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Spatial Variability of Soil Cadmium Content and Delineation of its Risky Zones in a Field in Bahr El-Baqar Region

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ABSTRACT

Soil pollution with heavy metals is a great concern as this considerably affects plant both quantity and quality and consequently animal and human health. Detection of the spatial distribution of heavy metals provides good source of information for appropriate soil remediation procedures. Geostatistics and its different interpolators are of great importance for revealing the spatial distribution of any soil variable. The aim of this work is to delineate the spatial distribution of cadmium content insoil irrigated with polluted drainage water of Bahr El-Baqardrain. A total of 100 soil samples were collected over a field of 4.6 ha located in Bahr El-Baqar area, Sharkia Governorate, Egypt. Ordinary kriging was applied as an interpolator for cadmium content interpolation. Prediction assessment was performed using cross-validation calculating two different statistics; mean error (ME) and mean squared standardized error (MSSE). Results showed that the model is unbiased and accurate since ME and MSSE values were of -0.004 and 1.17 respectively. Three management zones were obtained based on cadmium content named as zone 1, zone 2 and zone 3and their range values were0.500 – 1.140, 1.141 – 1.676 and 1.677 – 2.125, respectively. The delineated zones indicate that the field has different multiplicative degrees of cadmium pollution regarding agricultural land use. It is recommendedthat such polluted soils must be appropriately remediatedbefore agricultural land use. It is also recommended that the irrigation water source that comes from Bahr El-Baqardrain should be substituted with a good unpolluted irrigation source.

Keywords: Spatial variability, management zones, soil heavy metals, kriging

INTRODUCTION

Soil contamination in the region of Bahr El-Baqar is a result of the utilization of polluted water that comes from Bahr El-Baqar drain in irrigating that soils. Bahr El-Baqar drain water contains different pollutants of heavy metals such as lead, cadmium, nickel, and mercury (Park and Shin, 2006). Bahr El-Baqar drain collects untreated wastewater from two main drains, the first is Belbeis drain and the second is Qalubiya drain (Taha *et al*., 2004). The main sources of the gathered wastewater are industrial activities, agricultural and municipal wastewater. The concentration of heavy metals in Bahr El-Baqar water drain followed the order: Fe> Zn>Mn> Cu>Pb> Ni> Cd (El-Eweddy, 2000). Heavy metals content measured in the soils of Bahr EL-Baqar region decreases as follows: Cd > Cu> Zn > Cr> Ni> Pb (Omran and Abd El Razek, 2012). Cadmium is considered as one of the most hazardous pollutants as this negatively affects agricultural soil even at low concentration (Onweremadu and Duruigbo, 2007; Yobouet *et al*., 2010). Kidney disease is the main effect of cadmium on human health. However pulmonary, cardiovascular, and musculoskeletal systems were reported among the adverse effects of cadmium(Robertsa, 2014). The spatial distribution of soil heavy metals is essential to assess their risk in order to establish a decision-making framework for land use and management.

The detection of spatial distribution of soil parameters is essential for identifying the management zones (Shaddad *et al*., 2016) and it allows to give a decision whether to exploit soil in agriculture or in residential use. This can be achieved using spatial model systemof geostatistics which enable the users to guesstimate soil variables at un-sampled locations. The estimation is then non-destructive, time saving and provides fine-scale information as compared with the traditional methods of laboratory soil analysis. The delineated management zones can be used in different aspects in soil sciences such as soil remediation, soil reclamation, and soil fertility management etc (Shaddad and Hendawi, 2018). One of the most unbiased geostatistical estimators is ordinary kriging, it is called "best linear unbiased estimator" (BLUE) (Castrignano, 2011). Therefore, ordinary kriging was the most common used to predict and map soil parameters at un-visited locations (Lopez-Granados *et al*., 2015; Meul and Van Meirvenne, 2003; Sumfleth and Duttmann, 2008).

The aim of this work is to delineate and identify the critical polluted spotsof the investigated areaby classifying it into different zones based on the risk of cadmium content and to give a resolution approach for soil management and irrigation water sources.

MATERIALS AND METHODS

Site description and sampling

This study was conducted on an approximate area of4.6 ha field located in Bahr El-Baqar region, Sharkia Governorate, Egypt (30° 51' 53.31'' N, 32° 02' 50.45'' E). The study area has been cultivated for about ten consecutive years and has been directly irrigated with contaminated water from Bahr El-Baqar drain without any pretreatment. A total of 100 soil samples (Fig.1) based on a quite regular grid 25m x 25m at 0.20 m depth were collected and transported to the soil laboratory for analysis.

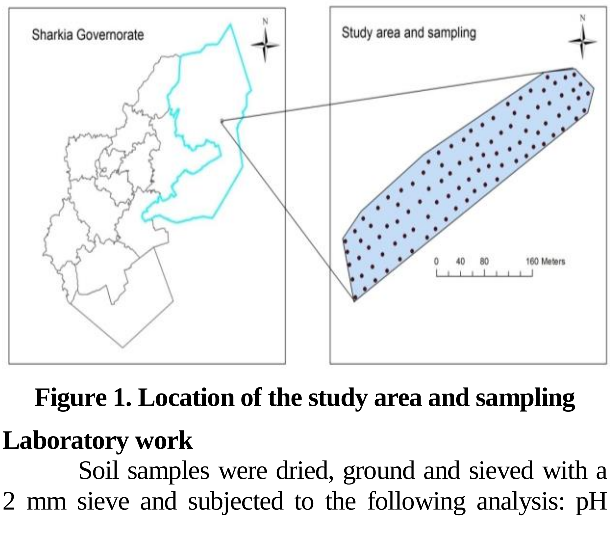

Figure 1. Location of the study area and sampling

Laboratory work

Soil samples were dried, ground and sieved with a 2 mm sieve and subjected to the following analysis: pH was measured using a glass electrode in 1:2.5 soil water suspension, soil texture fractions (sand, silt and clay) were determined according to the international pipette method (Piper, 1950). Cadmium, zinc and copper contents were extracted by shaking a 1:5 ratio of air-dried soil to 1M nitric acid solution for two hours according to Mielke *et al.* (1983). The extracts were filtered, and the final extractions were analyzed using atomic absorption spectrometer (AA analyst Perkin Elmer Instruments), (Shelton, Connecticut, USA).

The soil texture down to 0.20 m includes two textures of light clay and heavy clay according to the Moeys (2016) as shown in table 1 for 30 soil samples distributed over the field.

Table1. Soil texture classes over the field

Soil Texture class	Number of samples	Sand (200 – 20 µm) range (%)	Silt (20 – 2µm) range (%)	Clay (<2µm) range (%)
Heavy clay	14	42.76 – 21.12	24.82 – 7.09	59.72 – 45.29
Light clay	16	54.34 – 45.74	13.63 – 6.03	44.90 – 39.06

Geostatistical analysis

The spatial map of cadmium was developed using ordinary kriging and was classified into three geometric intervals named as (zone 1, zone 2, zone 3). Before map interpolation, an exploratory data analysis was performed to verify the normality of the studied soil variable by calculating the skewness.

Prediction assessment

Prediction performance was assessed using cross validation (Isaaks and Srivastava, 1989), whereby one observation (z) at a time is temporally detached from the data set and re-estimated (z*) from the remaining data. Two statistics were calculated to assess the precision and accuracy of estimation. These are: mean error (ME), as an indicator of bias, and mean standardized squared error (MSSE) (scaled by the predicted standard deviation of estimation), as a measure of accuracy:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(z_i - z^*)$$

$$MSSE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{z_i - z^*}{\sigma}\right)^2$$

Where N is the number of active observations and σ the kriging standard deviation.

The first statistic should be close to zero indicating that the estimation is unbiased,whereas the second one should be close to one indicating that the estimation is accurate because it corresponds to the ratio between an experimental variance and a theoretical one (Carroll and Cressie 1996).

Delineation of risky zones

Delineation of risky zone was performed based on the threshold limit values provided by New York State Department of Environmental Conservation (NYS DEC). NYS DEC are defined for removing human health risks.The unrestricted use involves agricultural use (Table2).

Table 2. Levels of soil heavy metal content in soil used to guide cleanup and land use decisions ($mg.kg^{-1}$)

Heavy metal ($mg.kg^{-1}$)	NYS DEC	
	Unrestricted use	Residential use
Cadmium	0.43	0.86
Nickle	72	140
Copper	270	270

Area and average value for each zone were calculated using the tools available in ArcGIS software 10.1 (USA).

RESULTS AND DISCUSSION

Descriptive data analysis

Cadmium content was selected for geostatistical analysis because it was the only variable out of soil heavy metals that exceeds the threshold limit value. Descriptive statistics of cadmium content and pH (Table 3) show that the two variables are approximately symmetric since the skewness valuesare -0.344 and -0.377 respectively. Hence, the data set can be used directly for geostatistical analysis without transformation.

Table 3. Descriptive statistics of Soil pH and heavy metals

Variable	Count	Min	Max	Mean	STD	Skewness	Kurtosis
pH	100	7.62	8.35	8.04	0.155	-0.377	0.065
Cd^{2+}	100	0.500	2.125	1.31	0.491	-0.344	-1.446
Ni^{2+}	100	15.5	37.25	22.65	5.060	1.382	1.024
Cu^{2+}	100	12.75	38.00	20.69	6.029	0.568	-0.799

For Cd content, a stable variogram model was fitted to the experimental variogram with nugget effect of 0.011, partial sill of 0.288 and range of 262 m (Table 4 and Fig. 2).A spherical model was fitted to the experimental variogram of pH with nugget effect of 0.009, partial sill of 0.0.013 and range of 59.63 m (Table 4 and Fig. 3)

Table 4. Variogram model parameters

Variable	Model	Nugget effect	Partial sill	Range (m)
Cd	Stable	0.011	0.288	262
pH	Spherical	0.009	0.013	59.63

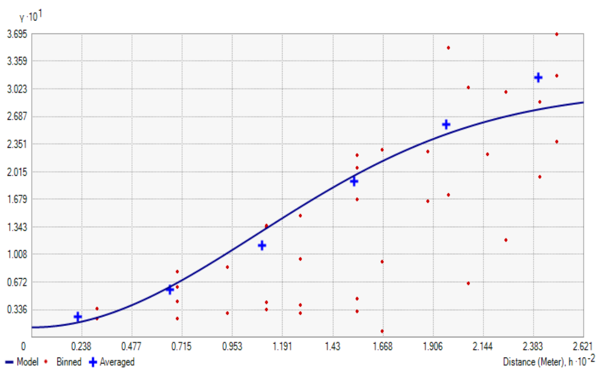

Figure 2. Variogram model for Cd

Table 5 shows the cross-validation results with ME value of -0.004 which is close to zero which indicates that the model is unbiased. The MSSE value is 1.17. Although the MSSE values were somewhat far from 1 but still within the tolerance interval (0.575 – 1.425) ($1\pm3\sqrt{2/N}$, N is number of observations) (Chiles and Delfiner, 1999), which means that the model is accurate.

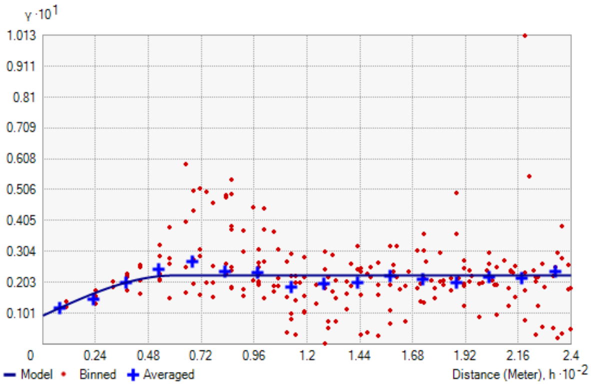

Figure 3. Variogram model for pH

Table 5. Cross-validation results

Variable	Count	ME	MSSE	Tolerance interval
Cd^{2+}(mg.kg^{-1})	100	-0.004	1.17	0.575 – 1.425
pH	100	0.003	0.945	0.575 – 1.425

Three different zones based on cadmium content were delineated named as zone 1, zone 2 and zone 3 (table 6). Cadmium content in the three zones indicates that the whole field is considered as a polluted soil for agricultural use.The risk of zone 3 is two times more compared with zone 2 and three times more compared with zone 1 since the threshold limit values for cadmium is 0.43 mg.kg^{-1}. The spatial map of cadmium content (Fig.4) shows that the area with low values of Cd content (zone 1) was found in the north-eastern part of the field which may be ascribed to the nearness of that area to the water source (drainage water) which indicate a higher infiltration rate (0.21 cm/h) compared with zone 2 and zone 3 with infiltration rate of 0.15 cm/h and 0.13 cm/h respectively. Therefore, the nearer the area to water source the lesser the soil cadmium content even the whole field is considered as polluted soil but with different degrees of Cd pollution. Also, there were two different crops cultivated at the sampling time, berseem (*Trifoliumalexandrinum*) was grown in the north-eastern partof the study area and wheat (*Triticumaestivum*) was grown in the rest of the same study area. Berseemwith ahigh biomass crop might be the reason of decreasing soil Cd content in zone1 of the study area as this plant can bioaccumulate soil heavy metals in its tissue more than wheat (Bhatti *et al.* 2016). Precautions should be considered when this plant used for animal as a fodder. It is also important to mention that the area cultivated with wheat being subjected to phosphate fertilizers as a pre-dose -during plowing stage – which contain elevated levels of cadmium and this might be the reason of the high content of cadmium in zones 2 and 3.The fact that the study area being irrigated for about ten years by the drainage water is a great hazard that should be taken into consideration. This means that using the drainage water for irrigation over time would accumulate more cadmium in soil and plants and then the problem will be highly complicated on the long run.

Table 6. Delineation of risky zones

Variable	Zone 1	Zone 2	Zone 3
Cd range (mg.kg^{-1})	0.500 – 1.140	1.141 – 1.676	1.677 – 2.125

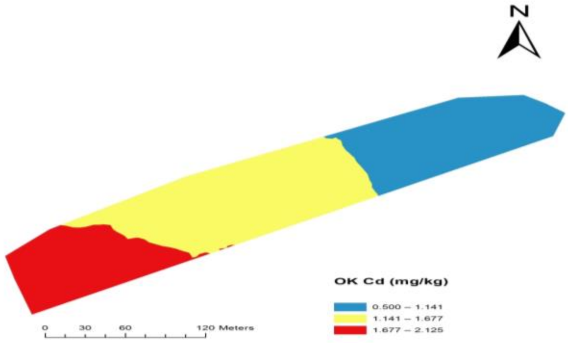

Figure 4. Kriged spatial map of cadmium

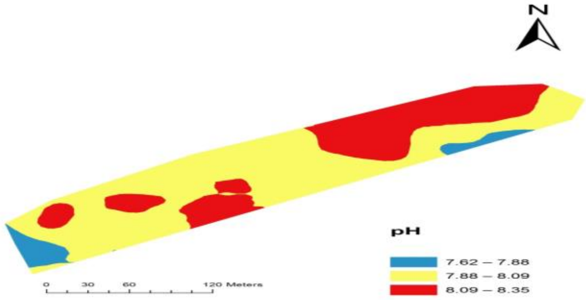

Figure 5. Kriged spatial map of pH

CONCLUSION

Bahr El-Baqar drain is the main source of irrigation water for soils located at the end of irrigation canals of the neighboring areas where fresh water is insufficient for irrigation. This drain contains various heavy metal pollutants which affect greatly the soil health due to the accumulation of heavy metals in soil. In this work, the spatial variability of cadmium content was investigated as well as the delineation of risky zones based on a threshold limit value. The results showed that the studied area should not be used for agricultural purposes as this negatively affects human and animals' health. However, one would suggest to remediate such soils by planting certain species of plants that could absorb soil pollutants and then used for agriculture when irrigated with another source of irrigation water.

Irrigation water quality assessment systems should be reviewed in relation to the quality of agriculture, and the conditions and type of soil in each area so that all available water sources can be exploited to the fullest extent.

The toxicity concentrations of each heavy metal in irrigation water should be based on the water use period in irrigation, where the permitted concentrations are greater in the case of short-term use compared to the long-term permissible limits.

Appropriate remediation methods for this water before use in irrigation should be applied. Growers should keep continuous monitoring for concentrations of heavy metals, whether in water, soil or plant.

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التباين المكاني وتحديد مناطق خطورة التلوث بالكادميوم في حقل بمنطقة بحر البقر

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يعتبر تلوث التربة بالعناصر الثقيلة من المشكلات الثقيلة من المشكلات الكبرى حيث يؤثر ذلك على جودة النباتات وبالتالي يؤثر على صحة الحيوان والانسان. كما ان معاملة التربة اعتمادا على المتوسط العام للعينات أصبحأمرا غير موصى به عالميا. لذا فمن الضروري دراسة التباين المكاني للعناصر الملوثة بهدف تحديد المناطق التي تحتاج الى معالجة من عدمه وكذلك اتخاذ قرار باستخدام او عدم استخدام الارض في الزراعة. تقدم طرق الجيواحصاء وسيلة مهمة لكشف التباين المكاني لصفات التربة المختلفة. يهدف هذا العمل الى دراسة التباين المكاني لمحتوى التربة من الكادميوم ثم تقسيم المنطقة المدروسة الى مناطق خدمة مختلفة يحدد على اساسها كيفية معاملة التربة. تم اخذ 100 عينة تربة من حقل يبلغ مساحته 4.6 هكتار يقع في منطقة بحر البقر بمحافظة الشرقية وتم تقدير محتوى التربة من الكادميوم. تم انتاج خرائط التباين المكاني للكادميوم باستخدام الكرجنج العادي. تم تقييم نتائج التنبؤ المكاني بحساب مؤشرين هما متوسط الخطأ كمقياس للانحياز، متوسط مربع الخطأ القياسي كمقياس للواقعية. أظهرت النتائج ان متوسط الخطأ كان - 0.004 بينما متوسط مربع الخطأ القياسي كان 1.17. تم تقسيم المنطقة الى ثلاثة مناطق سميت بمنطقة 1، منطقة 2 و منطقة 3 وكان مدى قيم الكادميوم بها 0.500 – 1.140، 1.141 – 1.676، 1.677 – 2.125 في اشارة الى احتواء المنطقة المدروسة على ثلاث درجات متضاعفة في شدتها من حيث التلوث بالكادميوم اعتمادا على الحد المسموح به للاستخدام الزراعي (0.43 جزء في المليون). توصي هذه الدراسة بمعالجة المناطق المختلفة قبل استخدامها في الزراعة كل على حسب حاجته والبحث عن مصدر آمن لمياه الري الغير ملوثة بمياه الصرف الصحي. يجب مراجعة أنظمة تقييم جودة مياه الري فيما يتعلق بنوعية الزراعة ، وظروف التربة ونوعها في كل منطقة بحيث يمكن استغلال جميع مصادر المياه المتاحة إلى أقصى حد. يجب أن تستند تركيزات السمية لكل معدن ثقيل في مياه الري إلى فترة استخدام المياه في الري ، حيث تكون التركيزات المسموح بها أكبر في حالة الاستخدام قصير الأجل مقارنة بالحدود المسموح بها على المدى الطويل. استخدم طرق العلاج المناسبة لهذا الماء قبل استخدامه في الري. يجب على المزارعين متابعة المراقبة المستمرة لتركيزات المعادن الثقيلة ، سواء في الماء أو التربة أو النبات.