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Environmental Contaminations of Particle-Reactive Radionuclides (Pb ,Cs) in Sediment of Burullus Lake

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ABSTRACT

The lakes are a very important part of the Egyptian aquatic ecosystem, which includes the Nile River, underground water reservoirs and shore coasts on the Mediterranean and Red Seas. So it is very important to study environmental contaminations of particle-reactive nuclides (such as Pb and Cs) in Burullus Lake, and the affecting of environmental variables on distributes contaminations of these nuclides in it. The concentrations and distribution of radionuclides in Burullus Lake have been determined using high-resolution gamma spectrometry to evaluate the environmental radioactivity. The status of ^{226}Ra and ^{210}Pb disequilibrium was discussed in relation with environmental variables. An irregular distribution pattern of ^{210}Pb and ^{137}Cs probably incurred due to fall out of these radionuclides into the lake. To interface between behavior of radionuclides and environmental variables, we used Canonical Correlation Analysis (CCA). It is cleared that total organic matter (TOM) has an influence on the retention and migration of ^{137}Cs in Burullus Lake.

***Key words*:** Burullus Lake, Contaminations, ^{21}0Pb, ^{137}Cs

Introduction

Contaminated sediments, in both freshwater and marine systems, are a significant issue worldwide (MackeviČienė *et al.,* 2002). Lakes act as sinks for the materials which pass through the various aquatic chemical and biological cycles including radioactivity contaminations (El-Reefy *et al.,* 2009). The primary reason for being concerned about radioactivity contamination of the environment is that it may result in exposure on humans. The two major reasons for focusing concern on humans have to do with human values and the relative radioresistance of many plants and lower animals (Eisenbud and Gesell, 1997). Thus, it is important to measure contaminations of discharge in order to better understand and help manage the quality of our environment.

The accumulation of particle-reactive contaminants in recent sedimentary deposits of riverine and shallow lacustrine systems is of environmental concern because of the possible release of these pollutants into the water column during sediment resuspension followed by subsequent bioaccumulation in aquatic ecosystems (Jweda and Baskaran , 2011). Atmospherically delivered particle-reactive radionuclides, such as ^{210}Pb and^{137}Cs, have been extensively utilized in coastal systems as proxies for contaminants and tracers of particle dynamics because direct study of the transport, deposition, and resuspension of particle-reactive species is difficult (Jweda *et al.,* 2008).In addition these environmental radiotracers have been utilized for dating purpose on time scales spreading from some years to several decades (Srisuksawad *et al.,* 2013).

The isotope ^{210}Pb occurs as part of the radioactive decay chain of ^{238}U, which decays through a series of non-volatile intermediates to ^{226}Ra with a half-life of 1622 years. ^{222}Rn, an inert gas with a half-life of 3.825 days, decays via a series of short-lived daughters to ^{210}Pb, with a half-life of 22.26 years (Srisuksawad *et al.,* 2013). ^{210}Pb is scavenged in the atmosphere and is subsequently deposited via wet and dry precipitation onto the Earth's surface. Atmospheric deposition of ^{210}Pb at the air–water interface and subsequent scavenging by particles in the water column result in unsupported or excess ^{210}Pb in the particulate phase (Jweda and Baskaran , 2011). In other words; the activities of supported ^{210}Pb (= ^{226}Ra) will not decrease with time as a result from the continuous supply of ^{210}Pb from uranium and its daughters. While as the unsupported ^{210}Pb (=$^{210}Pb_{ex}$) radioactivity in the sediments decreases by a factor of 2 every 22.26 years half-life. The rate of change of unsupported ^{210}Pb activity down a sequence may thus be used to establish the sedimentation rate (Srisuksawad *et al.,* 2013). The regional and local meteorology plays a significant role in the atmospheric deposition of ^{210}Pb because of the different continental and oceanic ^{222}Rn exhalation rates (Beks *et al.,* 1998). ^{137}Cs is often employed in conjunction with ^{210}Pb to establish reliable chronologies and mixing rates of sediments in dynamic systems where physical and/or biological mixing has occurred (Jweda and Baskaran , 2011).

Cesium-137 is a fission product that is of great concern due to its relatively long physical half-life of 30.2 y and its bioavailability. Most of cesium compounds are water-soluble with chemical affinities similar to

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those of potassium (UNSCEAR, 1982). Tremendous amounts of ^{137}Cs were released into the atmosphere by open air nuclear bomb tests conducted during 1950s and 1960s and by the Chernobyl nuclear disaster occurred in1986 and finally the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident happened in 2011. Since the released ^{137}Cs had spread out over the world and deposited on the ground (Park *et al.,* 2013). Cesium-137 is known to bind to clay minerals in the topsoil layers (Bouncier *et al.,* 2011). The aquatic behavior of radionuclides plays the central role in their migration, as water is one of the prime agents, which helps to move and distribute elements on earth. Consequently, aquatic ecosystem both greatly affects and is affected by the fate of radioactive substance (Khater, 1998). The long-term measurements of natural and anthropogenic radionuclides have been widely used as tracers of submicrometre particles to study erosion, transport and deposition of sediment (Likuku *et al.,* 2006). So the objective of this study was to determine the base-line values of both ^{210}Pb and ^{137}Cs inventories in bottom sediment of Burullus Lake, as the environmental contamination of these radionuclides is danger because these elements have tendency to bioaccumulate in marine organisms.

Materials and Methods

Study Area

Burullus Lake is located in the north-central Nile delta region, Egypt (31° 35ˉ N and 31°10ˉ E) along the Mediterranean shore as shown in Figure (1) (Masoud *et al.,* 2011). The Lake is a protected area (Chen *et al.,* 2010). It is the second largest lake in Egypt with a surface area of ≈500 km^2 and ≈2 m maximum depth. The Lake is open water with patches of aquatic plants. Most of those plants covered the shore line and also in the middle. The eastern, southern and western borders of the lake are characterized by agricultural lands and fish farms. It has one direct channel (El Bughaz) of communication with the Mediterranean Sea in addition to Brimbal Canal, which exists in the western extremity of the Lake and receives fresh water directly from Rossetta branch during the flood periods (Masoud *et al.,* 2011). The Burullus lake has been used as a water reservoir for irrigation of agricultural land, through discharges of drains (El-Reefy *et al.,* 2009). The Lake receives 2.46 x 10^9 m^3 y^{-1} of brackish water through drains (Masoud *et al.,* 2011).

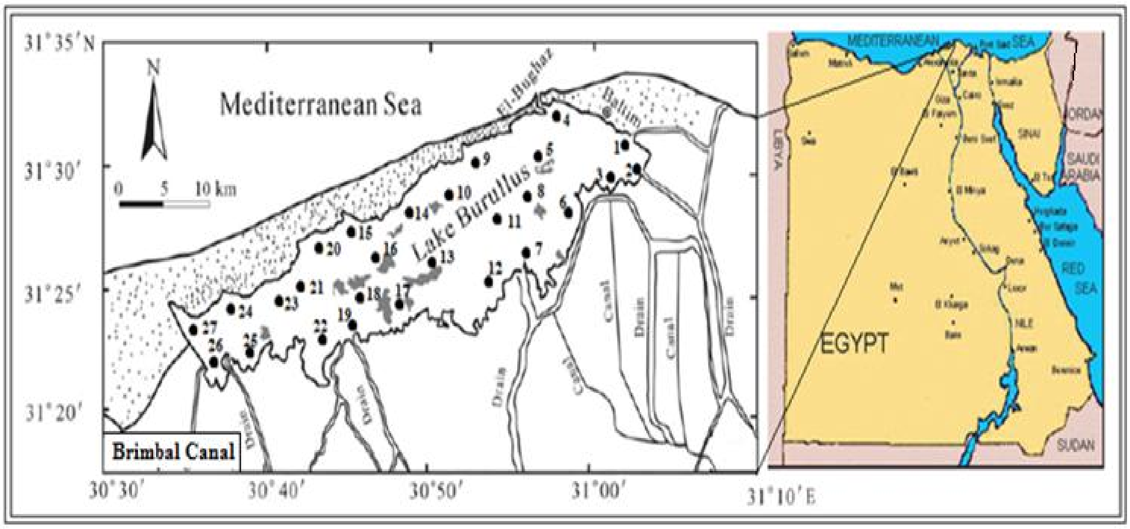

Fig 1. Burullus Lake location map and sampling stations

Samples collection

The samples were collected from the area of study along the lake in 2012. Totally twenty seven sediment samples from different sites have been collected from Burullus Lake as in Figure (1). The geographical description and physic-chemical parameters of collected samples are shown in Table (1). Global Positioning System (GPS) device (Garmin 76) was used to determine the positions latitudes and longitudes. The collected samples were carried out using an oceanographic ship by a grab sampler (Ekhman type).The pH of sediment was measured with glass electrode with pH meter (model Jenway 3071) after calibration with buffer solutions of pH 7. The sediment samples were dried in an oven at 80°C, pulverized, homogenized and sieved through a 0.125 mm mesh.Water salinity will be determined by the direct Gravimetric Method (APHA, 1992). The organic content percentage in sediment samples was determined as weight loss after ashing the samples at 750 °C for about 30 minutes (USDOE, 1992).

Table 1. Geographical description and physic-chemical parameters of Burullus Lake.

Sampling site	No. of samples	Longitude (E)	Latitude (N)	Sampling date	Water depth (cm)	pH	TOM (%)	Salinity (‰)
1	2	31°04′28.8″	31°33′23.2″	2/1/2012	50	7.72	9.8	2.7
2	1	31°04′27.6″	31° 32′07.7″	2/1/2012	120	7.82	8	2.2
3	1	31° 04′03.1″	31°31′46.7″	2/1/2012	120	8.25	8.2	2.6
4	3	30°59′ 54″	31° 34′18.7″	2/1/2012	70	7.7	5.6	36.1
5	2	30°57′39.2″	31°32′ 39.9″	2/1/2012	150	7.7	13	9
6	2	30°59′42.2″	31° 30′ 46.3″	3/1/2012	65	7.71	26.2	8.2
7	1	30°58′01.3″	31° 30′58.1″	3/1/2012	75	7.65	11.4	1.9
8	2	30°58′ 20.4″	31° 32′ 27.5″	3/1/2013	80	7.57	14	9.5
9	2	30°55′ 29.7″	31° 33′ 22.3″	2/1/2012	100	7.7	12.6	2.7
10	3	30°55′ 25″	31° 32′ 73.7″	2/1/2012	110	7.82	13	3.6
11	3	30°55′ 34.3″	31°30′ 15.7″	3/1/2012	90	8.08	13	3.4
12	1	30°52′ 37.8″	31°27′ 54.1″	2/1/2012	80	7.87	9	3.1
13	2	30°49′ 08.6″	31° 28′ 55.8″	2/1/2012	50	7.54	18.8	1.8
14	1	30°52′ 98.4″	31° 32′ 21.8″	2/1/2012	110	7.48	19.6	2.5
15	3	30°46′ 12.0″	31° 29′ 15.2″	2/1/2012	110	7.69	19.2	1.6
16	1	30°46′ 49.7″	31° 28′ 45″	2/1/2012	70	7.76	16.4	1.5
17	3	30°48′ 54.5″	31° 25′ 18.1″	2/1/2012	60	8.03	8.4	3.3
18	2	30°45′ 46.4″	31° 24′ 38.2″	2/1/2012	90	7.46	13.4	1.1
19	3	30°45′ 30.2″	31° 26′ 11.6″	2/1/2012	100	7.45	13.6	1.4
20	1	30°43′ 17.8″	31° 28′ 07.6″	2/1/2012	120	7.7	3.5	1.8
21	2	30°40′ 55.2″	31° 25′ 42.9″	2/1/2012	120	7.6	2.6	1.9
22	1	30°42′ 48.9″	31° 25′ 23.6″	2/1/2012	110	7.1	13.5	1.4
23	1	30°39′ 41.7″	31° 25′ 25.5″	2/1/2012	110	7.47	16	2
24	2	30°36′ 53.7″	31° 25′ 22.5″	2/1/2012	90	7.61	12	2.3
25	1	30°36′ 32.5″	31° 23′ 23.8″	2/1/2012	70	6.92	14.2	0.9
26	2	30°35′ 09.7″	31° 24′ 06.3″	2/1/2012	110	7.4	13.2	5
27	2	30°34′ 45.6″	31° 24′ 51.5″	2/1/2012	95	7.29	16.2	1.5

Experimental techniques

Gamma spectrometric analysis

The samples were analysed non-destructively, using gamma-ray spectrometry with a high-purity germanium (HP- Ge) detector at Nuclear Laboratory, Physics Department, Faculty of Women's for Art, Science and Education, Ain Shams University. The γ- spectrometry technique used to determine the activity concentrations in units of Bq/kg for ^{226}Ra, ^{210}Pb and ^{137}Cs.

For the radiometric analysis, each dried sample was splattered by quartering, weighed and transferred to 200-ml capacity polyethylene Marinelli beakers, then sealed and stored for four weeks to both prevent the escape of the radiogenic gases (^{222}Rn and^{220}Rn) and to allow the attainment of radioactive equilibrium in the decay chain. After equilibrium, the samples were subjected to gamma-ray spectrometric analysis. Each sample was measured during an accumulation time between 20 h and 24 h. After the measurement of each sample, an empty cylindrical plastic container (polyethylene Marinelli beaker) was placed in the detection system for a counting period of 48 h to collect the background count rates.

This detector has a relative efficiency of approximately 50% of the 3″ x 3″ NaI(Tl) crystal efficiency, with a resolution of 1.90 keV and a peak/Compton ratio of 69.9:1 at the 1.33 MeV gamma-ray transition of ^{60}Co. The detector is coupled to conventional electronics and connected to a multi-channel analyser (MCA) card installed in a PC. The detector is shielded from the background radiation, using a 10-cm thick lead shield, internally lined with a 2-mm thick copper foil. The software program MAESTRO-32 was used to accumulate and analyse the data. The efficiency calibration was performed by using three well-known reference materials obtained from the International Atomic Energy Agency for the U, Th and K activity measurements: RGU-1, RGTh-1 and RGK-1, respectively (IAEA 1987; Anjos *et al.,* 2005 and El-Aassy *et al.,* 2012).

The specific activity of ^{214}Pb was measured using the 295.2 keV and 351.9 keV peaks, whereas the specific activity of ^{214}Bi was measured using the 609.3 keV, 1120.3 keV and 1764.5 keV peaks and the specific activity of ^{226}Ra was measured using 186.1 keV peak. The average of these activities indicates ^{238}U series (^{226}Ra). The specific activity of ^{210}Pb was measured using the 46.5 keV and 661.6 keV peak for ^{137}Cs.

Quality control (QC) procedures are used to verify the accuracy of investigation data. To check the quality of data from field sampling efforts, field duplicated will be collected for analysis. Laboratory QC checks are used with analytical a methodology that includes participating in international comparison and regular measurements of reference samples. Specific activity of ^{210}Pb in reference sample IAEA-RGU is 4940 (Bq/kg dry weight) while the measured value of the reference sample is 4819±348 (Bq/kg dry weight).

Inductively coupled plasma–mass spectrometry (ICP-MS) analysis

Some samples were analyzed using inductively coupled plasma–mass spectrometry (JMS-PLASMAX2)utilizing the latest model of reversed double-focusing mass spectrometer equipped with quadruple focusing system Qj known as(QQHQC) .The samples were analyzed at the Central Laboratory for Elemental and Isotopic Analysis, Nuclear Research Centre, Atomic Energy Authority, Egypt.

Radioactivity counting

The net area count after background corrections in each photo-peak was used in the computation of the activity concentration (C) in units of Bq kg^{-1} for each of the radionuclides in the samples using the following expression, after (Jibiri *et al.,* 2007):

$$C(\mathrm{Bq\ Kg^{-1}}) = \frac{C_n}{\varepsilon P_\gamma M_S} \qquad (1)$$

Where C_n is the count rate under each photo-peak due to each radionuclide, ε is the detector efficiency for the specific γ-ray, P_γ is the absolute transition probability of the specific γ-ray, and M_s is the mass of the sample (kg). The lowest limits of detection (LLD) were obtained from the relation (Jibiri and Bankole, 2006):

$$\mathrm{LLD} = \frac{4.66\ S_b}{\varepsilon \times I_\gamma} \qquad (2)$$

Where S_b is the estimated standard error of the net background count rate in the spectrum of the radionuclide and Iγ is the abundance of gamma emissions per radioactive decay. The LLD values obtained were 1.307, 10.94 and 0.025 Bq kg^{-1} for ^{226}Ra, ^{210}Pb and ^{137}Cs, respectively.

Results and Discussion

It is important to analyses the physic-chemical parameters of Burullus Lake in order to evaluate their contributing effect on radionuclides concentration. Water depth, pH, TOM and salinity of Lake are given in Table (1) and shown in Figure (2).

Table 2. Specific activity of ^{226}Ra, ^{210}Pb$_{total}$, ^{210}Pb$_{ex}$, ^{137}Cs and ^{210}Pb$_{total}$/^{226}Ra activity ratio in sediment samples of Burullus Lake .

Sampling Site	^{226}Ra (Bq kg^{-1})	^{210}Pb$_{total}$ (Bq kg^{-1})	^{210}Pb$_{ex}$ (Bq kg^{-1})	^{137}Cs (Bq kg^{-1})	^{210}Pb/ ^{226}Ra
1	11.62±0.31	60.07±17.53	48.45±17.22	0.49±0.05	5.17
2	LLD*	n.d**	-	LLD*	-
3	LLD*	n.d**	-	LLD*	-
4	8.79±0.34	259.96±74.18	251.17±73.84	0.83±0.12	29. 57
5	9.88±0.36	264.95±60.59	255.07±60.23	2.74±0.14	26.82
6	9.04±0.40	LLD*	-	5.34±0.22	-
7	9.13±0.32	LLD*	-	4.86±0.15	-
8	11.53±0.45	LLD*	-	3.63±0.17	-
9	9.75±0.38	115.01±23.41	105.26±23.03	3.99±0.17	11.79
10	12.41±0.46	18.78±6.31	6.37±5.85	3.91±0.19	1.51
11	11.64±0.34	LLD*	-	2.16±0.15	-
12	12.97±0.45	LLD*	-	3.78±0.14	-
13	10.62±0.34	103.80±31.4	93.18±31.06	2.78±0.12	9.77
14	11.53±0.41	97.53±35.22	86.00±34.81	7.65±0.23	8.46
15	9.99±0.37	61.71±3.33	51.72±2.96	0.88±0.16	6.18
16	10.30±0.40	177.06±51.73	166.76± 51.33	2.20±0.18	17.19
17	10.22±0.34	84.23±27.47	74.01±27.13	0.50±0.08	8.24
18	14.63±0.42	71.69±16.33	57.06±15.91	1.59±0.13	4.90
19	12.17±0.48	LLD*	-	1.75±0.14	-
20	LLD*	n.d**	-	LLD*	-
21	11.85±0.38	LLD*	-	1.18±0.09	-
22	LLD*	n.d**	-	LLD*	-
23	13.73±0.41	LLD*	-	1.53±0.12	-
24	12.19±0.47	240.18±45.65	227.99±45.18	7.84±0.38	19.70
25	LLD*	n.d**	-	LLD*	-
26	10.18±0.34	177.01±47.38	166.83±47.04	1.13±0.10	17.39
27	11.53±0.45	275.10±68.02	263.57±67.57	1.07±0.15	23.86
Range	8.79-14.63	18.78-275.10	6.37-263.57	0.49-7.84	1.51-29.57
Average	11.17±0.34	133.80±33.90	123.59±33.54	2.81±0.15	12.72

** The lowest limits of detection (LLD) ** Not detect* ^{210}*Pb ex =* ^{210} *Pb total –supported* ^{210}*Pb (=*^{226}*Ra)*

The depth of Burullus Lake is fluctuated from 50 to 150 cm. Lakes are classified as shallow (H<7 m) and deep (H>7 m) (IAEA, 2003).According to this, Burullus is a shallow lake. The deepest area of the lake is located near El Bughaz. Hence, it is the direct channel of communication with the Mediterranean Sea. The pH values of sediment lake was found in the alkaline side (pH > 7.0) as pointed by (Abdo, 2005a). It is fluctuated between 6.92 and 8.25 tendencies to the alkaline side. This is may be due to increase photosynthetic activity of planktonic algae (Fathi and Abdelzahar, 2005). Otherwise, the lowest values of pH were recorded near Brimbal canal as shown in Fig (2). The total organic matter content (TOM) of sediment is ranged from 3 to 27 %. It is obvious that, the highest values of TOM are located at shoreline of lake. This is may be due to effect of the drainage water along offshore of the Lake. The salinity values are ranged from 0.9 to 36.1 ‰ with highest value at El Bughaz channel as shown in Figure (2). This is may be due to the effect of sea water input from the Mediterranean Sea. Otherwise, the lowest values of salinity are detected at south western of the Lake. This is due to fresh water of Brimbal Canal. According to the results, the Burullus Lake is a brackish basin.

The activity concentrations of ^{226}Ra (^{238}U) series, $^{210}Pb_{total}$,$^{210}Pb_{ex}$ and ^{137}Cs (Bq/kg dry weight) in sediment samples and $^{210}Pb_{total}$/ ^{226}Ra activity ratios are shown in Table (2). The detected value of ^{226}Ra was ranged from 8.79 to 14.63 Bq/kg with average value 11.17±0.34 Bq/kg. The detected value of $^{210}Pb_{total}$ was ranged from 18.78 to 275.10 with average value 133.80±33.90 Bq/kg. On the other hand, the activity concentration of $^{210}Pb_{ex}$ was ranged from 6.37 to 263.57 Bq/kg with average value 123.59±33.54 Bq/kg. And the detected value of ^{137}Cs was ranged from 0.49 to 7.84 Bq/kg with average value 2.81±0.15 Bq/kg.

It is obvious that the activity concentration of ^{226}Ra changed in a narrower lower range than the range of concentrations reported by the UNSCEAR, 2000 survey. Otherwise, the activity concentration of $^{210}Pb_{total}$ is changed with wide range with highest values at El Bughaz channel and Brimbal Canal. These data indicate that the anomalously high levels of Pb may be due to effect of the contamination of atmosphere. It is seen that there is disequilibrium between Ra-Pb in sediment samples. This is reverted to many reasons ^{210}Pb and ^{226}Ra specific activities depend on the rock type from which the sediment is formed, the atmospheric deposition, and the physical and chemical properties of sediment and radionuclides (Khater, 1998).In addition, radium is strongly adsorbed to particles in freshwater otherwise; in seawater they are primarily dissolved(Moore and Shaw, 2008). In other words, ^{226}Ra tends to stay mobilized in the seawater while its daughter ^{210}Pb tends to attach to particulate matter and be removed from water column (Sirelkhatim *et al.,* 2008). These differences in chemical behavior between Ra and Pb may explain the obvious Ra-Pb disequilibrium. The presence of atmospheric deposition of ^{210}Pb is varied according to upward radon flux and meteorological conditions (Beks *et al.,* 1998).
The excess^{210}Pb was determined by the difference between ^{210}Pb $_{total}$ and supported ^{210}Pb activity =^{226}Ra. $^{210}Pb_{ex}$ in the sediment is derived from re suspension material, which implies that resuspension events can significantly alter the mobility of particulate matter and particle-reactive contaminants in Burullus Lake. We observed that the highest concentration of $^{210}Pb_{ex}$ along the lake was located near El Bughaz channal and Brimbal canal. The concentration of $^{210}Pb_{ex}$ could be affected by the atmospheric contaminations especially in open area, Figure (3) clarifies the image pathways of Pb-210 in Burullus Lake. The unsupported ^{210}Pb is derived from both atmospheric depositions and the watershed erosion transferred into the lake water which is then incorporated into lake sediment.

The ^{137}Cs might have been deposited in sediment of Burullus Lake, presumably a result atmospheric contamination of nuclear weapon tests and nuclear accidents. ^{137}Cs does not exist in sediment naturally and it is a product of fallout radioactivity. It is obvious that there is an increase in ^{137}Cs values in shoreline of the lake due to the highest values of TOM contents. Because of high solubility of Cs in brackish water (Ueda *et al.,* 2009). It can be assumed that its excess was released into lake environment from the surrounding soil through the water current (El Reefy *et al.,* 2009). There is similar distribution between Cs and TOM in the lake as shown in Fig (2).We confirmed that there is an excess in ^{137}Cs values by the results obtained from ICP-MS. The determination of the total isobars at mass 137 is clearly relevant to the sum of Cs-137 and Ba-137 at mass137.Then the presence of Ba-137 is an indicator for the presence of Cs-137,which emits gamma rays of energy 661.6 keV through its short-lived decay product called ^{137}Ba (Nada *et al.*, 2009 and Ptois *et al.,* 2007). Table (3) shows the concentrations of Ba-137 in some sediment samples which were analyzed by ICP–MS (134.9, 120.7 and 109.5) ppm for samples 6, 14 and 24, respectively.

The activity ratio of $^{210}Pb_{total}/^{226}Ra$ was ranged from 1.51 to 29.57 with average value (12.72). There is surface enrichment of ^{210}Pb with respect to their progenitor ^{226}Ra as it is evident from the activity ratios of $^{210}Pb_{total}/^{226}Ra$ are greater than unity. This could be attributed to radium-226 is decaying to ^{222}Rn gas and the mobility of the radon is regarded as one of the main causes of disequilibrium in the uranium decay series (El Mamoney and Khater ,2004). Also, the fact of ^{210}Pb is particle reactive in nature and can easily be removed from the seawater by adsorption onto settling particles resulting in their enrichment in surface sediment relative to their progenitor (^{226}Ra) (Sirelkhatim *et al.,* 2008).
A comparison of radionuclides activities in the sediment of the studied area and in other coastal and aquatic environments is done. The value of ^{137}Cs activity in the sediment is lower than in the study done by El-Reefy *et al*., (2009). Otherwise we found the value of ^{137}Cs is in agreement with that measured in Nasser Lake by Khater *et al.,* (2005).On the other hand, the concentration of ^{210}Pb in the present study is higher than the value

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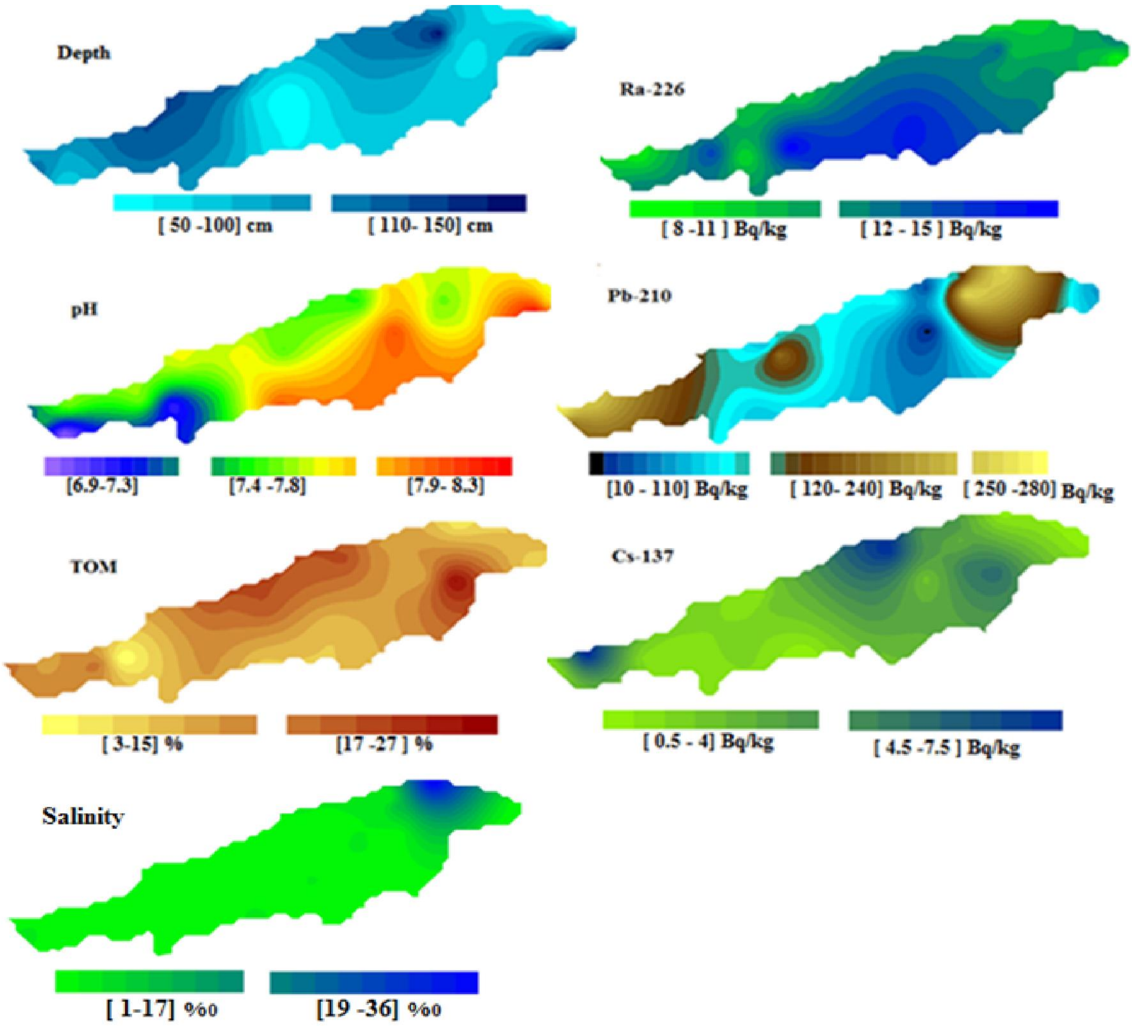

Fig 2. Contour maps of environmental variables (Depth, pH, TOM and salinity) and radionuclides concentrations (^{226}Ra, ^{210}Pb $_{total}$ and ^{137}Cs) (Bq Kg^{-1}) for sediment samples

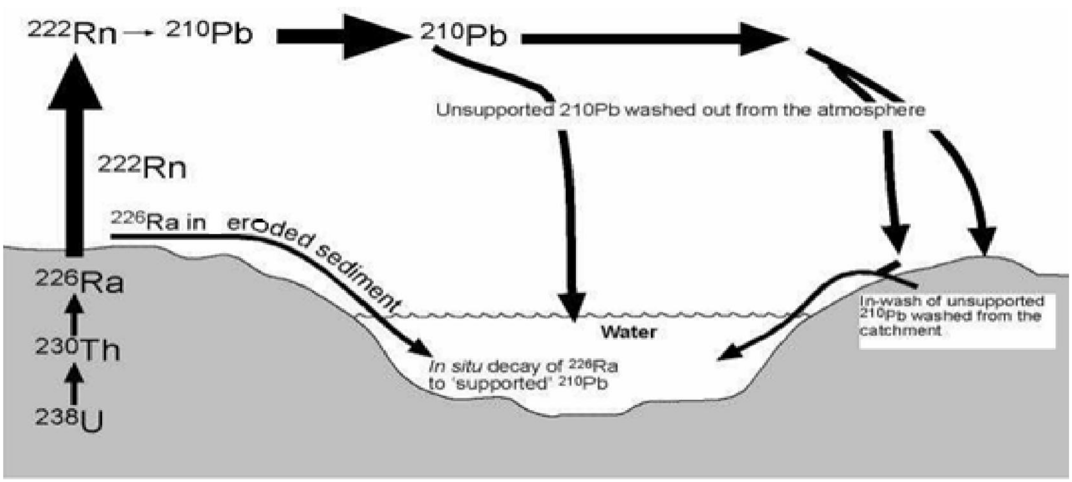

Fig 3. Image picture for pathways of Pb-210 in Burullus Lake

of ^{210}Pb measured in some of the Egyptian lakes such as Qarun, Bardawill, Edku and Nasser Lake by Khater (1998)

Table 3. The concentration of Ba-137 in Burullus sediment samples

Sample No.	Concentration (ppm)
6	134.9
14	120.7
24	109.5

Statistical analysis

There are environmental variables that controlled and affected the behavior of radionuclides concentrations in Burullus Lake. So to know the effect of these variables and predict the distributions of radionuclides, Canonical Correlation Analysis (CCA) was carried out. Canonical correlation analysis was a relatively unknown statistical technique. Canonical correlation is allowed for the assessment of the relationship between independent variables and multiple dependent measures. CCA is carried out between environmental variables (pH, TOM and Salinity) and radionuclides (Ra-226,Pb-210 and Cs-137). It is obvious from the Figure (4) there is negative correlation between ^{226}Ra and pH and Salinity. Otherwise, Pb-210 is related to salinity with positive and intermediate correlation. This confirms the disequilibrium between Ra-Pb according to their different behavior in Burullus Lake. On the other hand, there is no relation between ^{226} Ra, ^{210}Pb and organic matter. While ^{137}Cs has a good correlation with TOM and it has negative correlation with salinity. Because of the possible correlations between the activity concentrations of ^{137}Cs in sediment and both of TOM and salinity, a regression equation with these two independent variables was evaluated. The simple linear model was chosen to fit the experimental data. With these two independent variables the prediction of the activity concentration (C_{Cs}) was expressed by the following equation:

$$C_{Cs} = (0.96\pm1.46)+(0.14\pm0.09)TOM+(-0.01\pm0.06)Salinity$$

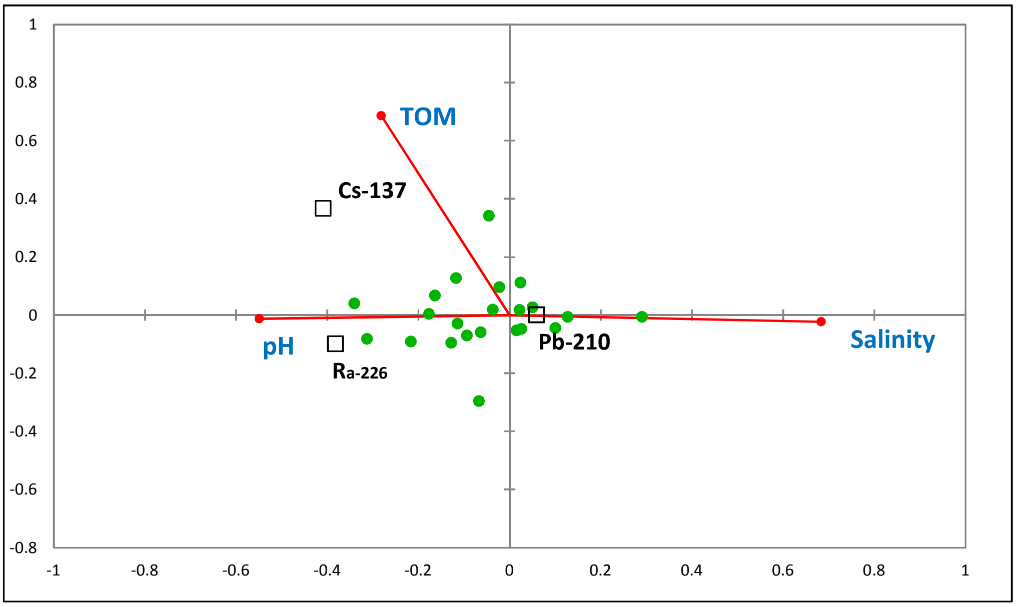

Fig 4. Correlation coefficient with CCA between environmental variables (pH, TOM and salinity) and radionuclides concentrations (^{226}Ra, $^{210}Pb_{total}$ and ^{137}Cs)

Conclusion

Burullus Lake is a shallow, alkaline and brackish lake. There is increment in TOM along shoreline of lake. This could be due to the existence of many drains discharge water into the Lake. On the other hand, there is disequilibrium between ^{226}Ra and ^{210}Pb. This is may be due to the geochemical differences between Ra and Pb. Furthermore, there is excess of Pb in Burullus Lake especially near El Bughaz channel and Brimbal cannal. In addition, Pb-210 is absorbed onto the fine grained sediment mainly silt clay. The fine grained sediment has high values of Pb-210 (both supported and unsupported value). It is obvious that ^{137}Cs is present in the sediment. There is excess in Cs which may have been released into the lake from surrounding soil. This is confirmed by the results of analysis of some samples with ICP-MS. It is clarified that TOM has high influence on ^{137}Cs distribution in Burullus Lake. This is obvious from contour maps; there is similarity in distribution of TOM and Cs in Lake. The activity ratios of ^{210}Pb/^{226}Ra are greater than unity because surface enrichment of Pb with respect to their progenitor Ra. Finally, the contaminations of particle-reactive patterns (such as ^{210}Pb and ^{137}Cs) present in sediment of Burullus Lake may be due to atmospheric contaminations.

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