STATISTICAL EVALUATION OF NATURAL RADIOACTIVITY IN SEDIMENTS ALONG THE EGYPTIAN MEDITERRANEAN COAST

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Sediments samples were analyzed for gamma emitting radionuclides using a high resolution, low background PC multichannel spectrometer, using a coaxial HPGe Aptec detector. The area under investigation was the Egyptian Mediterranean coast extended from El-Salloum to El-Arish. Various statistical analyses have been carried out for the data obtained from sediments radioactivity analysis and grain size analysis. The objective was to identify the homogenous groups and the groups responsible for making the combined variances and contributing for the significant differences. Correlation analysis, multifactor analysis of variance, Fisher's least significant difference (LSD) and cluster analysis have been carried out. Correlation analysis showed a high correlation between the naturally occurring radionuclides such as the uranium series and the thorium series. ^{40}K has weak correlation with dose, mean grain size and density of the sediments and no correlation with uranium and thorium series members and ^{7}Be. Multifactor analysis of variance has been indicated significant differences of detected radioisotopes among stations under consideration. In order to identify the sources of these differences, Fisher's least significant difference (LSD) test has been carried out. Cluster analysis has been classified Rashid as a unique station of its own characteristics. This was due to the high background radiation and presence of the black sand. It also classified El-Salloum and El-Gamil as second and third stations, which have different characters than the other stations. The other groups and classes of all stations have been identified and discussed. On the other hand, cluster analysis represented and identified all the relevant groups of the detected radioisotopes.
Keywords: *Natural radioactivity, Sediments, Egyptian Mediterranean coast, Statistics, Analysis of Variance, Cluster analysis*

INTRODUCTION

The earth's crust is notably heterogeneous, with over a hundred-fold variation in its concentration of K, Th and U [1]. The three radionuclides tend to concentrate in a variety of ways to produce different types of radioactive anomalies that are important in calculation of radiation dose. In Egypt, monazite black sand deposits are extensive as one of the major anomalies, along the beaches of Rashid in the north east coast of the Mediterranean Sea [2].

The majority of radionuclides in soil are attached or captured by fractions of soil with diameters less than 0.02 mm, larger fractions contain only traces of these radionuclides. This phenomenon is independent of the type of soil [3].

About 300 samples of sediments were analyzed for gamma emitting radionuclides. Uranium series (^{234}Th, ^{226}Ra, ^{214}Pb and ^{214}Bi), thorium series (^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl), ^{40}K

and ^{7}Be have been detected as natural radioactive isotopes. Gamma measurements have been carried out by means of high resolution, low background, PC-multichannel spectrometer using a coaxial HPGe Aptec detector. The area under investigation was the Egyptian Mediterranean coast positioned from El-Salloum (31°33\40\\ N 25°09\44\\ E) to El-Arish (31°08\31\\ N 33°47\17\\ E). The sediments samples, of 1.5-2 kg each, were collected bimonthly during the period from March 1998 to March 2000 from in-shore area (inter-tidal area) at depth 0-15 cm. The results of natural radioactivity concentrations and grain size analysis were published in separate papers [4-5]. Radiological assessment of the Egyptian Mediterranean coast has been done and published [6].

The aim of this work was to establish baseline statistical information of radioactivity background levels and its spatial distribution. Additionally, it was to identify the homogenous groups and the groups responsible for making the combined variances and contributing for the significant differences.

STATISTICAL METHODS

Various statistical analyses have been carried out for the data obtained from sediments analysis and grain size analysis using software Statgraphics Plus for windows 4.0, 1994-1999 by Statistical Graphics Corp. These methods were as follows:

1. Correlation analysis (Pearson product moment correlation),
2. Multifactor analysis of variance (Type sum of squares with confidence limit 95%),
3. Multiple range test (used Fisher's least significant difference (LSD) procedure),
4. Cluster analysis (Clustering method: Nearest neighbor method – single linkage and Distance metric: squared Euclidean).

RESULTS AND DISCUSSION

1. Correlation Analysis:

Table 1. presents the correlation coefficients (r) of radioactive isotopes concentrations detected in sediments along the Egyptian Mediterranean coast and their mean grain size (Mz), density and absorbed dose rate. High correlations were detected between the natural radioisotopes of uranium series (^{234}Th, ^{226}Ra, ^{214}Pb and ^{214}Bi) and thorium series (^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl) with correlation coefficients more than 0.963 and this is in agreement with the finding of Elejalde et al., [7]. Radioisotopes of thorium series were more strongly correlated than the radioisotopes within the uranium series. ^{40}K has weak correlation with dose (r = 0.49), Mz (r = 0.36) and density of the sediments (r = -0.41) and no correlation with uranium and thorium series members and ^{7}Be.

The absorbed dose rate of outdoor gamma radiation has been calculated from and dependent mainly on the ^{238}U, ^{232}Th and ^{40}K concentrations in sediments [8]. Consequently, positive correlations have been detected between absorbed dose rate values and the uranium series (^{234}Th, ^{226}Ra, ^{214}Pb and ^{214}Bi), thorium series (^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl) and ^{40}K with correlation coefficients ranged between 0.49 to 0.68 as shown in Table (1). On the other hand, Barisic et al., [9] reported that the distribution of ^{40}K, uranium and thorium in sediments is strongly influenced and governed by grain size distribution. Therefore, reasonable positive correlation was detected between the values of absorbed dose rate and mean grain size (r = 0.74). This indicated that the grain size is considered as one of the important factors describing the radioactivity contents of the sediments.

Table 1. Correlation coefficient matrix among the concentrations of the detected radioactive isotopes (Bq/kg) and absorbed dose rate (nGy/h) in sediments of the Egyptian Mediterranean coast and their densities (g/m^3) and mean grain size-Mz(Φ).

	^{234}Th	^{226}Ra	^{214}Pb	^{214}Bi	^{228}Ac	^{212}Pb	^{212}Bi	^{208}Tl	^{40}K	^{7}Be	Dose	Mz	Density
234Th	1	0.99	0.98	0.98	0.96	0.96	0.96	0.96	-.19	0.07	0.60	0.29	0.30
^{226}Ra	0.99	1	0.99	0.98	0.97	0.97	0.97	0.97	-.15	0.08	0.64	0.32	0.28
^{214}Pb	0.98	0.99	1	0.99	0.99	0.99	0.99	0.99	-.05	0.11	0.67	0.31	0.20
^{214}Bi	0.98	0.98	1	1	0.99	0.99	0.99	0.99	-.04	0.12	0.68	0.31	0.20
^{228}Ac	0.96	0.97	0.99	0.99	1	1.00	0.99	0.99	0.02	0.12	0.68	0.29	0.17
^{212}Pb	0.96	0.97	0.99	0.99	0.99	1	0.99	0.99	0.03	0.12	0.68	0.29	0.17
^{212}Bi	0.96	0.97	0.99	0.99	0.99	0.99	1	0.99	0.03	0.12	0.68	0.29	0.17
^{208}Tl	0.96	0.97	0.99	0.99	0.99	0.99	0.99	1	0.03	0.12	0.68	0.29	0.17
^{40}K	-.19	-.15	-.05	-.04	0.02	0.03	0.03	0.03	1	0.08	0.49	0.36	-.41
^{7}Be	0.07	0.08	0.11	0.12	0.12	0.12	0.12	0.12	0.08	1	0.26	0.30	-.26
Dose	0.60	0.64	0.67	0.68	0.68	0.63	0.68	0.68	0.49	0.26	1	0.74	-.12
Mz	0.29	0.32	0.31	0.31	0.29	0.29	0.29	0.29	0.36	0.30	0.74	1	-.36
density	0.3	0.28	0.2	0.2	0.17	0.17	0.17	0.17	-.41	-.26	-.11	-.36	1

^{7}Be and density have no correlation with the majority of radioisotopes under investigation. This is due to that ^{7}Be comes from the upper atmosphere. This is in agreement with the finding of Pham et al., [10] that there is no correlation between ^{7}Be with grain size.

2. Multifactor Analysis of Variance:

Multifactor analysis of variance (ANOVA) has been covered all the set of data (2020 values) of the corresponding radioisotopes concentrations, taking into consideration the station differences. The data were categorized according to radioisotope types and stations as two different factors. Table (2) shows ANOVA results, which categorizes the variability among values according to the contributions of the two factors. The contribution of each factor was measured with removal of the effects of the other factor. The resulted P-values, which used to test the statistical significance of each of the factors revealed statistically significant differences at the 95.0% confidence level among the studied values (2 P-values were less than 0.05). In order to know which means are significantly different from which others for each significant factor, multiple range tests has been carried out.

3. Multiple Range Tests:

Multiple range statistical method tests were performed to radioisotope concentrations values taking into consideration the stations differences. A multiple comparison procedures have been applied between each pair of means to determine which means are significantly different from each others. Fisher's least significant difference (LSD) was used to discriminate between means.

Table 2. Multifactor analysis of variance (ANOVA) results.

Source	Sum of squares	DF	Mean square	F-ratio	P-value
Main Effects					
Radioisotopes	2.271e6	11	206489.0	78.95	0.00
Stations	1.137e6	18	63158.4	24.15	0.00
Residual	6.123e6	2341	2615.56		
Total (corrected)	9.512e6	2370			

All F-ratios were based on the residual mean square error.

Four homogenous groups were identified as shown in Table (3). Within each homogenous group (column) the levels containing x's from a group of means within which there are no statistically significant differences. LSD test showed that ^{40}K was present in one separate group and had significant differences with the other radioisotopes under investigation. There were no significant differences among the second group of the uranium series members (^{234}Th, ^{226}Ra, ^{214}Pb and ^{214}Bi) with ^{228}Ac. The third group contains the same members as the second group except ^{234}Th and has ^{212}Pb as one member of thorium series. The fourth group contains all members of Th series (^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl) in addition to ^{214}Pb and ^{214}Bi from uranium series and the other natural isotope ^{7}Be.

4. Cluster Analysis:

Cluster analysis is one of multivariate techniques used to identify and classify groups with similar characters in a new group of observations. Each observation in a cluster is most like others in the same cluster. Cluster analysis was carried out through two axes; the first was to identify stations with similar characters. The other axis was to identify similar characteristics among radioisotopes and the sediments grain size parameters.

Table 3. Multiple range tests for values by radioisotopes levels.

Method: 95.0 percent LSD						
Levels	**Count**	**LS Mean**	**Homogeneous groups**			
^{7}Be	70	0.77	X			
^{208}Tl	214	4.91	X			
^{212}Bi	182	8.65	X			
^{212}Pb	222	10.19	X	X		
^{214}Bi	224	13.02	X	X	X	
^{214}Pb	224	13.64	X	X	X	
^{228}Ac	218	13.83	X	X	X	
^{226}Ra	219	19.62		X	X	
^{234}Th	221	20.96			X	
^{40}K	226	114.05				X

4.1. Among the stations

Figure 1. shows dendrogram of classification of the Egyptian Mediterranean coast stations as groups according to the radioactive isotope concentrations and grain size parameters in their sediments. Rashid was classified as unique stations due to the high background radiation and the presence of the black sand. This can be deduced from the relatively high distance at which its cluster was joined. El-Salloum was the second station that has special characters and then El-Gamil. These stations have relatively higher concentrations of radioactivity and considered as concentration basins along the Egyptian Mediterranean coast. The closest stations in their characters were Matrouh and Ras El-Hekma and then Montaza and El-Arish in one group. Sidi Abd El-Rahman and Eastern Harbour were grouped as much closed stations and connected to El-Mex and then to Nobareya in bigger group. Abu Qir (bay) has close characters similar to El-Brolos and connects to Damietta and then to Port Said as bigger group. This entire group was affected by sedimentation of Nile River.

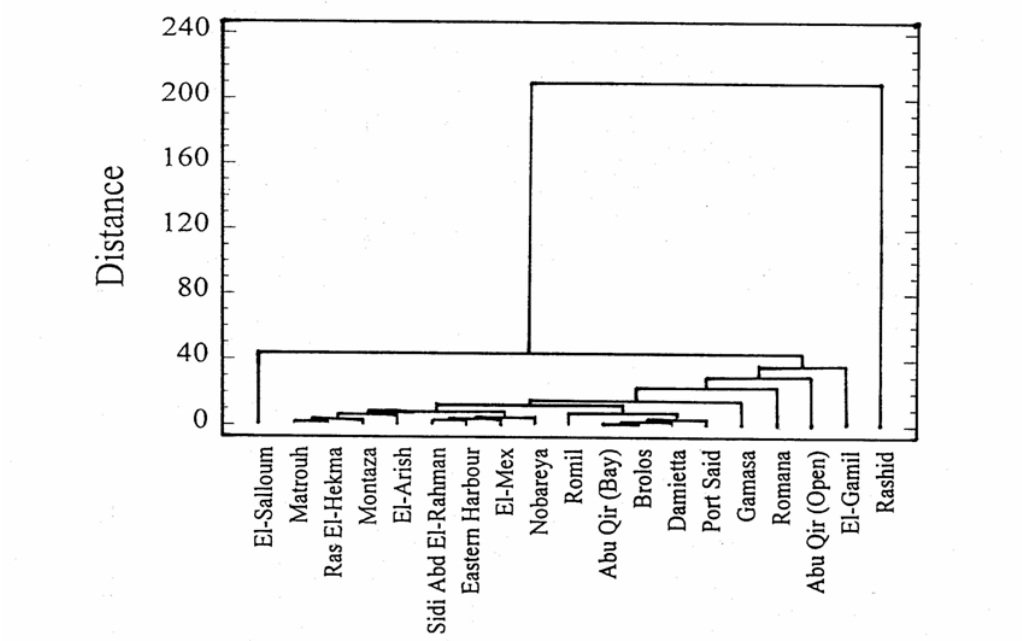

Figure 1. Dendrogram for Egyptian Mediterranean coast stations concerning radioactive isotope concentrations and grain size parameters in sediments**.**

4.2. Among the radioisotopes and grain size parameters:

Figure 2. shows dendrogram for radioactive isotopes concentrations and grain size parameters in sediments along the Egyptian Mediterranean coast. ^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl were represented as one group with similar characteristics as they originate from ^{232}Th series. ^{214}Pb and ^{214}Bi and were close to each other in one group, the same as ^{234}Th and ^{226}Ra. ^{214}Pb ^{214}Bi and were more related to the ^{232}Th series data, that all were clustered in one group. ^{7}Be was the next radioisotope related to this group as higher order group. Pair of combination has been identified as gravel percent and sorting. ^{40}K data have been identified in another group order far from the other radioisotopes. This may be due to the origin of ^{40}K is primordial single occurrence radioisotope. ^{40}K has been grouped closely with the group of gravel percent and sorting and all

together grouped with Mud percent to one high order group. The close relation between ^{238}U and ^{232}Th series members but not with ^{40}K is in agreement with the results of Elejalde et al. [7].

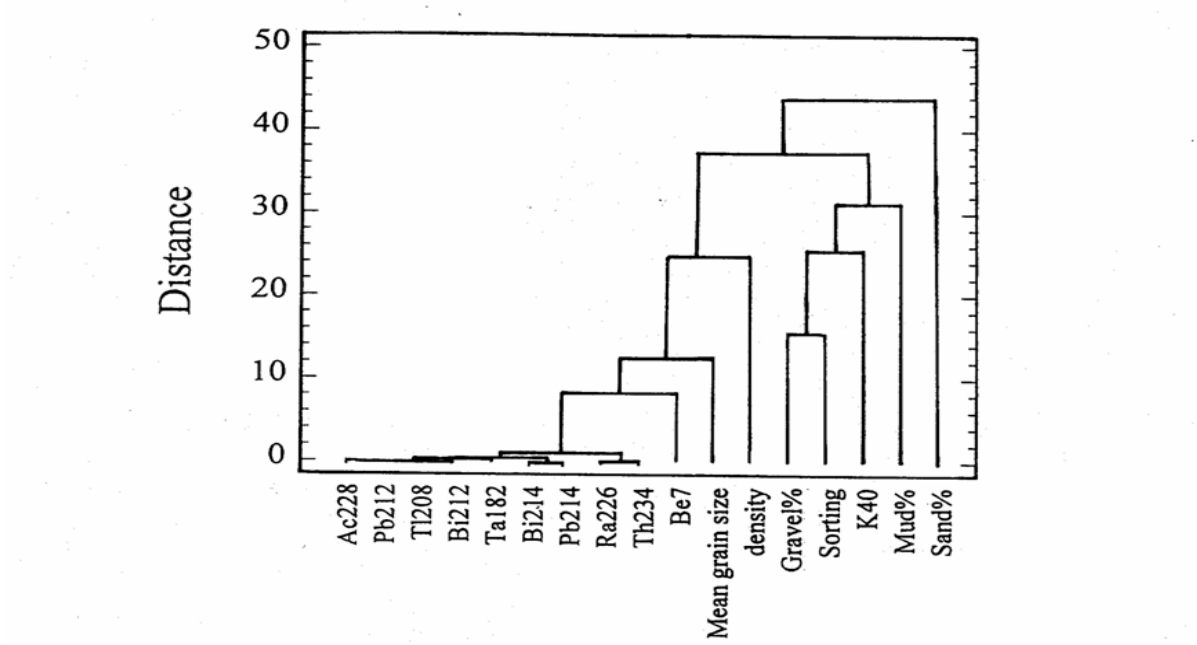

Figure 2. Dendrogram for radioactive isotope concentrations and grain size parameters along the Egyptian Mediterranean coast**.**

CONCLUSION

- Correlation analysis indicated high correlation between uranium (^{234}Th, ^{226}Ra, ^{214}Pb and ^{214}Bi) and thorium (^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl) series members with no correlation with ^{40}K and ^{7}Be.
- Cluster analysis confirmed the close relation between the two natural series and clustered them as one group.
- Cluster analysis showed ^{40}K has been recognized in another group far from the other radioisotopes.
- Cluster analysis has been classified Rashid as a unique station of its own characters and then El-Salloum and El-Gamil.
- Positive correlations have been detected between absorbed dose rate values and the uranium series (^{234}Th, ^{226}Ra, ^{214}Pb and ^{214}Bi), thorium series (^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl), ^{40}K and mean grain size.
- Multifactor ANOVA test indicated significant differences among the detected radioisotopes.
- ^{40}K was presented in one separate group and had significant differences with the other radioisotopes.

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