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GIS Appraisal of Cadmium and Lead in the Western Area of Nile Delta, Egypt

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THE INVESTIGATED area covers approximately 400,000 feddan, western area of Nile delta, and almost irrigated by fresh water of Nile River. Occasionally, due to shortage of fresh water in some periods, farmers use to irrigate their land with mixed water (low quality) from fresh water canals and drainage water (agricultural, domestic, industrial water a effluents). Also, the deposition of polluted air emitted from industries and vehicles, in this area, is also another source of soil pollution by Cd and Pb. The objective of this investigation was to study the distribution of DTPA-Cd and Pb in soil and their spatial variation in this area.

The amounts of DTPA extractable Cd varied from 0.05 to 3.90 mg/kg and those of Pb varied from 0.12 to 12.40 mg/kg. These values are much grater than the background levels reported in the literature. These data indicated that most soils in this area heavily polluted by Cd and Pb.

The topographic analysis of the contour lines and spot heights produced a Digital Elevation Model (DEM) for the studied area. Elevation values ranged between 3 below sea level to about 40 meter above sea level. The DTPA-extractable Cd data were best fitted spherical model while DTPA- extractable Pb data were best fitted Gaussian model. The range showed that maximum interpolation of the concentration of Cd and Pb were 6766-72805 m. The nugget variance of concentration of Cd and Pb were 0.17-8.83 m. DTPA-Cd and DTPA-Pb represented high spatial dependence. The Ordinary Kriging maps showed the spatial distribution and interpolation of concentrations of DTPA-Cd and DTPA-Pb. These maps, for concentrations of these parameters, showed significant increase with space and time in the soils closer to the sources of contamination and significant decrease with distance from these sources.

Keywords: GIS. Cadmium, Lead, Spatial Modeling, Kriging, Surface Interpolation, Geostatistics, Soil Pollution, Western Nile Delta.

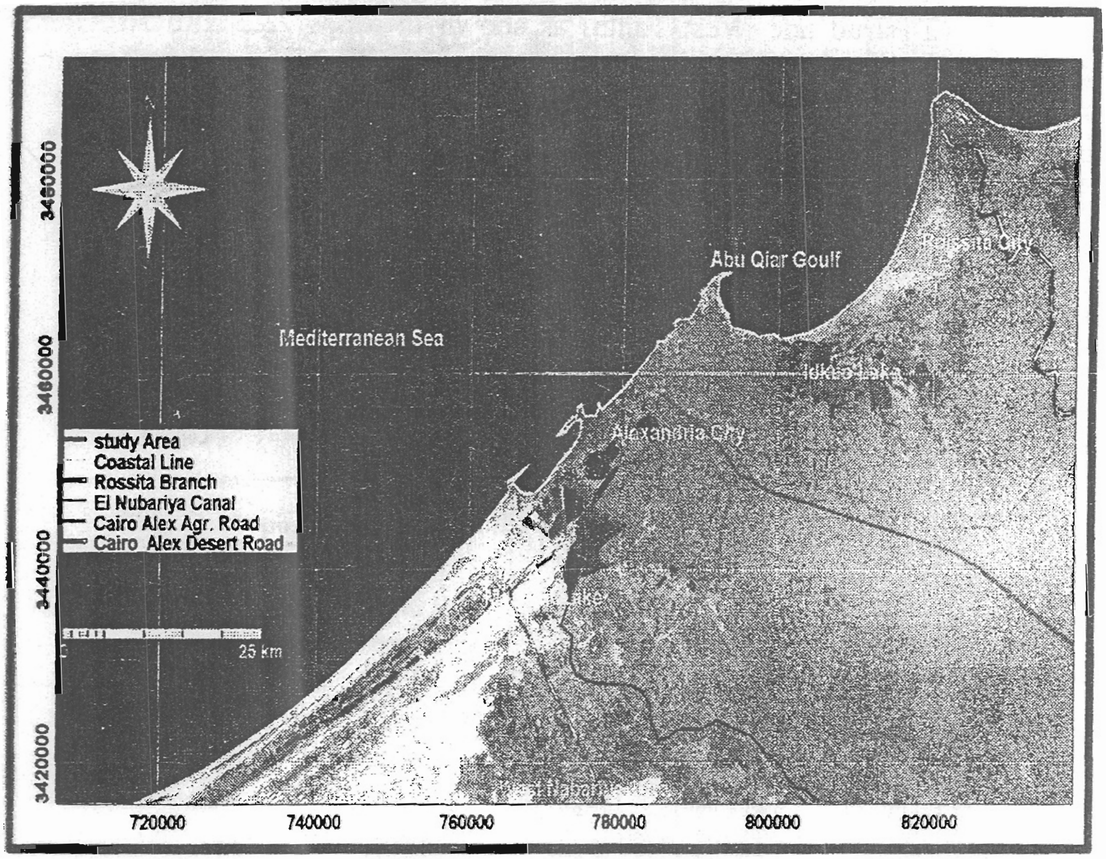
Increased community awareness of environmental issues and stringent environmental legislation has made it necessary to identify and assess polluted sites. During the last five decades, there were increasing concerns about soil pollution by Cd and Pb. Man`s activities are the major sources of these elements, relative to the natural, in the environment. The soil has been found the major sink for these emitted elements. The high values of enrichment factor (EF) for Cd and Pb indicate the significance of the atmospheric deposition as a source of metals in soils and plants (Alloway, 1993). Local, regional and global biogeochemical cycles of cadmium and lead have been affected to a great extent by man's activities. On a global basis, a number of estimates indicated that the contributions from anthropogenic sources, for these elements to the soils, are at least two or three orders of magnitude greater than from natural sources (Nriagu & Pacyna, 1988). The most common routes leading to the introduction of Cd and Pb into the environment are the disposal of industrial effluents, application of sewage sludge, deposition of air-born elements, mining landfill operation, use of agricultural chemicals, gas exhausts, and fuel production. Lead is emitted to the atmosphere from various sources such as leaded gasoline and waste incinerator (Adriano, 1987; Alloway, 1995, Mielke 1999, Mc Intyre, 2003 and Bang & Hesterberg, 2004).

The new approach for soil spatial variability can be a basic for classifying soil attributes spatial data by using natural grouping and by employing a geographical information system (Burrough, 1987 and Zhang *et al.*, 1996). Evaluating the environmental impact of pollutants, such as Cd and Pb must start with a determination of its spatial distribution. This is especially important in an urban area considering the complex heterogeneous nature of soil. For a geostatistical layer, there are three standard ways in which data can be assigned: (i) equal interval, (ii) quintile, and (iii) natural grouping or smart quintile (Johnston *et al.,* 2003). Natural grouping are used in thematic information extraction and pattern recognition (Jensen, 2005). Geostatistical techniques have been employed to describe the spatial distribution of several contaminants in soils (Atteia *et al.*, 1994; Von Steiger *et al.*, 1996; Bierkens, 1997; Goovaerts *et al.*, 1997; Carlon *et al.*, 2001; Van Meirvenne & Goovaerts, 2001 and Cattle *et al.*, 2002). These techniques provide means to estimate either the value of a soil attribute at locations between samples, or the probability that the attribute value will exceed a given threshold at a particular location. Such information is essential for mapping potential risks to the environment or human health. Spatial distribution, interpolation and maps of soil properties can be obtained by different techniques such as inverse distance calculations (Breget *et al.*, 1992), factorial Kriging (Bochi *et al.*, 2000) or ordinary Kriging (Lopez-Granados *et al.*, 2005). The spatial dependence of Pb in some agricultural soils, affected by industrial fallout, was evaluated in South Sardinia, Italy Bonifacio *et al.* (1996). They found that Pb was spatial dependence and their semivariogram fitted the spherical model. This paper highlights the methodology of spatial variation of environmental degradation that is effective and feasible for exploring soil pollution patterns in western area of Nile Delta of Egypt.

Material and Methods

Study area

The studied area is located West Nile Delta. It is bounded by the latitudes 30° 33' - 31° 30' N and the longitudes 29° 50' - 30° 45' E. This area covers a vast cultivated land representing Western area of Nile Delta (Map 1). These lands are subjected to aerosols deposition from various industrial activities in addition to irrigation with drainage water from drains mostly receiving industrial effluents.



Map. 1. TM image acquired on December, 2000 for location of the study area.

Soil sampling and analysis

Upper soil layer samples (0-10 cm) were collected from different sites which were geo-referenced using Global Positioning System (GPS) for 145 and 175 site at Western Area of Nile Delta for Cd and Pb, respectively (Map 2). The soils were air-dried, ground in a wooden mortar, passed 2 mm sieve and stored for analysis. Proportion of this 2 mm sieved-soil was finely ground to pass 1 mm sieve for trace elements analysis.

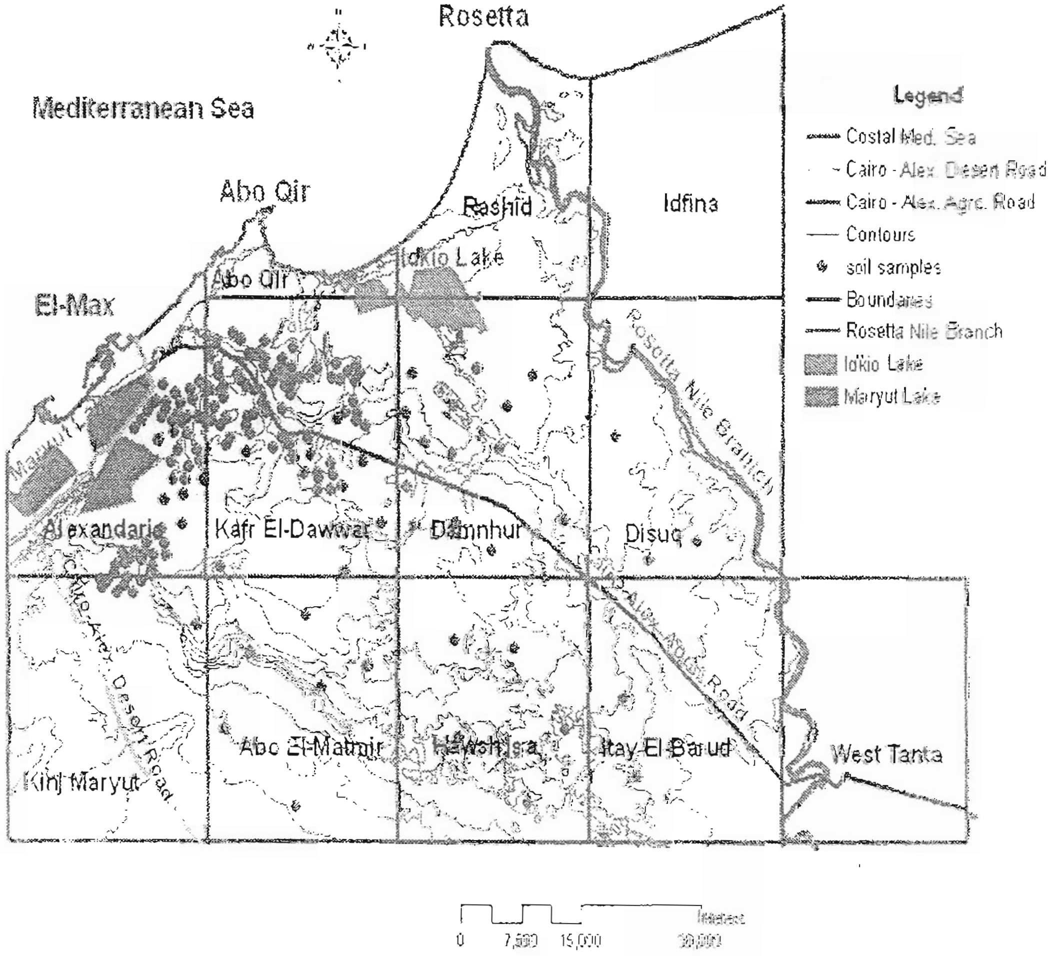
The amount of extractable soil cadmium and lead were obtained by extracting with DTPA-reagent (Lindsay & Norvell, 1978) and its concentration was measured by Perkin Elmer atomic absorption spectrophotometer.

Descriptive statistical analysis

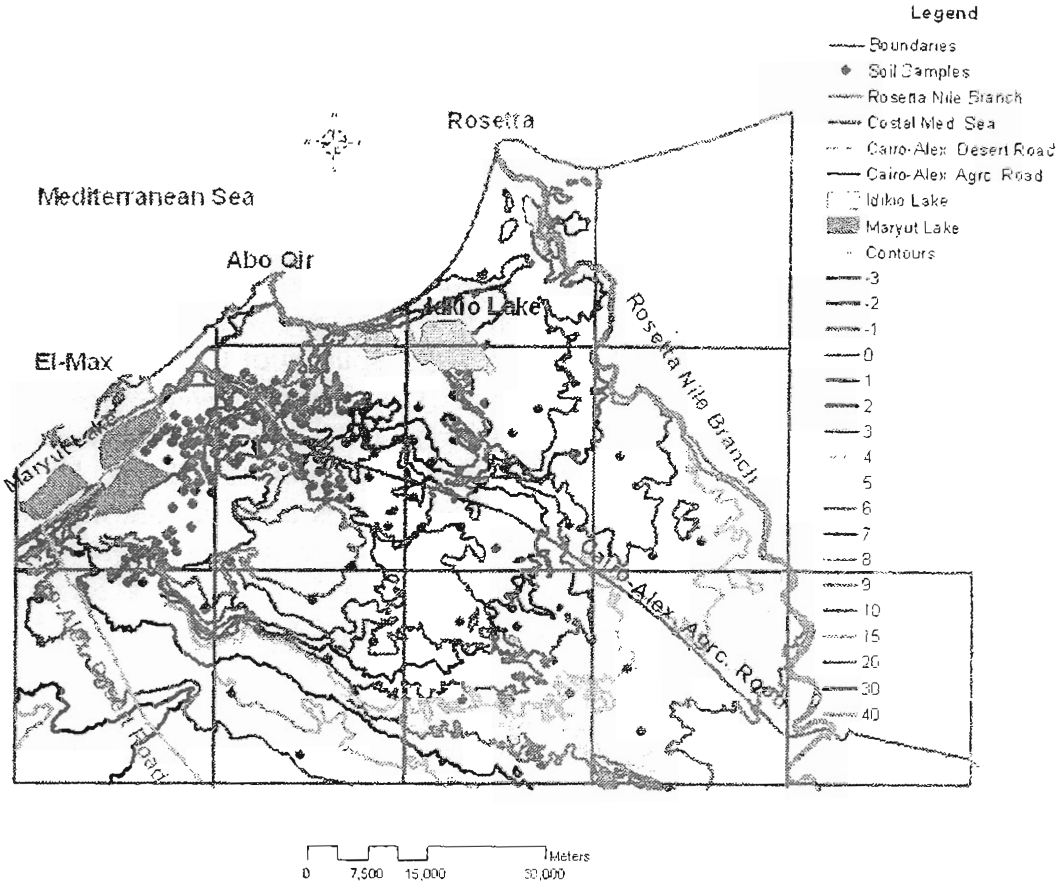
The data analyses were carried out using descriptive statistical parameters (minimum, maximum, mean, median, standard deviation, and variance) and were calculated for DTPA- Cd and DTPA-Pb SPSS software (2002) and the histograms for the two variables were obtained.

Building up digital georeference database

The spatial data input was carried out by on screen digitizing of 12 topographic map sheets at scale 1:50,000 (Alexandria – Kinj Maryut – Abo Quir – Kafr El-Dawwar – Abo El-Matmir – Rashid - Damnhur – Howshisa – Idfina – Disuq – Itay El-Barud and West Tanta) as shown in Maps 2&3 into ArcGIS (version 9) software (ESRI, 2004). The DEM was produced from the contour lines using interpolation technique throughout spatial analyst in ArcGIS software. TM image acquired on Dec. 2000 were obtained and input to ERDAS imagine software (version 8.5), (ERDAS, 2003).



Map. 2. Boundary of cities and locations of soil samples in the study area.



Map . 3. Topographic map and locations of soil samples in the study area.

GIS spatial modeling and surface interpolation through Kriging

Geostatistical analysis was carried out at a two steps: (a) the calculation of the experimental semi-variogram and fitting a model; and (b) interpolation through Ordinary Kriging, which uses the semi-variogram parameters (Stein, 1998). The semi-variogram is defined as a spatial dependence function of the distance "h" between locations in the observation space. Geostatistical analysis (Variogram model, Ordinary and Simple Kriging) for cadmium and lead spatial variability were carried out using ArcGIS software (ESRI, 2004).

Variogram model tested in this study was: $\gamma(h) = C_o + C\ f\ (h/a)$

Where γ = semivariance, h = separation distance, a = range, C_o = nugget, , C_o C = sill, $f(h/a) = [h/a]$ for the linear-plateau; $f(h/a) = [1.5(h/a) - 0.5(h/a)]^3$ for the spherical; $f(h/a) = [1 - \exp(h/a)]$ for the exponential and $(h/a) = [1 - \exp- \ (h^2 / a)]$ for the Gaussian model (Journal & Huijbregts, 1978 and Wackemagel, 1995). Ordinary Kriging takes into account both the structured and random characteristics of spatially distributed variables (soil DTPA-Pb and soil DTPA-Cd), thus providing tools for their description and optimal estimation. This preliminary test indicated that the soil test values were best estimated using the best fitted of variogram and ordinary Kriging as indicated by cross validation tests (Johnston *et al.*, 2003). We used Smart quintiles to delineate classes based on natural grouping of data values (Johnston *et al.*, 2003). Break points were identified, based on mathematical criteria that the computer uses to uncover statistical patterns that are inherent in the data.

Results and Discussion

DTPA-extractable Cd

The amounts of DTPA- extractable Cd in soil samples varied from 0.05 to 3.90 mg kg^{-1} (Table 1, and Fig. 1 & 2). According to the background level of DTPA-Cd in the soils of this regions reported by Elsokkary & Lag (1980), these soil are heavily polluted by Cd. The main hot spot sources of Cd in the studied area are located at El-Max and Kafer-El-Dawer. The observed lower levels of Cd in soils are related to sites at distance greater than 10 km from the hot spot sources. However, the high values of Cd are related to sites affected by the industrial complex of El-Max and Kafer-El-Dawer. It is reported that most Cd deposited on soil from atmosphere and/or from water of irrigation or both would be accumulate on the top soil layer (Stern *et al.*, 1996; Lindberg & Stratton, 1989; Rule & Iwashchenko, 1998; Bloom *et al.*, 2003 and Neculita *et al.*, 2005).

DTPA-extractable Pb

The amounts of DTPA-extractable Pb varied from 0.12 to 12.4 mg kg^{-1} (Table 1). These levels are greater than the background level (0.15 mg kg^{-1}) for soils collected from this area (Elsokkary & Lag, 1980). Extremely high values of DTPA-Pb are found in soils of sites located near by the black carbon plant (South West Alexandaria), self-burning municipal solid waste of Abis and industrial complex of El-Max and Kafer-El-Dawer. These sites can be considered the hot spots for Pb emission. On the other hand, the lowest DTPA-Pb levels were measured in soils of sites at distance greater than 10 km east south and south west the hot spot sources. Sutherland (2000) reported that these soils are anthropogenically pollution with Pb from vehicle emissions. Fig. 3&4 show the frequency distribution of DTPA-Pb in soils. These data show that DTPA-Pb has high variability in soils.

TABLE 1. Descriptive statistical analysis of DTPA- Cd and DTPA-Pb in soils.

Statistical Parameters	DTPA-Cd	DTPA-Pb
Minimum	0.05	0.12
Maximum	3.90	12.40
Mean	0.98	4.61
Range	3.85	12.28
Median	1.00	4.00
Standard Deviation	0.95	3.34
Variance	0.90	11.17
Skewness	1.68	0.51
Kurtosis	2.19	- 0.79
No. of sample	143	175

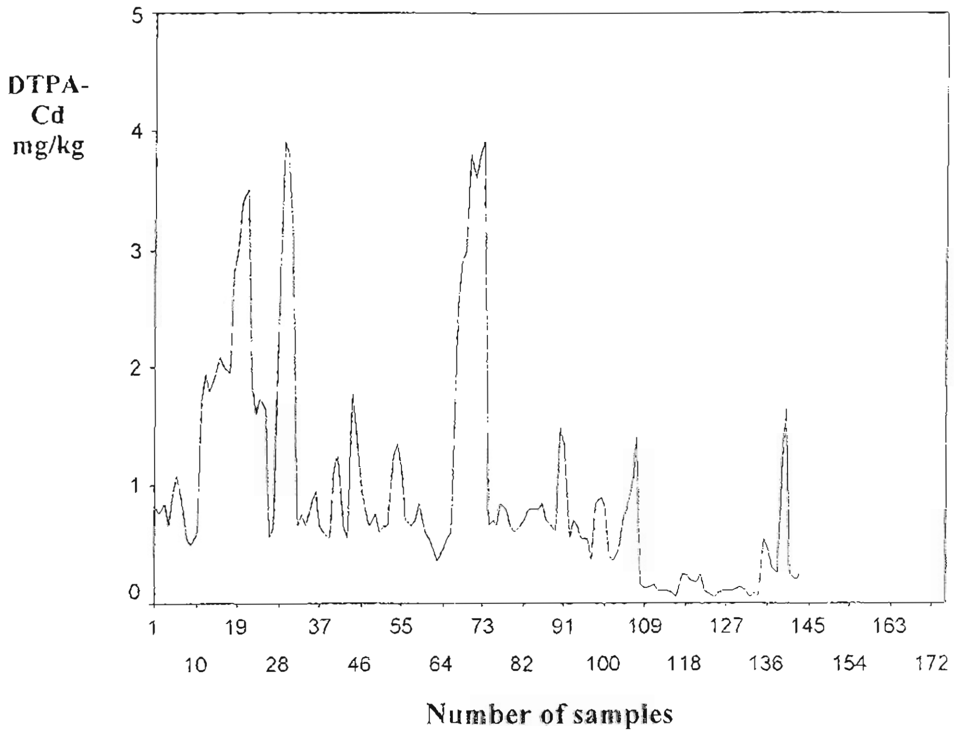


Fig .1. Variability of DTPA-Cd mg/kg in study area.

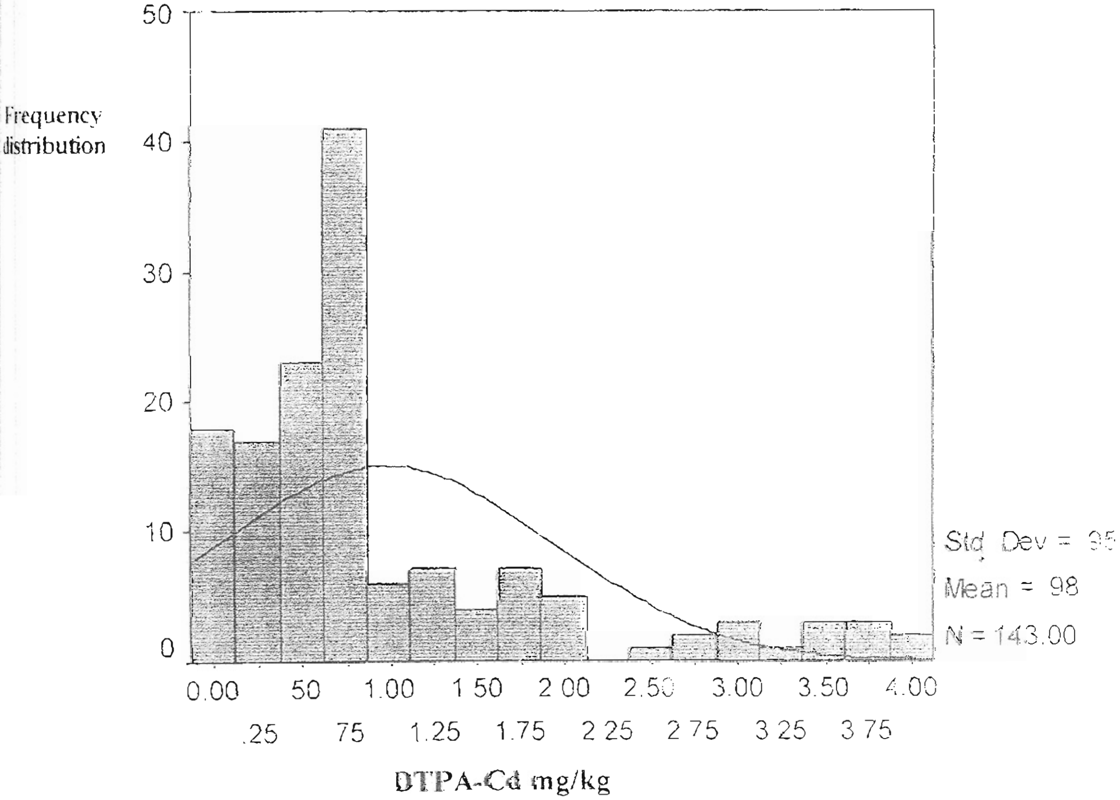


Fig .2. Frequency distribution of DTPA-Cd mg/kg in study area .

Contaminate variability

Descriptive variance

Table 1 showed that that DTPA-Pb has more variability than DTPA-Cd. This is attributed to the greater number of soil samples (175) used for DTPA-Pb compared with the number of samples (145) used for DTPA-Cd. The histograms for DTPA-Cd and DTPA-Pb are shown in Figures (2 and 4). The distribution of these variables is positively skewed, indicating the dominance of low values with the presence of a little high value that might have an impact on the final estimates (Issaka & Srivastiava, 1989). On the other hand, variance indicates that DTPA-Pb has spread on a wide range contrary to DTPA-Cd, which is distributed around a high number of samples with low values. The occurrence of high levels of DTPA-Cd is related mainly to sites located at close proximity from the industrial complex of El-Max and the soild waste dumpsite of Abis and industarial complex of Kafer El-Dawer while the low levels are measured in soil samples far away from remote area.

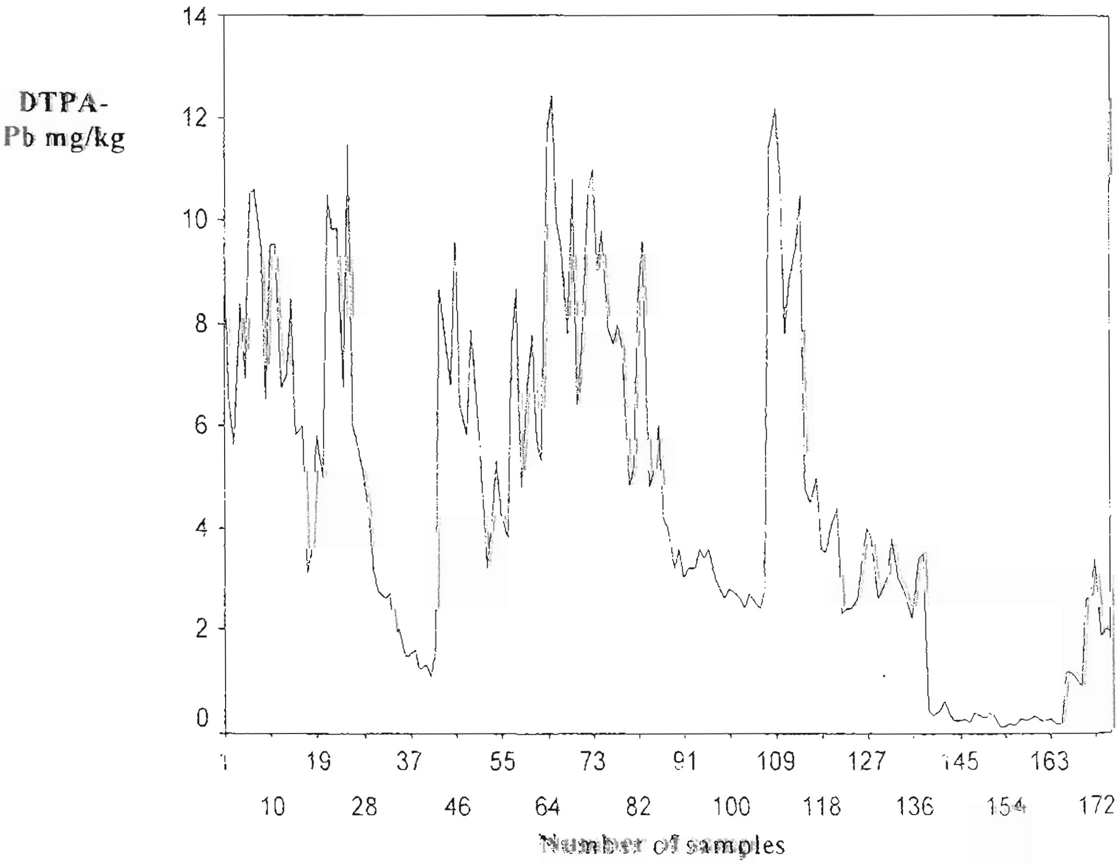


Fig.3. Variability of DTPA-Pb mg/kg in study area.

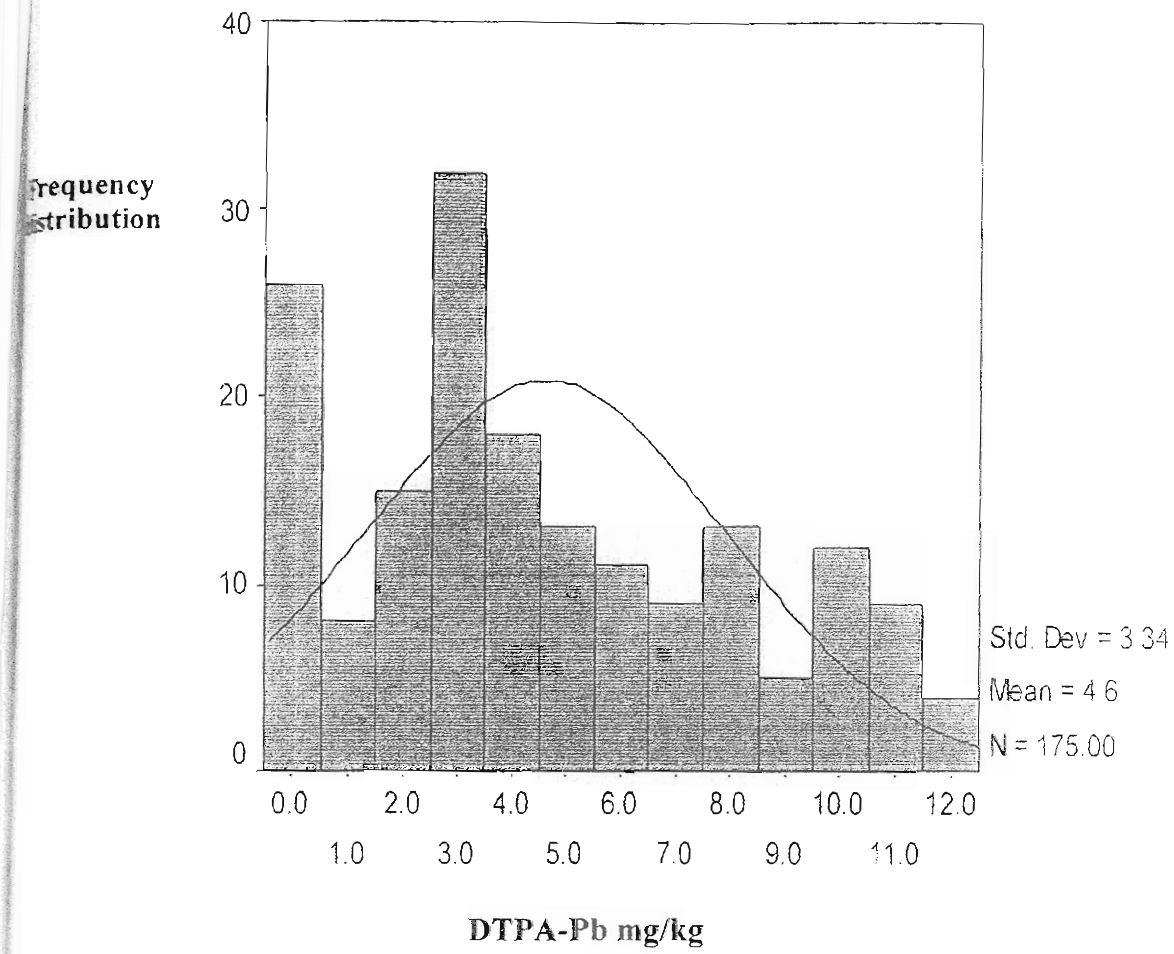
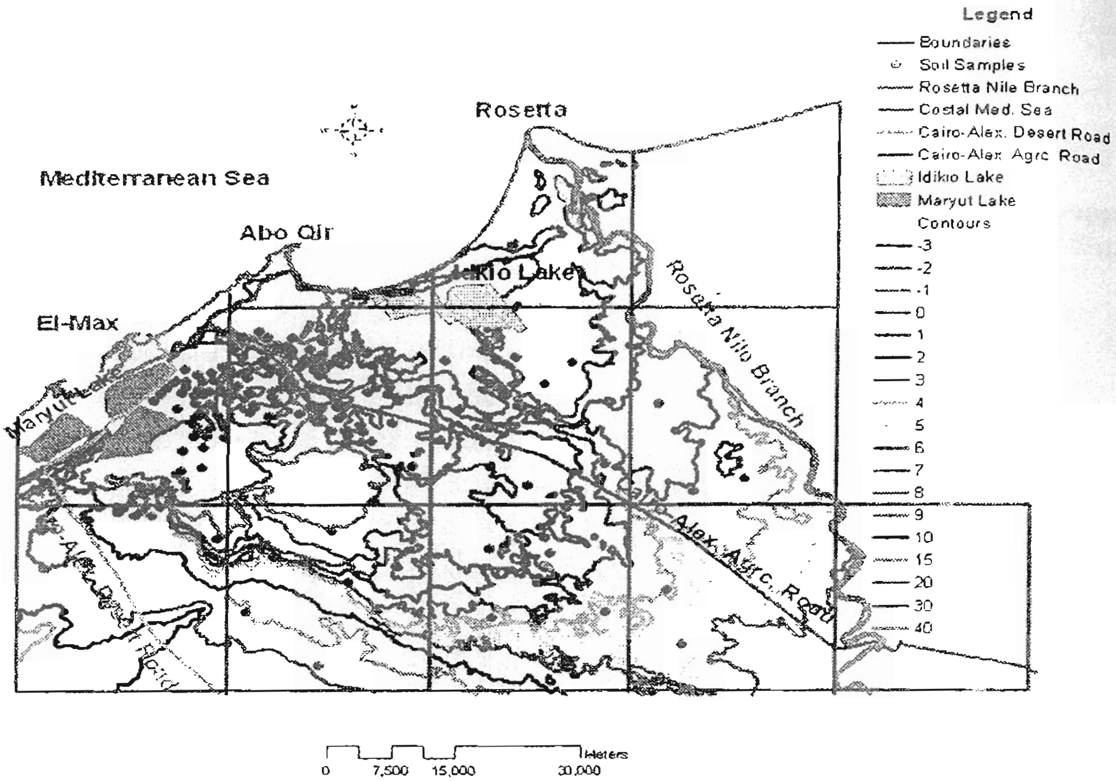


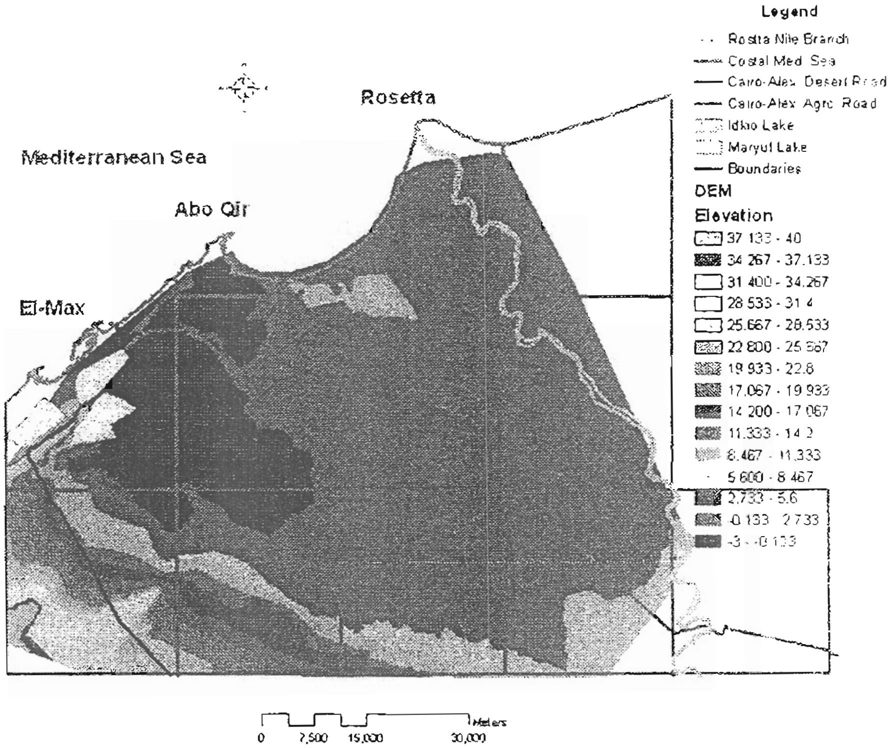
Fig.4. Frequency distribution of DTPA-Pb mg/kg in study area .

Spatial variability

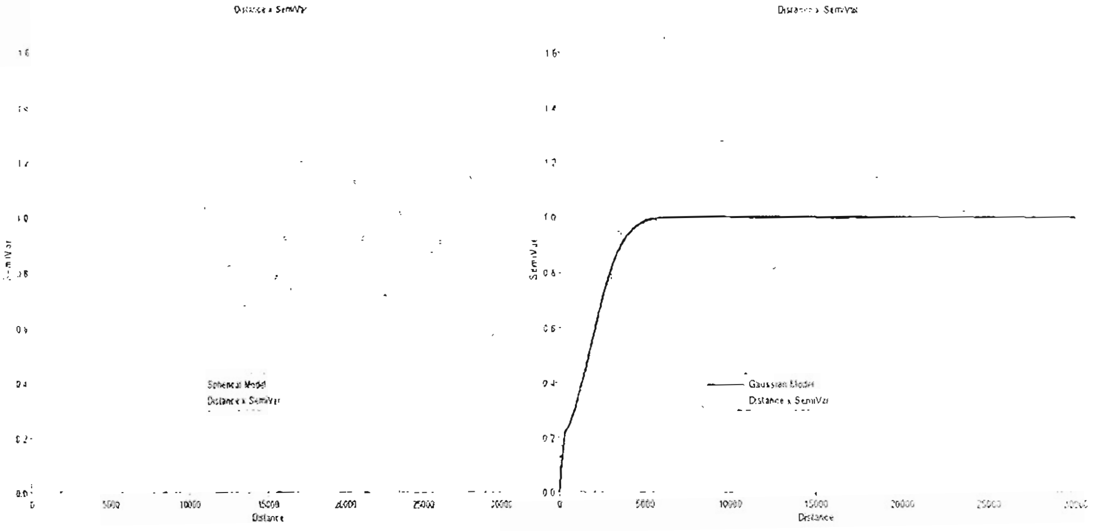
The topographic analysis of the contour lines and spot heights (Map3) produced a Digital Elevation Model (DEM) for the studied area. Elevation values ranged between 3 below sea level to about 30 meter above sea level (Map 4). The DTPA-extractable Cd data were best fitted spherical model while DTPA-extractable Pb data were best fitted Gaussian model (Fig. 5 & 6). The range showed that maximum interpolation of the concentration of Cd and Pb were 6766-72805 m (Table 2). The nugget variance of concentration of Cd and Pb were 0.17-8.83 m (Table 2). DTPA-Cd and DTPA-Pb represented high spatial dependence. The Ordinary Kriging maps showed the spatial distribution and interpolation of concentrations of DTPA-Cd and DTPA-Pb (maps 5, 6). These maps, for concentrations of these parameters, showed significant increase with space and time in the soils closer to the sources of contaminants and significant decrease with distance from these sources (Webster & Oliver 2000).



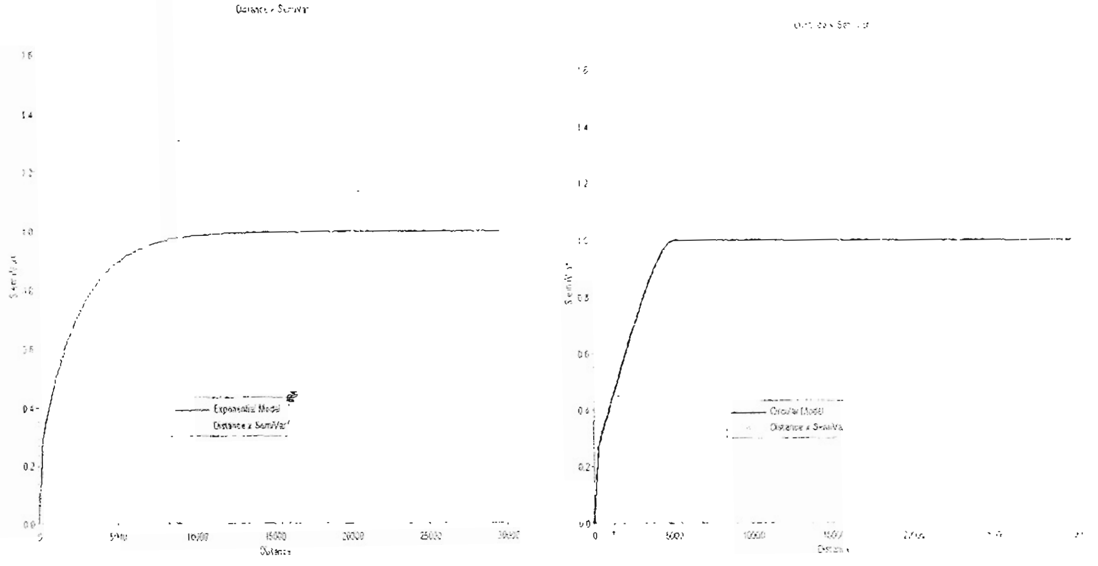
Map.3. Topographic map and locations of soil samples in the study area.



Map. 4. Digital Elevation Model (DEM) of Western Nile Delta.


(A) Spherical Model

(B) Gaussian Model

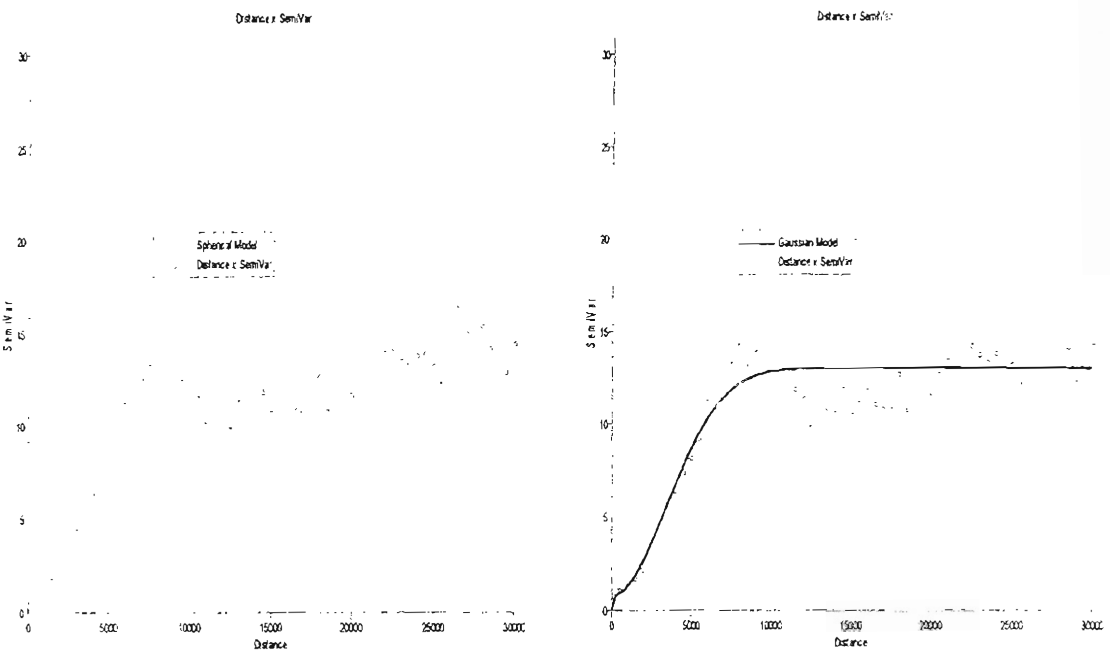

(C) Exponential Model

(D) Circular Model

Fig . 5. The Semivarigram of soil DTPA – Cd mg kg^{-1} and their fitted models.

(A) Spherical Model

(B) Gaussian Model



(C) Exponential Model

(D) Circular Model

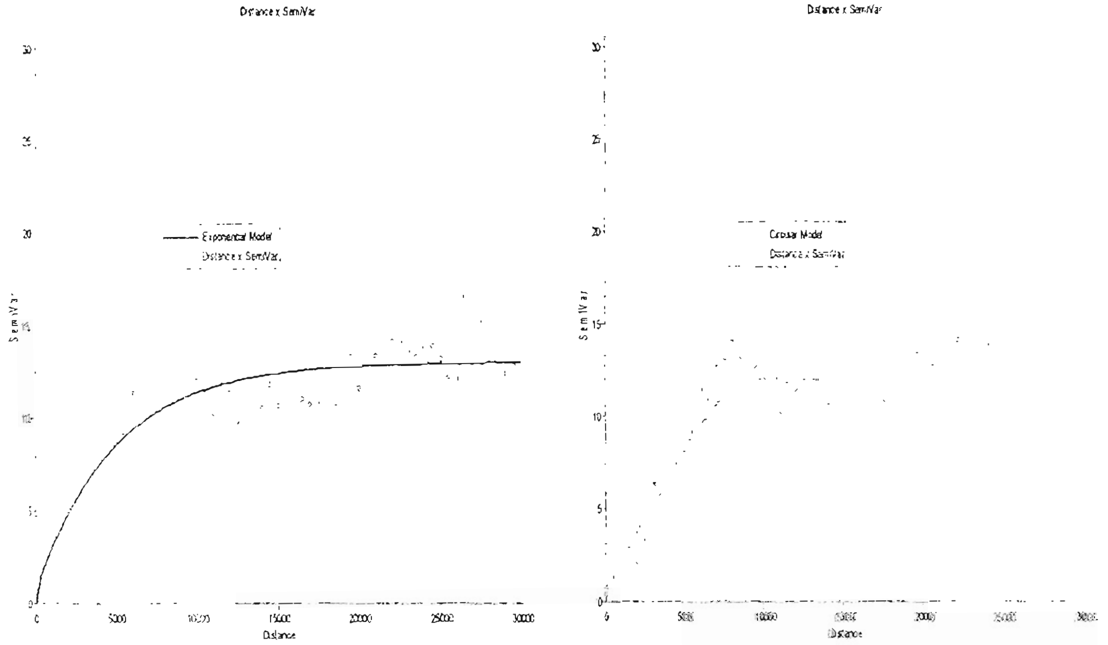
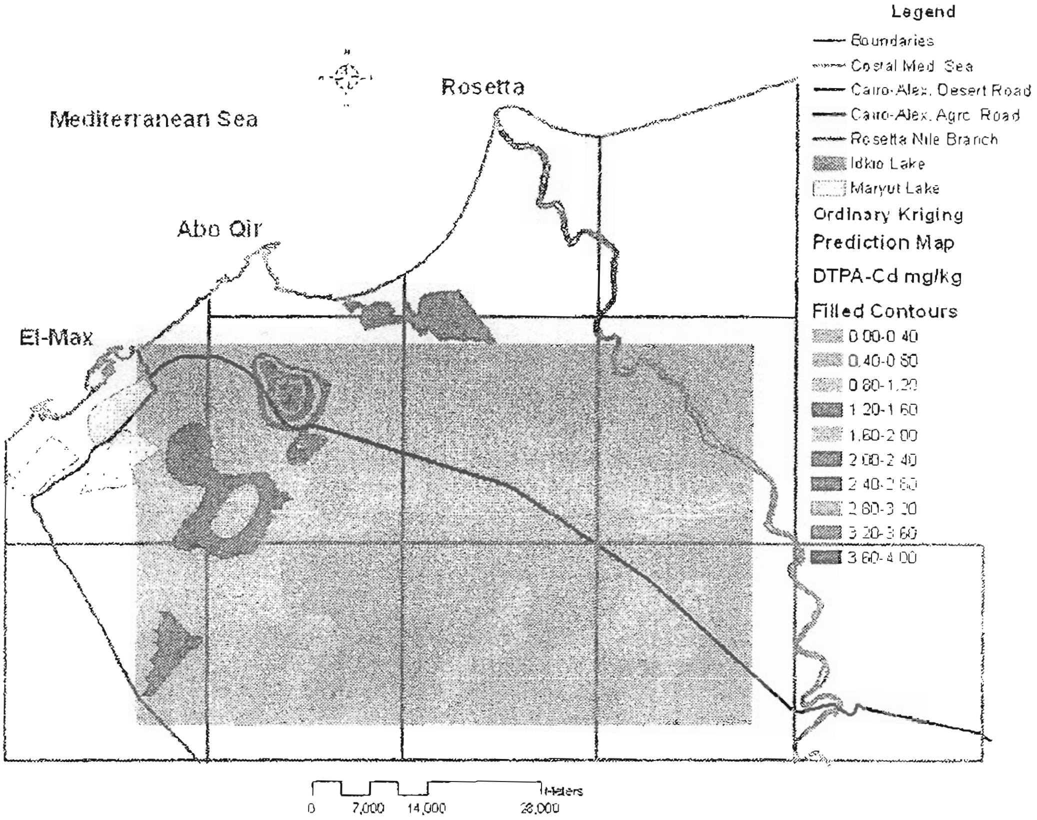
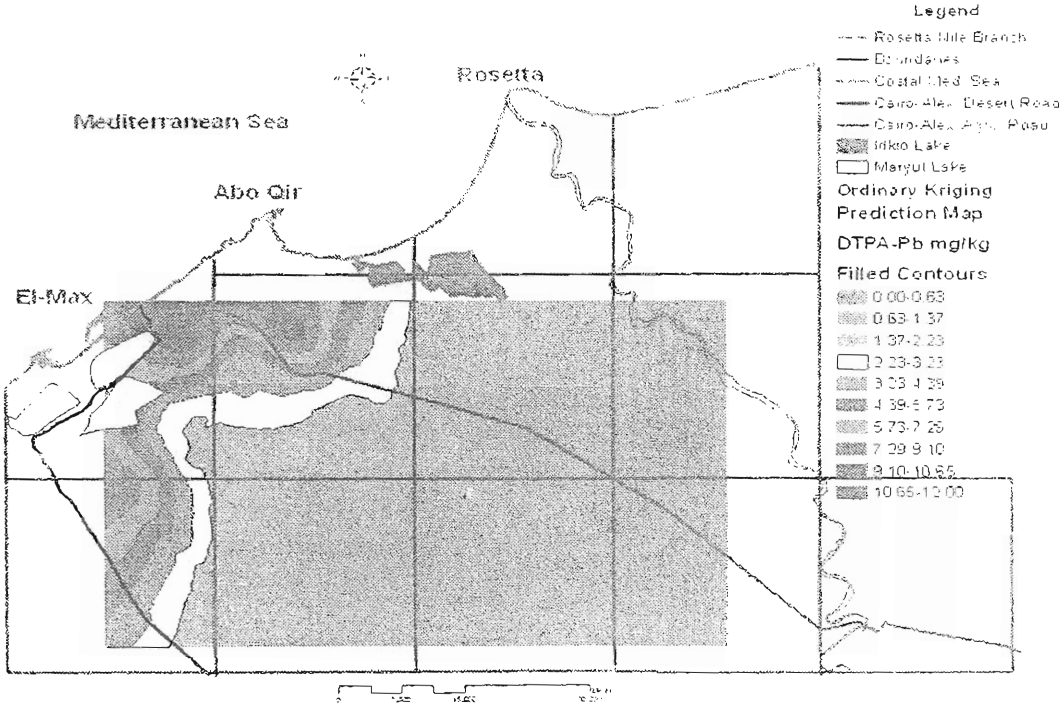


Fig . 6. The Semivarigram of soil DTPA – Pb mg kg^{-1} and their fitted models .



Map. 5. Ordinary Kriging of DTPA-Cd mg/kg in the study area.



Map. 6. Ordinary Kriging of DTPA-Pb mg/kg in the study area.

TABLE 2. Variogram Model Parameters of DTPA-Cd and DTPA-Pb (mg/kg).

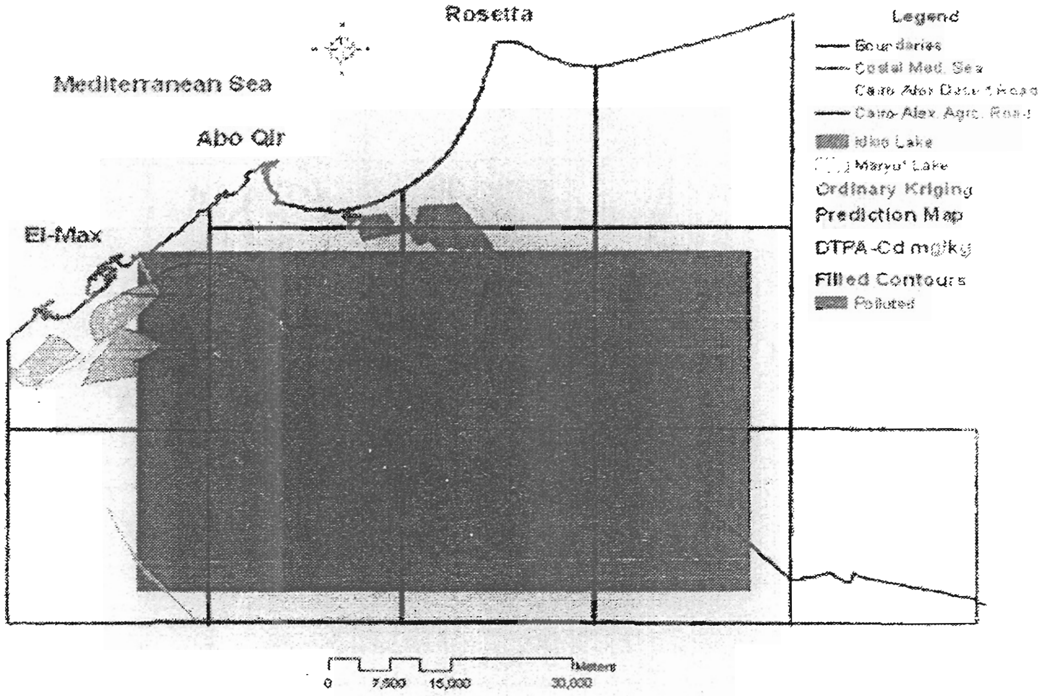
Model	DTPA-Cd				DTPA-Pb			
	Nugget	Sill	Range	R^2	Nugget	Sill	Range	R^2
Spherical	0.168	1.17	6766	0.98	6.34	17.97	72805	0.82
Gaussian	0.322	1.03	5908.3	0.91	8.83	19.33	72805	0.96
Exponential	0.00	1.41	81402	0.84	4.54	17.4	72805	0.78
Circular	0.186	1.15	6087.3	0.78	6.54	19.86	72805	0.74

Risk assessment of spatial soil polluted areas

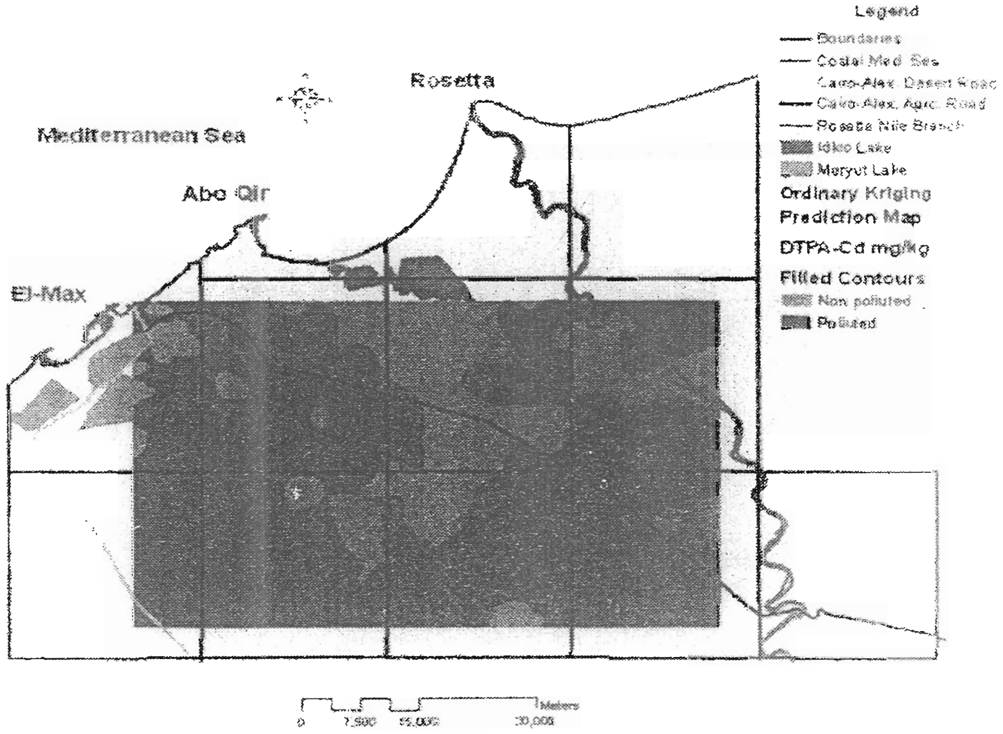
The kriging maps indicated that uncertainty is larger in the high cadmium and lead values zone. in this, zone the data variance is the largest. Two background levels for DTPA extractable Cd and Pb (Elsokkary & Lag, 1980 and Aboulroos *et al.*, 1996) were applied in this study to identify the percentage polluted and non-polluted area. The interpolation of DTPA-Cd and DTPA-Pb (mg/kg) tends to overestimate of concentration, leading to most locations being classified as polluted comparing with the background levels of this two metals.

One of the most basic yet not the simplest of questions are to clearly define what understand by contaminated space and to propose, if possible, a common definition. There are socio-economic, technical, political and legal factors that must be contemplated if one wishes to obtain an optimal solution to the problem of contamination.

The Kriging risk map of contaminated DTPA-Cd and DTPA-Pb, according to Elsokkary & Lag (1980) showed that the polluted area of Cd and Pb were 100% and 55%, respectively (Maps 7 & 9 and Table 3).On the other hand, the polluted areas for this two metals were 85% and 55%, respectively according to Aboulroos *et al.* (1996), as shown in Maps 8&10 and Table 3 . The most hot spots of pollution are located at proximity Alexandaria, Kafer El-Dawar. These hot spots emit, into the surrounding ecosystem, hazerd wastes as gaseous, effluent and/or soild materials.



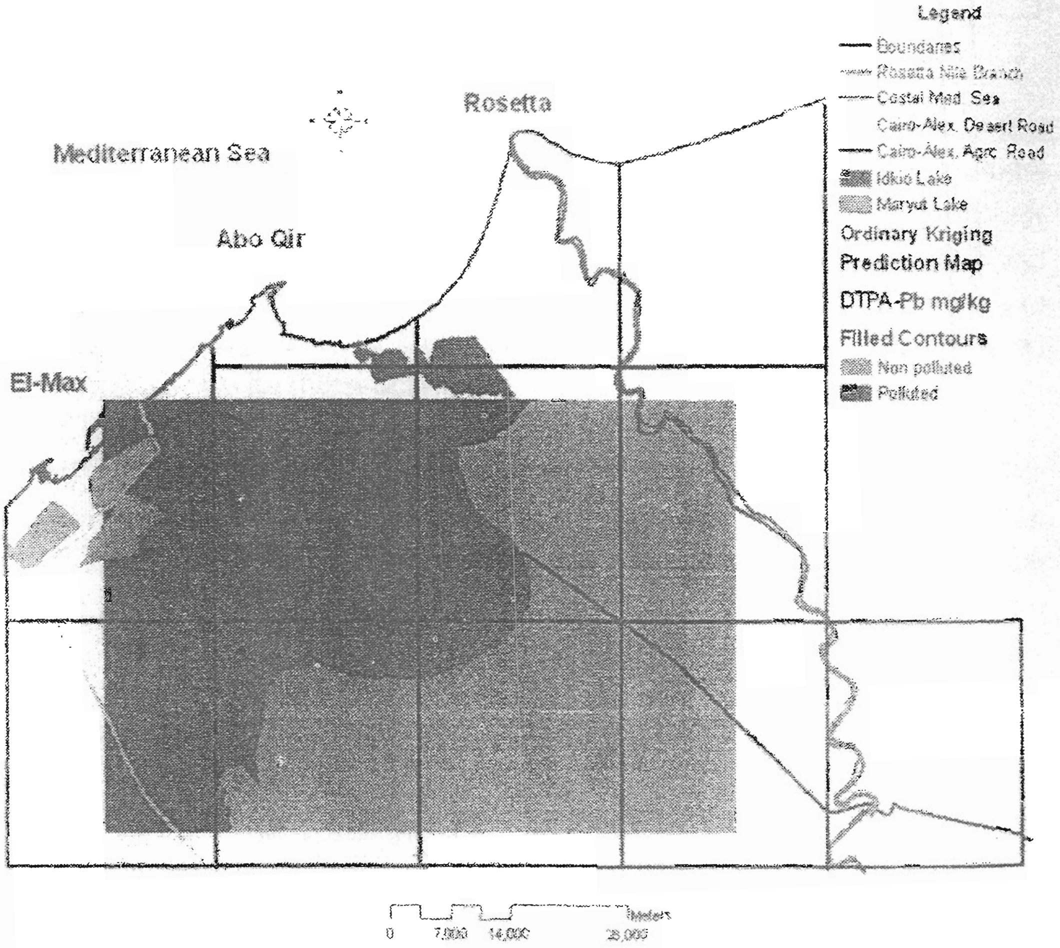
Map. 7. Ordinary Kriging of risk assessment of contaminate DTPA-Cd mg/kg in the study area according to Elsokkary & Lag (1980).



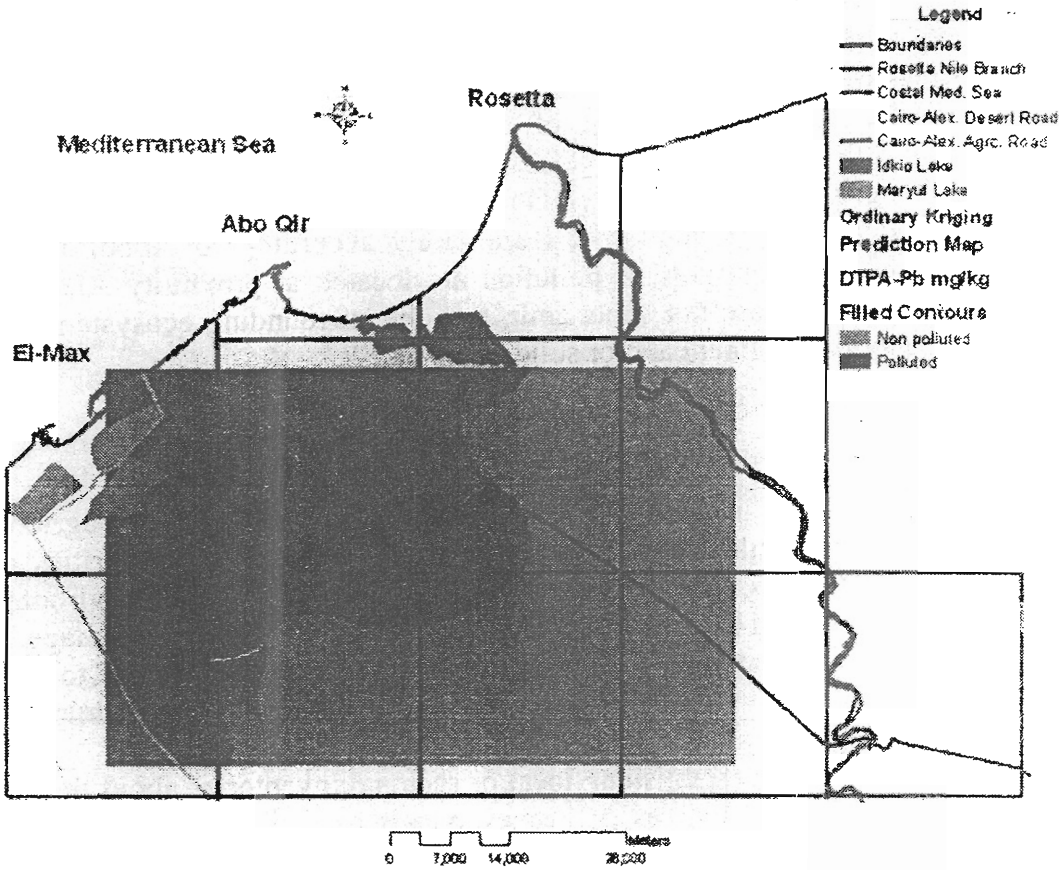
Map. 8. Ordinary Kriging of risk assessment of contaminate DTPA-Cd mg/kg in the study area according to Aboulroos *et al.* (1996).

TABLE 3. Percentage area of polluted and non-polluted of soils with Cd and Pb according to the background levels reported by Elsokkary & Lag .

Area	Elsokkary & Lag (1980)				Aboulroos et al. (1996)			
	DTPA-Cd		DTPA-Pb		DTPA-Cd		DTPA-Pb	
	feddan	%	Feddan	%	feddan	%	feddan	%
Polluted	400,000	100	340,000	55	330,000	85	340,000	55
Non-polluted	00	00	60,00	45	60,000	15	60,000	45



Map. 9. Ordinary Kriging of risk assessment of contaminate DTPA-Pb mg/kg in the study area according to Elsokkary & Lag (1980).



Map. 10. Ordinary Kriging of risk assessment of contaminate DTPA-Pb mg/kg in the study area according to Aboulroos *et al.* (1996).

Conclusions

The results obtained in this study showed extremely high values of DTPA-Cd and DTPA-Pb in soils of sites located near by the Black carbon plant south westEl-Max, self-burning municipal solid waste dumpsite of Abis and industrial complex of El-Max and Kafer El-Dawer. The main hot spot sources of metals pollution in the studied area are oil refining, petrochemicals, cement production, chemical industries, self burning of municipal solid waste and industrial complexes and the high way traffic.

Digital Elevation Model values ranged between 3 below sea level and about 40 meter above sea level of the study area. Descriptive variance analysis showed that DTPA-Pb has more variability than DTPA-Cd as the variance is much higher. This is attributed to the greater number of soil samples (175) used in DTPA-Pb compared to the number of samples (145) used for DTPA-Cd analysis. These analyses showed that the DTPA-extractable Cd data were best fitted spherical model while DTPA- extractable Pb data were best fitted Gaussian model. The range showed that maximum interpolation of the concentration of Cd and Pb were 6766-72805 m. The nugget variance of concentration of Cd and Pb were 0.17-8.83 m. DTPA-Cd and DTPA-Pb represented high spatial dependence. The ordinary Kriging showed significant increase with space in the soils closer to the sources of contaminants and significant decrease with distance from these sources. The Kriging risk map of contaminated DTPA-Cd and DTPA-Pb, according to Elsokkary & Lag (1980) showed that the polluted area of Cd and Pb were 100% and 55%, respectively). On the other hand, the polluted areas for this two metals were 85% and 55%, respectively according to Aboulroos *et al.* (1996). The most hot spots of pollution are located at proximity Alexandaria, Kafer El-Dawar. These hot spots emit, into the surrounding ecosystem, hazerd wastes as gaseous, effluent and/or soild materials.

Recommendations

1- The problem of increasing Cd and Pb contamination of the agricultural environment should be represented to the governmental authorities as an important issue to be dealt with now, by evaluating levels of environmental contamination and by acting to minimize further environmental damage.
2- National (or international) accepted guidelines should be developed to assist in the selection of environmental strategies, analytical methodology and indicator organisms.
3- There is a need for establishing local or regional inventories about the natural and anthropogenic sources of heavey metals as well as local and regional aspects of environmental cycling. These data should be quantative in general and estimates should be made on confidence levels.
4- More information are required about the sources of heavey metals in plant crops together with elements inputs to the agricultural lands from the various sources. The long-term behaviour of heavey metals in soils requires more investigations.
5- Data are required on the significance of plant crops grown in the contaminated soils for human dietary intake.
6- GIS powerful capabilities in spatial database development, spatial data processing, managing and modeling are required.
7- GIS can improve not only the analytical capabilities for emission inventory and pollution management but also the ability to communicate work results and research findings to the decision makers and the public in general.

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التوزيع الفراغى للكادميوم والرصاص باستخدام نظام المعلومات الجغرافية بمنطقة غرب دلتا النيل – مصر

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تشمل منطقة الدراسة غرب دلتا النيل بمساحة قدرها ٤٠٠ ألف فدان وتتعرض لمصادر مختلفة من التلوث حيث تروى بمياه عذبة عالية الجودة ولكن نتيجة للنقص فى هذه المياه فى بعض فترات السنة يلجأ المزارعون للرى بمياه مخلوطة منخفضة الجودة من مياه النيل ومياه صرف (زراعى – صحى – صناعى) بالإضافة إلى مصادر تلوث الهواء الناتجة عن احتراق مخلفات المصانع والعالقات التى تترسب من الهواء على سطح التربة واحتراق وقود السيارات على الطرق المجاورة للأراضى المنزرعة ويعتبر ذلك مصادر تلوث التربة بعنصرى الكادميوم والرصاص ويهدف البحث إلى دراسة توزيع قيم عنصرى الكادميوم والرصاص فى الصورة المتاحة بمحلول DTPA وكذلك التوزيع الفراغى لهذه العناصر بمنطقة الدراسة.

وقد أوضحت نتائج الدراسة أن قيم عنصر الكادميوم المستخلصة بمحلول DTPA قد تراوحت من ٠,٠٥ إلى ٣,٩٠ ملليجرام/كيلوجرام وقيم الرصاص المستخلصة بمحلول DTPA قد تراوحت من ٠,١٢ إلى ١٢,٤٠ ملليجرام/كيلوجرام وهذه القيم أعلى كثيرا من مستويات التلوث المذكورة بالمراجع المختلفة وتشير هذه النتائج إلى أن معظم الأراضى ملوثة بشدة بكل من عنصرى الكادميوم والرصاص.

تم تجهيز ١٢ خريطة طبوغرافية بمقياس رسم ١: ٥٠,٠٠٠ وتم ادخالها وعمل Digitizing لتحويلها إلى صورة رقمية وتحليلها باستخدام برنامج ArcGIS وتم عمل نموذج الارتفاعات من ٣م (تحت مستوى سطح البحر) إلى ٤٠م (فوق مستوى سطح البحر) وقد أوضح تحليل التباين الوصفى أن قيم الرصاص المتاح أكثر اختلافا وتباينا من الكادميوم المتاح وبالنسبة للتحليل الجيوإحصائى (المكانى) باستخدام برنامج ArcGIS اتضح أن تركيز الكادميوم المتاح اتبع نموذج Spherical model بينما تركيز الرصاص المتاح اتبع نموذج Gaussian model ، أما بالنسبة لقيم المدى Range للكادميوم والرصاص كانت ٦٧٦٦ و ٧٢٨٠٥م والتباين مع المسافة variance Nugget كان ٠,١٧ و ٨,٨٢م وقد تم رسم خرائط Ordinary kriging لتوضيح التوزيع الفراغى لعنصرى الكادميوم والرصاص وقد أوضحت أن التركيزات المرتفعة من هذه العناصر كانت بالقرب من مصادر التلوث ويعتبر تلوث هذه الأراضى التحدى لتطوير الزراعة المستدامة لذا يجب الاعتماد على تطبيق قوانين البيئة والتحكم فى مصادر التلوث التى تؤثر سلبا ومباشرة على الأراضى الزراعية وانتاجيتها.