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An investigation on microelements' spatial changes in Malekan through Geographic Information System

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ABSTRACT

The main goal in this research was to study the spatial structure and mapping the spatial distribution of Fe, Zn, Mn and Cu soil microelements using geostatistics techniques in GIS. The study area was located at Malekan town, Iran. To do this research, a grid with 1km*1km dimensions was generated and 200 mixed soil samples were taken from the study area. The amounts of Mn, Zn, Cu and Fe soil samples were determined in the soil lab. In order to do geostatistical analyses, semi-variograms were developed and then the most suitable theory model fitted to the experimental semi-variograms. Semi-variograms parameters (Sill, Nugget effect and Range) were used to do ordinary kriging in the GIS environment and the microelements values in the unknown locations were estimated. Mentioned steps above resulted in microelements soil fertility maps (zonation maps). Fe element had moderate spatial structure (Nug/Sill*100=34.83%) and Cu, Mn, and Zn showed stronger spatial structures in the study region. It was realized that there is a reverse relation between effect range of the elements and their coefficient of variation (cv). Generated maps showed that under study region suffers from Fe and Zn microelements deficiency (around 95% and 81% of lands) so that more than 80 percent of the agricultural areas need for Fe and Zn fertilizers. Moreover there was no deficiency for Mn and Zn elements in more than 85% of the region. Researchers are recommended to apply short distance sampling methods in their future studies.

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INTRODUCTION

Spatial variation of soil characteristics is a natural issue; but understanding these variations, particularly in agricultural lands, seems to be inevitable in case of an accurate planning and management to reach a sustainable land utilization as well as profit making improvement. Soil characteristics differ spatially and chronologically from the smallest to the largest scales. They are being affected by intrinsic characteristics (such as factors forming the soil) and extrinsic ones (such as land preparation, fertilization, irrigation and etc.). So, in order to get a proper understanding on the effects of factors such as management and achieving a proper cultivation method, it will be profitable to identify and quantify variability of soil characteristics [1]. Considering population growth and increased need for foods and nutrients, it is important to preserve the natural resources to make permanent and accurate use of them. It also seems to be important to conduct different research projects in order to find a suitable solution to preserve the soil.

In order to produce agricultural crops, soil fertility receives much attention in soil analysis process. Soil fertility refers to the amount of nutrients available to the plant inside the soil. Plants need different nutrients to grow efficiently, some of which are microelements as Fe, Mn, Zn and Cu. Regular soil sampling, investigating spatial variability of elements and fertility mapping play an important role in managing soil fertility [2].

The main aim of this research is to study the spatial variability of microelements such as Fe, Mn, Zn and Cu and to make zonation maps of Malekan lands as a part of Uromia Lake district according to geostatistics and GIS techniques. Geostatistics is able to provide a wide variety of statistical estimators to evaluate a particular characteristic in the unselected areas through the data collected from the selected sample areas [3].

Compared to classic statistics, geostatistics not only analyses the amount and spatial location of the element under study, but also provides the condition to calculate the estimation error. In geostatistics, first we

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are trying to focus on existence or lack of spatial structures (relationship between the amount of elements and direction of the soil samples) and then to analyze data if such a structure exists. In other words, procedure is divided into two parts: first, figuring and modeling spatial structure through variograms and then as per the characteristics of the fitted variograms model at the first step, Kirging method is applied to estimate the amount of the elements at unknown areas. Kirging is an estimation method (interpolation) which is based on weighted moving average logic. One of the most important characteristics of Kirging is to consider the spatial structures of the areas in the estimation process and to calculate the error corresponding to each and every estimation. This function is not possible in the other classic estimation methods (IDW) [3].

Utilizing geostatistical techniques such as Variography and Kirging in GIS environment provides the opportunity to achieve useful information and fertility maps through estimation data and at the same time to use GIS possibilities and functions to better management of soil fertility.

X.M.Liu et al [4] with the aim of investigating variability of microelements such as Fe, Zn, Cu and Mn selected a 541km area to do sampling, after analyzing 134 samples of paddy soil they could finally identify variability characteristics of 4 mentioned elements through geostatistics and GIS. According to this research, exponential model is used to fit a model to experimental variograms of Zn and Mn elements and the effect range of these elements are calculated to be 4.4 and 2.97 respectively.

Experimental variogram of Fe is also fitted through linear model, having effect range of 23.48km. Regarding Cu, there did not exist any spatial dependency and Nugget is dominant in this case. They concluded that spatial distributions of these four elements have got a significant relationship with soil structure and human activities.

X.Guo et al [5] tries to study the spatial structure of some elements such as Ozette, K (Potassium), P (phosphorus) and organic substances of the soil. Through application of geostatistical techniques and GI, they concluded that experimental semivariograms of all elements except K (Potassium) can be fitted by spherical model. In this research paper, semivariogram of K (Potassium) is fitted through Sill Linear and Exponential models. Effect ranges of K (Potassium) and Ozette also are calculated to be the same.

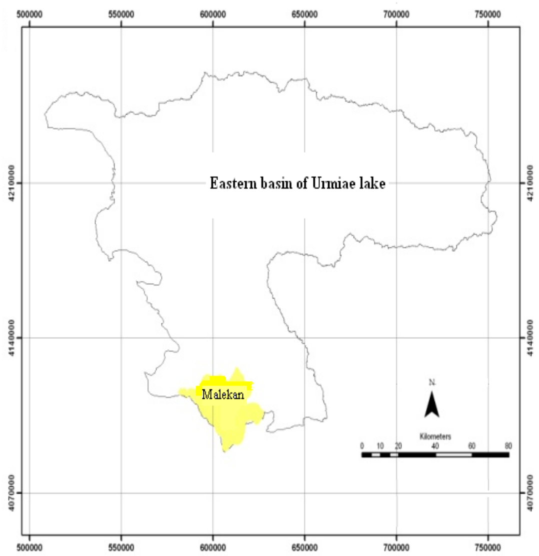

Fig. 1: Eastern part of the Uremia Lake and the study region

METHODS AND MATERIALS

Region under study:

Malekan town, as a part of eastern district of Uromia Lake, is located at the southwest of East Azerbaijan. It's limited to Bonab and Maragheh from north and east sides. From south and west also it is neighboring West Azerbaijan province (figure1). Malekan is about 840 Km2, covering 1.8% of the total land of the province. Its altitude ranges from 1290m in western parts to 2000m in northeastern parts. It is mostly covered with lands lower than 1700m high. Average annual rain fall of the area is 360mm and temperature also ranges from $8.7^{o}C$ to $12.5^{o}C$. Total cultivated area is equal to 49665 acres covering farmed crops such as wheat, provender grass, barley and gardened products such as apple and grapes. Soil texture of the region is Clay Loam and Loam having around 2 to 16 DS (Deci Siemens) electrical transfer. Presently, some areas of the district are exposed to salinity and the issue aggravates with the withdrawal of the Uromia Lake and decreased water level in the wells of the area during the last few years. Ph. saturation extract of the soil is 7.7 to 8.9. High alkaline nature of major parts of the area has led the absorption and availability of the nutrient microelements to be seriously problematic [6].

Research data collection:

In order to do this research work, Malekan region is selected as a grid with 1500*1500m2 dimensions, then the geographical coordinates of relevant points in the form of UTM were transferred into a handhold GPS to navigate the accurate location of each sample point.

After traveling to the region, researcher tried to take samples from 0-30cm deep under the ground. Soil samples are transferred to laboratory and after preparation, the amount of microelements such as Zn, Fe, Mn and Cu were analyzed and calculated through Atomic Absorption Spectrophotometer (AAS). Laboratory results along with the coordinates of sample region (UTM) were stored as fields and records in a computer file for later processing operations.

Statistical investigation of research data:

Since normal distribution of studied elements are the main condition to use Kriging estimator, so non-parametric Kolmogorov-Smirnov (K-S) test was applied to test normal distribution nature of data. Some other descriptive parameters for each element including mean, standard deviation, least and highest ranges, kurtosis coefficient, skewness and correlation of variation (cv) are calculated as the primary survey of data. This stage of the study is done through SPSS software.

Geostatistical investigation of the research data:

Geostatistics can be used to estimate the amount of soil elements in the unknown areas and to make zonation maps [5]. In this stage, spatial structure of microelements is studied through geostatistical analyses. For this purpose, first experimental semivariograms of each microelement is prepared and then structural characteristics and their variations are studied to secure required reasons to apply geostatistical techniques such as Kriging. In fact, semivariograms is equal to half the mean square of samples difference locating around "h" distance from each other as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x+h) \quad Z(x)]$$

In this equation, N(h) refers to the number of sample pairs, Z is amount of the element and x stands for geographical location of samples. Data collected through semivariogram serve as input values for kriging method to estimate the amount of the elements in unknown areas. But, before the application of experimental semivariograms in the estimation process, it is absolutely required to fit them the most suitable theoretical model. So, second part of this stage tries to investigate suitable models for fitting purposes. Different theoretical models, such as linear, spherical, exponential and Gaussian models are investigated in this research paper. $\frac{Nugget}{Sill} \times 100$ Measure is used to figure the rigidity and durability of spatial structure. After selecting suitable theoretical models for fitting experimental semivariograms of elements, semivariograms parameters of elements such as Range, Nugget and Sill are identified. Later, above mentioned parameters are used in ordinary Kriging to calculate relative weight of known data to estimate unknown point as per their location. Through this method, all the elements data in unknown points are calculated.

Finally, after estimating areas with no sample and evaluating results through maps and error indices, fertility maps are secured in GIS environment and required recommendations are made as per resulted geometrical and descriptive information (map and table) to be followed at fertility management.

RESULTS AND DISCUSSIONS

Descriptive statistics: CV (coefficient of variation) is one of the most significant indices used to investigate the variability relative intensity of variables. As it is shown in table 1, CV of the elements studied in the research is not having a significant fluctuation, least and the most fluctuation belongs to Zn and Fe respectively. As per non-parametric K-S test (figure 2), it is identified that microelements distribution is not normal. It is also required to make them normal before processing them. In the present research paper, some normalization functions are tested and finally research data logarithms are presented to be processed.

Table 1: Amount of descriptive parameters for studied microelements

Elements	CV	Kurtosis	Skewness	SD	Mean	Median	Mode	Range
Cu	42.6	-.123	.764	.61474	1.4428	1.29	0.82	2.88
Fe	39.06	-.081	.778	1.62668	4.1638	3.81	2.36	7.78
Mn	40.95	.088	.820	2.95710	7.2208	6.54	4.98	14.94
Zn	50.38	5.871	2.080	.25271	.5016	0.42	0.36	1.56
Cu logarithm	155.5	-.174	-.154	.18687	.1202	0.11	-0.09	.98
Fe logarithm	28.55	-.732	.083	.16659	.5877	0.58	0.5	.81
Mn logarithm	22.96	6.400	-1.056	.18863	.8215	0.815	0.8	1.54
Zn logarithm	53.7	.324	.647	.18347	-.3417	-0.38	-0.44	.99

Table 2: Results of K-S test for studied microelements

Elements	Asymp. Sig. (2-tailed)	Kolmogorov-Smirnov Z
Cu	.013	1.583
Fe	.022	1.502
Mn	.002	1.873
Zn	000	2.463
Cu logarithm	.812	.637
Fe logarithm	.522	.813
Mn logarithm	.588	.773
Zn logarithm	.075	1.281

Geostatistical analysis:

In the present research paper, at the first step spatial structures of collected data were investigated through semivariogram and then related parameters were identified. Figures 2, 3, 4 and 5 show experimental semivariograms along with fitted models for each scarce studied elements. Table 3 also shows calculated semivariogram parameters of each element.

Table 3: Calculated semivariogram parameters of studied microelements

Elements	Sill Partial	Sill	Nugget	Range	100*
Cu	0.14635	0.18895	0.0426	3226.4	22.55
Fe	0.096476	0.147976	0.0515	6600.5	34.83
Mn	0.17749	0.19499	0.0175	4971.4	8.98
Zn	0.166	0.1834	0.0174	2598.4	9.49

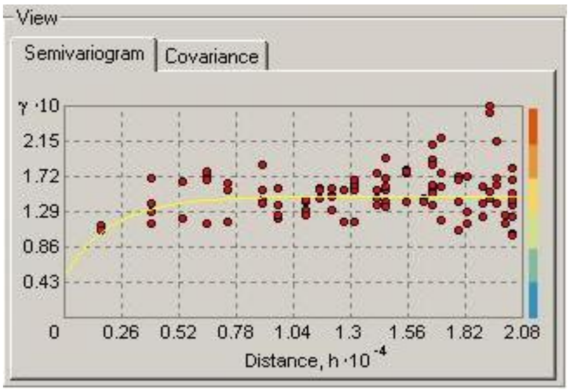

Fig. 2: Semivariogram of Fe (distance in meter)

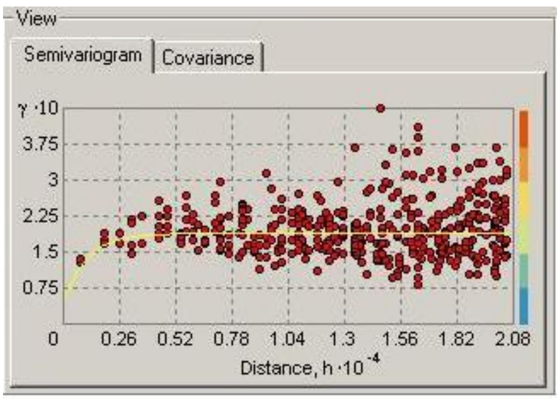

Fig. 3: Semivariogram of Cu (distance in meter)

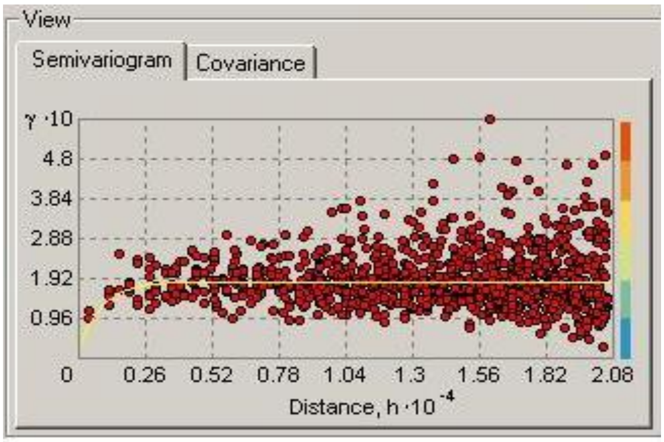

Fig. 4: Semivariogram of Zn (distance in meter)

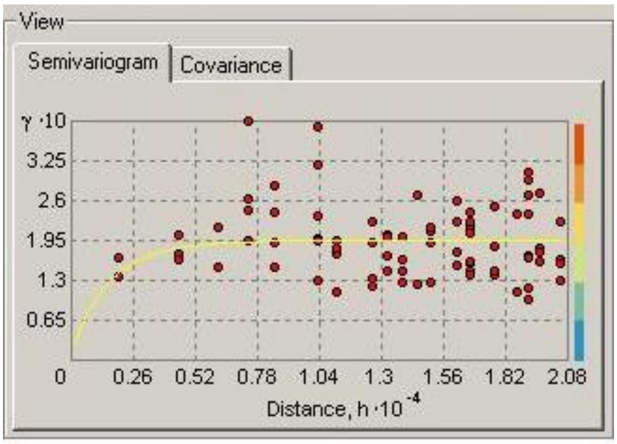

Fig. 5: Semivariogram of Mn (distance in meter)

As per obtained results, among all study elements, Fe and Zn with 6.6 and 2.59 km respectively have got the most and the least effect range. Calculated Fe effect range can signify the fact that its spatial structure is much wider than other studied elements and this characteristic can lead to a wide selection of known measures to estimate unknown areas with more accuracy in estimation process. In designing sampling network it is also possible to increase effect range of sampling distances. In this research work effect range of microelements were as Fe>Mn>Cu>Zn. Moreover, it is observed that elements with high effect range are having the least CV (correlation of variability) and vice versa. Correlation of variability for studied elements were as Fe<Mn<Cu<Zn. So, parameters obtained through Variography such as Range, Nugget and Sill were used as inputs for Kriging method to estimate microelements' amount in unknown areas, and it got possible to make zonation map for these elements. Figures 6 to 9 show maps created through kriging method. Since, elements' mean value was not known; ordinary kriging method was used to estimate the measures and to prepare required maps. In order to evaluate estimation error, first error evaluation indices such as Mean Standardized, Root Mean Square Standardized, Root Mean Square and Average Standard Error were calculated and then error map for each and every element were taken into account to assess the accuracy of zonation maps. Figures 10 to 13 show error maps of study elements.

Table 5: percentage of areas with less, sufficient and extra microelements

Elements condition	Zn ppm	Mn ppm	Fe ppm	Cu ppm
Shortage	95.23175	10.49477	81.06821	6.075982
Sufficiency	4.768247	85.52169	18.93179	87.5457
Extra	-	3.983539	-	6.378316
Total	%100	%100	%100	%100

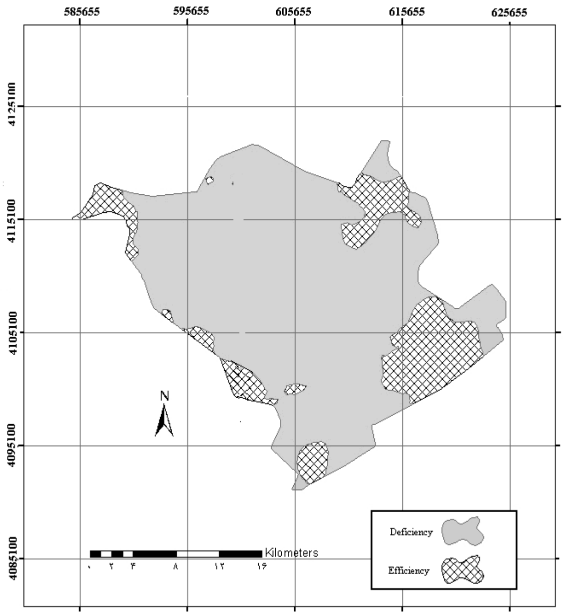

Fig. 6: zonation map for Fe

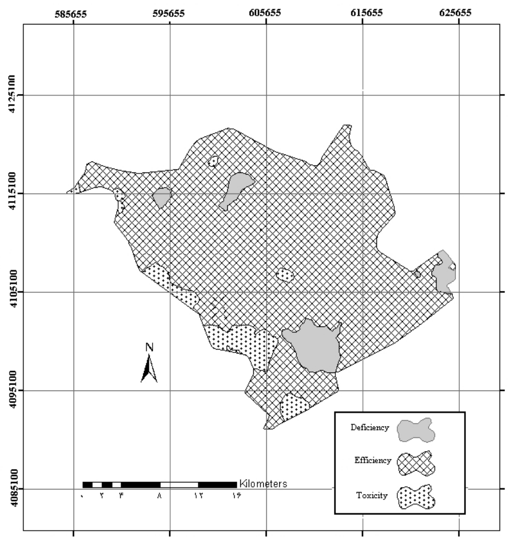

Fig. 7: zonation map for Cu

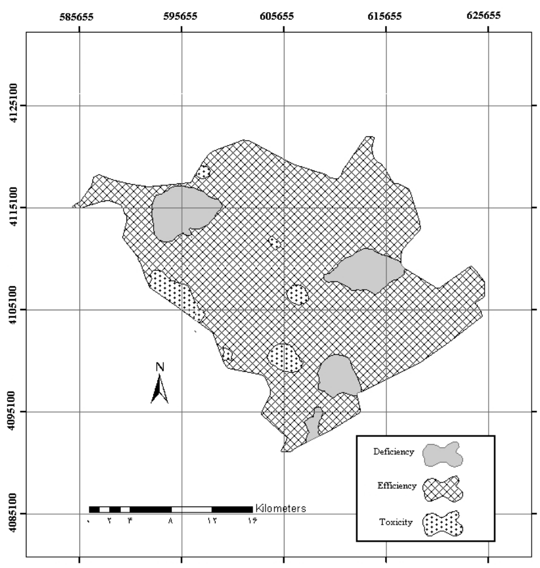

Fig. 8: zonation map for Zn

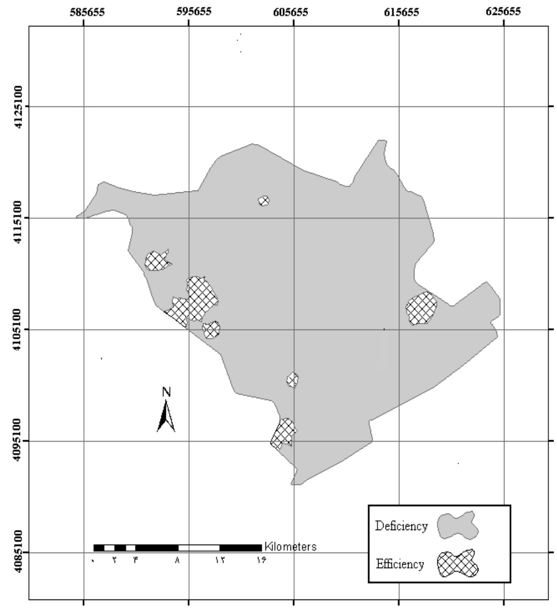

Fig. 9: zonation map for Mn

Investigating zonation maps signifies the fact that among all study microelements, Zn and Fe are ranked as first and second having highest shortages in the study area with 95% and 81% of lands respectively. Farm studies and observations beside crops' reactions to fertilizers having these two elements prove this fact as well. Mn and Cu also have got a suitable amount in the soil of study area. So, in order to improve crops' efficiency, it is highly recommended to distribute the Zn and Fe elements in the study areas. Investigating accuracy of zonation maps on the basis of error maps showed that estimated error in cases of Fe, Mn and Zn were negligible, having no effect on outcomes and amounts of recommended fertilizer in study area. In case of Cu, investigating zonation and error maps show that estimation error in some southern and southwestern parts of the area, which were classified as areas having more Cu, was considerable. In order to make an accurate zonation map for Cu, different models were fitted and other methods such as Spline, IDW and RBF were applied but finally Kriging methods has been identified as the most suitable one.

Conclusion:

Geostatistics along with GIS can be used as a powerful tool to identify polluted soils or soils having shortage of nutritional microelements. Some of the advantages of using such a tool in a consistent environment are convenient, accurate and quick processing. As per Kolmogorov-Smirnov (K-S) test, it is observed that microelements distribution was not normal, so logarithm conversion was used to normalize data. Investigating CV of microelements resulted in a trivial difference between their coefficients, while Zn and Fe are having 50.38% and 39.06% respectively as the most and the least ones. The CV order of the study elements were as Fe<Mn<Cu<Zn. Investigating elements' variography showed application of geostatistics to be advantageous in studying variability and making microelements' fertility map.

$\frac{Nugget}{Sill} \times 100$ measure was used to figure the rigidity and durability of spatial structure and finally it was concluded that Fe is having medium spatial structure and Zn, Cu and Mn are having stronger spatial structure. In fitting theory model to experimental semivariogram of elements, we get to that exponential model is the most suitable one. Studying effect range elements showed that Zn with 2.59Km and Fe with 6.6Km are having the least and the most effect range.

It was also observed that elements with high CV have lesser effect range. Investigating error maps of elements showed that zonation map for Cu was less accurate and it is required to do more exact researches in this regard (distance between sampling spots will decrease). With regard to less consumed elements in the soil of Malekan area, zonation maps showed that among all study elements, Zn and Fe were having the highest shortage (around 95% and 81%). Other elements were not considered to be insufficient though.

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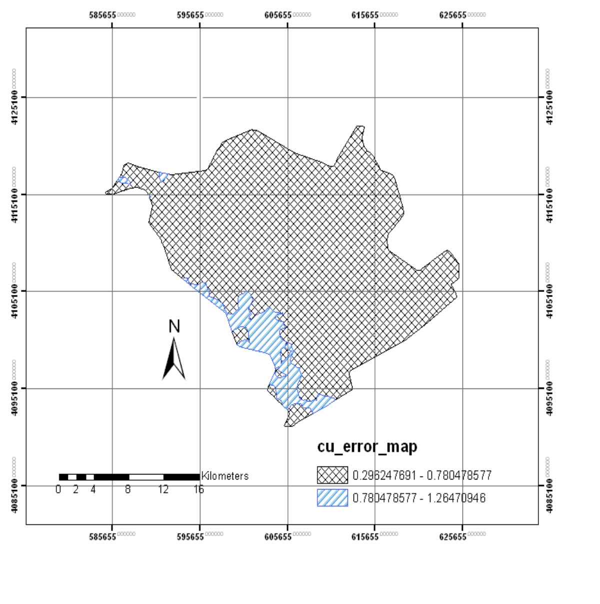

Fig. 10: error map for Cu

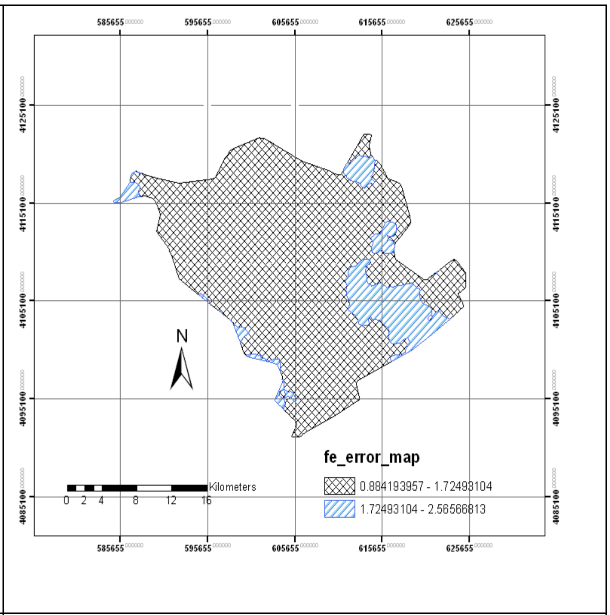

Fig. 11: error map for Fe

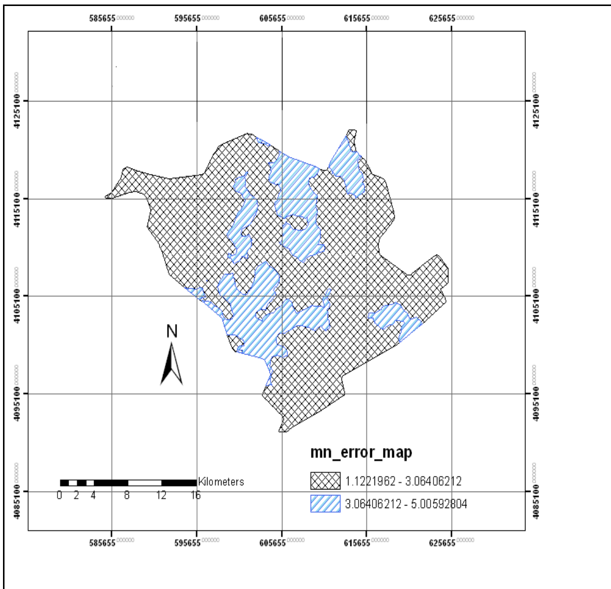

Fig. 11: error map for Mn

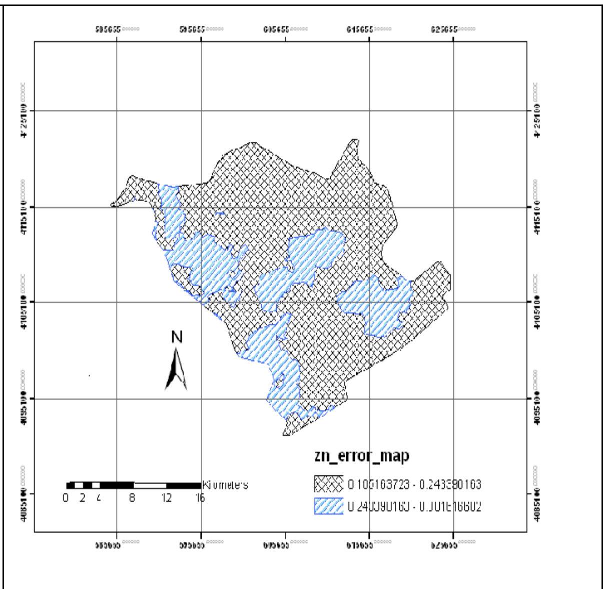

Fig. 11: error map for Zn

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