارنة مع النظام الضبابي. في الختام ، لا يعتمد التحسين على الأساليب والطرق الإحصائية فقط ، بل يجب استخدام طرق أخرى وبيانات كبيرة لمتغيرات التربة لتحسين عملية التنبؤ. تم تنفيذ جميع الحسابات بلغة ماتلاب

الكلمات المفتاحية: كريكنك، المنطق المضبب، دالة الفاريوكرام، بيانات التربة