Uranium series isotopes concentration in sediments at San Marcos and Luis L. Leon reservoirs, Chihuahua, Mexico

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Uranium series isotopes concentration in sediments at San Marcos and Luis L. Leon reservoirs, Chihuahua, Mexico

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Abstract. Spatial and temporal distribution of the radioisotopes concentrations were determined in sediments near the surface and core samples extracted from two reservoirs located in an arid region close to Chihuahua City, Mexico. At San Marcos reservoir one core was studied, while from Luis L. Leon reservoir one core from the entrance and another one close to the wall were investigated. ^{232}Th-series, ^{238}U-series, ^{40}K and ^{137}Cs activity concentrations (AC, Bq kg^{-1}) were determined by gamma spectrometry with a high purity Ge detector. ^{238}U and ^{234}U ACs were obtained by liquid scintillation and alpha spectrometry with a surface barrier detector. Dating of core sediments was performed applying CRS method to ^{210}Pb activities. Results were verified by ^{137}Cs AC. Resulting activity concentrations were compared among corresponding surface and core sediments. High ^{238}U-series AC values were found in sediments from San Marcos reservoir, because this site is located close to the Victorino uranium deposit. Low AC values found in Luis L. Leon reservoir suggest that the uranium present in the source of the Sacramento – Chuviscar Rivers is not transported up to the Conchos River. Activity ratios (AR) ^{234}U/ ^{238}U and ^{238}U/^{226}Ra in sediments have values between 0.9-1.2, showing a behavior close to radioactive equilibrium in the entire basin. ^{232}Th/^{238}U, ^{228}Ra/^{226}Ra ARs are witnesses of the different geological origin of sediments from San Marcos and Luis L. Leon reservoirs.

Keywords: *Uranium*, *^{210}Pb-^{137}Cs dating, fresh water sediments, radioactivity analysis, Chihuahua.*

PACS: 91.67.Pq; 91.67.Qr; 91.67.Ty.

INTRODUCTION

Disequilibrium in uranium and thorium decay series is an important and potential indicators for tracing migration of the these radionuclides in the environment [1]. They can show changes and disturbance in the lithology of a selected site. Usually, (dis)equilibrium is analyzed by means of the *activity ratios* (AR) between given radioisotopes of the same or different decay series.

U_{nat} and Th concentration in the earth crust is around 1.7 and 8.5 mg kg^{-1} for U_{nat} and Th respectively. They are associated to some oxides as uraninite, thorianite, which contents tend to have an increased value in igneous rocks.

The distribution of natural radionuclides in sediment cores and their AR has been studied by several authors [2-7] to know the effects of soil properties in biogeochemical mobilization of these radionuclides and understand their behavior in the environment.

The selected site for this study is located in the state of Chihuahua, Mexico's northern border. The Basin of Sacramento-Chuvíscar Rivers, which constitute the last major tributaries to the Rio Conchos, originates in the vicinity of a uranium deposit in San Marcos, Chihuahua, where a reservoir of the same name is located. The last Rio Conchos reservoir before joining the Rio Grande is created artificially by the Luis L. Leon "El Granero" dam [8].

Radiation Physics
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In Chihuahua State, several radioanomalies have been found. Some of them are located in San Marcos basin [9]. Here, both surface and ground waters are important resources to the region. The surface water gathered in San Marcos dam reservoir is used for agricultural purposes, whereas groundwater from shallow and deep wells is used for both agricultural and domestic activities. Previous studies in the mentioned site show the presence of uranium in surface waters, fish, and some plants [10-13].

Data about reservoir's water radioisotopes content shows high uranium specific activities up to 7.7 $Bq \cdot L^{-1}$. The high uranium concentrations in the area are attributed to the lixiviation and/or erosion of the uraniferous deposits located in this area [14-16].

Natural uranium and thorium concentration has not been reported before in the Luis L. Leon area. The main purpose of this paper is to verify if U- and Th radioisotopes are transported from San Marcos area to Luis L. Leon reservoir.

STUDY AREA, MATERIALS AND METHODS

Two sites were selected for this stud, the first is San Marcos reservoir, located approximately 25 kilometers West-Northwest to Chihuahua City, Mexico. It was built in the beginning of the XX century. It has a capacity of 4.45 million m^3 of water and is used in flood control and agriculture in the area. The lithology of the study area consists mainly of volcanic and volcanoclastic rocks of rhyolitic composition dikes and resurgent rhyolite domes and dikes of intermediate to basic composition [9]. It also has few outcrops of Cretaceous limestone in the northern boundary of the basin [16]. Uranium deposits at San Marcos, named as Victorino and San Marcos I, and their minerals have been recently described by Reyes-Cortés, et al. [17]. The mineral species found in the San Marcos deposits were: uranophane and metatyuyamunite at San Marcos 1 site; uranophane, uraninite, masuyite and becquerelite at Victorino site [17]. The other is the Luis L. Leon reservoir, located approximately 90 kilometers Northeast of Chihuahua City. It was built in 1968, having a water capacity of 854 million m^3. The reservoir is used in the fish hatchery to control the species that there exist, farm, agricultural and domestic use. The rocks exposed in the region are limestone, igneous intrusive and volcanic, whose ages range is from the Upper Jurassic to the Recent. At least three abandoned mines are located near to this reservoir: Carrizalillo, Chorreras and La Verde [8].

Sampling

Three sediment cores were collected manually following a well-established protocol with a steel tube (7 cm diameter and 40 cm length). Figure 1 shows the geographic location of Chihuahua State, as well as of the two reservoirs studied. One sediment core was extracted at 20 m depth from San Marcos reservoir in September 2007 (CSM), at a place close to the dam's wall. The two cores from Luis L. Leon reservoir were taken at 10 m depth, one near to the reservoir's entrance (ECLLL) and the other at the northern zone (NCLLL) in April 2012. Also some surface sediment samples were taken, close to the sediment cores sampling sites; table 1 shows the details of the location of sediment cores and surface sediments samples.

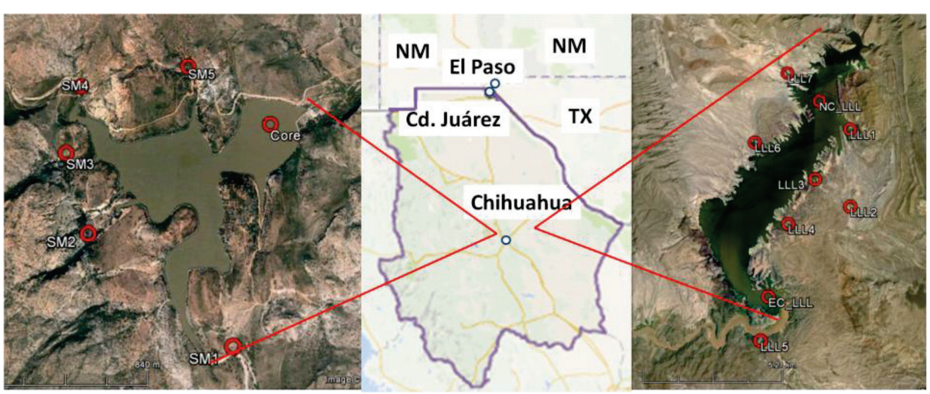

FIGURE 1. Study area showing the location and the sampling points for a) San Marcos and b) Luis L. Leon reservoirs

TABLE 1. Sampling details of sediment cores and surface sediments collected at San Marcos and Luis L Leon reservoirs' areas.

Reservoir	Sample type	Sample ID	Location (lalitude, longitude)
San Marcos.	Core	CSM	28.74174, -106.35683
	Surface sediment	SM1	28.77962, -106.35839
	Surface sediment	SM2	28.78555, -106.36757
	Surface sediment	SM3	28.78999, -106.36956
	Surface sediment	SM4	28.79408, -106.36915
	Surface sediment	SM5	28.79525, -106.36228
Luis L. Leon.	Core	ECLLL	28.88401, -105.30953
	Core	NCLLL	28.95626, -105.29211
	Surface sediment	LLL1	28.94499, -105.27856
	Surface sediment	LLL2	28.91572, -105.27756
	Surface sediment	LLL3	28.92618, -105.29260
	Surface sediment	LLL4	28.90981, -105.30293
	Surface sediment	LLL5	28.86896, -105.31165
	Surface sediment	LLL6	28.94045, -105.31855
	Surface sediment	LL7	28.96748, -105.30624

SM represents San Marcos area.
LLL represents Luis L. Leon area.

Laboratory analysis

The cores were cut into 2 cm thick sections. Sections were dried at 55 ºC to constant weight, ground to a powder with an agate mortar pestle, homogenized by sieving to <63 µm grain size and packed for further analysis.

Organic matter (OM) content was estimated by loss on ignition (LOI) at 550ºC according to [18].

^{210}Pb activity was determined by alpha counting of ^{210}Po, assuming secular equilibrium between ^{210}Pb, ^{210}Bi and ^{210}Po in the sediment after the sampling. The powder was digested with aqua regia (1:2) and ^{210}Po extracted using the technique of liquid-liquid extraction with tributyl phosphate (TBP), autodeposited on cupper disc and measured using an Alpha Analyst TM (CANBERRA) spectrometer. Samples were spiked with ^{209}Po as radiotracer yield [19-22].

^{238}U and ^{234}U ACs were determined for all samples, except in surficial sediments from San Marcos reservoir.

To obtain ^{238}U and ^{234}U ACs, all samples were spiked with ^{232}U and put under the radioanalytical analysis procedure. Total sample dissolution was performed by atmospheric acid digestion using HFc and HNO_3c (10:10). The uranium extraction was carried out by chromatography using UTEVA resins. Then, uranium was electrodeposited on stainless steel disc. Radiochemical yield was determined by the ^{232}U counting rate [23-26]. The ^{238}U, ^{234}U ACs were also determined by alpha activity measurements, using the same Alpha spectrometer.

All sections from the sediment cores and surface samples were analyzed for ^{238}U- and ^{232}Th-series isotopes (reported here as ^{226}Ra and ^{228}Ra), as well as ^{40}K and ^{137}Cs activities, by high resolution gamma spectrometry using a Canberra HPGe detector. Prior to the analysis, aliquots around 20 g were stored into petri dishes (15mm height per 75 diameter capacity), and hermetically sealed for at least 21 days in order to reach radioactive equilibrium between ^{226}Ra and ^{222}Rn, and their progenies. The detector was calibrated using RGU, RGTh and RGK IAEA certified reference materials in the same geometry as the measured samples. Counting time was 48 h; the analytical precision of the measurements was around 10%. Considering the appropriate corrections for laboratory background, the activity of ^{226}Ra (from ^{238}U-series) was determined from the 609 keV line of ^{214}Bi; ^{40}K activity from its 1461 keV line, ^{228}Ra (from ^{232}Th-series) activity was estimated from the 911 keV line of ^{228}Ac and ^{137}Cs from its 662 keV line.

To carry out the sediments' dating procedure, total $^{210}Pb_{tot}$ activities were estimated by measuring the activity of ^{210}Po, where secular equilibrium from ^{226}Ra to ^{210}Pb, ^{210}Bi and ^{210}Po in the sediment *after packing* is assumed [27] The sediment accumulation rate was obtained by the activity in excess $^{210}Pb_{exc,}$ as calculated from the difference of total and supported ^{210}Pb. Supported ^{210}Pb activity is equal to ^{226}Ra activity, by the secular equilibrium with its progenies attained before the measurement.

Dating

$^{210}Pb_{exc}$ (unsupported) was calculated in all cores in order to know which model would be applied [19].

$$^{210}Pb_{exc} = {}^{210}Pb_{total} - {}^{210}Pb_{sup} \qquad (1)$$

The Constant Rate of Supply model was selected; this model assumes that the supply of $^{210}Pb_{exc}$ to the sediment is constant through time [28], although the profile of this isotope may reflect the interaction of the sedimentation rate (SR) and radioactive decay. Then, $^{210}Pb_{exc}$ and SR can be variable through the time.

In this model the age *t* of each section at depth *z* is estimated by the following expression:

$$t = \frac{1}{\lambda_{Pb}} \ln\left(\frac{I(0)}{I(z)}\right) \qquad (2)$$

Where I*(0)* (Bq m^{-2}) is the total $^{210}Pb_{exc}$ inventory of the sediment core and *I(z)* is the total $^{210}Pb_{exc}$ in the sediment layer below depth z.

The sedimentation rate *R* (kg m^{-2} y^{-1}) is obtained directly from:

$$R = \frac{\lambda_{Pb} I(z)}{A(z)} \qquad (3)$$

Estimated ages obtained by applying this method were confirmed by comparison of the value derived from the ^{137}Cs activity measurements. Fallout of ^{137}Cs introduce this radioisotope in the water, and then in sediments. ^{137}Cs AC in sediment profiles has a peak in the vicinity of 1962-64 years associated to nuclear bomb testing in the atmosphere [29, 30], and in northern hemisphere, it has another peak related with year 1986 from the radionuclide dispersion produced by the Chernobyl accident [31-33].

RESULTS AND DISCUSSION

Sampling site of sediments affects both lithology and the environmental factors that may alter the weathering of the elements; consequently, sediments' radionuclides concentrations will be affected accordingly. The San Marcos reservoir has a narrowing that divides it into two vessels (West and East), and this may influence the sediment transport downstream along the lake (Figure 1). The sediment core CSM was collected in the vessel nearer to the dam's wall. This location is close to a spring located at the bottom of the San Marcos reservoir. The San Marcos dam collects water that runs from the West at the birth of the creek of the same name, near the Victorino uranium deposit during the rainy seasons. During these periods turbid water occurs frequently and it shows high organic matter content. During periods of drought in the lake the water level drops and the water looks very clean one.

Total $^{210}Pb_{tot}$ activities ranged from 84 to 313 Bq kg^{-1}, and the supported $^{210}Pb_{sup}$ activity varied from 60 to 275 Bq kg^{-1}. $^{210}Pb_{exc}$ activities were obtained by eq. (1). The $^{210}Pb_{exc}$ inventory in CSM was estimated to be 207.5±4 Bq m^{-2}, the mean $^{210}Pb_{exc}$ AC was 34.8 Bq kg^{-1} and its distribution did not show a monotonic behavior whereby the CRS model dating was applied (Figure 2). The $^{210}Pb_{exc}$ distribution is characterized by a near exponential decline, behavior typical of undisturbed soils. The model employed was corroborated by ^{137}Cs activities, where its maximum concentration were found at 36 cm depth, corresponding to 1963 weapons fallout peak, and at 16 cm depth, relevant to Chernobyl accident in 1986. The results obtained by

CRS method were accepted, as there is no discrepancy with the ^{137}Cs maker. The sedimentation rate calculated by eq.(3) shows high variability with time. These results were compared with data of rainfall in the region and a high correlation (r = 0.89) was observed. Consequently, low values in sedimentation rate belong to drought seasons and conversely high sedimentation rates are associated with periods of high rainfall contribution to the reservoir.

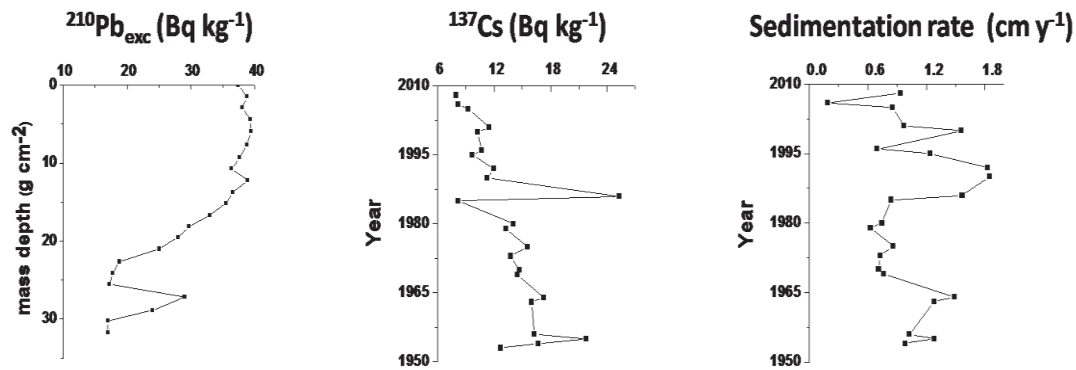

FIGURE 2. ^{210}Pb, ^{137}Cs concentration activities and sedimentation rate profiles (with uncertainty about 3 years) in sediment core in San Marcos reservoir (CSM).

All radionuclide concentration values were different if compare them in surface and core sediments (Table 2). Radionuclide concentrations were higher in surface sediments than in the sediment core, except for ^{137}Cs, because it corresponds to the two mentioned fallout events.

TABLE 2. Comparison of radionuclide concentrations among core and surface sediments at San Marcos reservoir. Different letter means that significant difference exists. Letter A means higher concentration.

	^{228}Ra	^{238}U	^{226}Ra	^{40}K	^{137}Cs
CSM	B	B	B	B	A
SMS	A	A	A	A	B

^{40}K, ^{228}Ra (^{232}Th) , ^{226}Ra and ^{238}U AC mean values in surface sediments were 1164, 377, 856, and 893.5 Bq kg^{-1}respectively (table 3); these results are alike those found in parent rocks in a previous study of the San Marcos – Victorino area [34] and correspond to their sampling locations, as pointed out above. On the contrary, core sediments' ACs are lower. These concentrations suggest that adsorption in core sediments correspond to the characteristics of the water column, provided in part by the spring located at the bottom of the reservoir, near the point where the sediment core was extracted.

Activity concentrations in both surface and core sediments are higher than the reported by UNSCEAR (2000), where reference values for earth crust are 35, 35, 30 and 400 Bq kg^{-1} for ^{226}Ra, ^{238}U, ^{228}Ra and ^{40}K, respectively. In core sediments ^{234}U and ^{238}U content shows a quite constant distribution (coefficient of variation =10%).

Activity ratios (AR) of U-series isotopes help in analyzing (dis)equilibrium and they may serve to reveal the relationship between factors such as weathering and adsorption [35]. The $^{234}U/^{238}U$ AR in core sediments were between 1.1 – 1.4 with a mean of 1.2, values close to the equilibrium (Table 3). High AR values were found in layers close to the water interface. This observation is consistent with values reported for San Marcos reservoir water in [14], that were obtained in a sampling performed at 2005, when the water level in reservoir was very low and most water in the vessel probably was supplied by the above mentioned spring.

^{40}K, ^{228}Ra (^{232}Th) and ^{226}Ra ACs show a coefficient of variation >20% in the sediment core profile (Figure 3); ^{40}K AC shows some increasing behavior with depth, finding the highest at the bottom of the core. ^{228}Ra (^{232}Th) shows variability in the profile due to high AC found in the first and last layers; if these values were considered as outliers, the behavior of the ^{228}Ra (^{232}Th) would be almost constant with depth, which could be explained by the low solubility of thorianite (ThO_2) and Th strong sorption onto the sediments. ^{226}Ra AC shows a non-monotonic behavior in the core profile.

The values of ^{226}Ra ACs divide the layers into two main groups, one for the layers closest to the surface, with ACs between 83 and 105 Bq kg^{-1}, and the other group for the deepest layers, with ACs between 57 and 71 Bq kg^{-1}. This behavior suggests that in deep strata reducing conditions prevail where ^{226}Ra is more soluble, while in shallow layers oxidation conditions could be found.

TABLE 3. Statistics of radionuclide concentrations and AR in San Marcos area.

CSM	^{40}K	^{226}Ra	^{228}Ra	^{238}U	^{234}U	$^{228}Ac/^{238}U$	$^{238}U/^{226}Ra$	$^{226}Ra/^{228}Ra$	$^{234}U/^{238}U$
Mean	971.9	80.4	147.6	92.7	112.7	1.6	1.2	0.6	1.2
S.D	181.9	16.4	30.4	9.6	10.5	0.3	0.3	0.2	0.1
Range	749.9 - 1257.6	57 - 104.8	106.9 - 210.6	78.7 - 106.7	99.5 - 125.9	1.1 -2-4	0.8 - 1.7	0.3 - 0.7	1.1 - 1.4
C.V (%)	18.7	20.4	20.6	10.4	9.3	20.8	24.0	30.3	6.5
SSM									
Mean	1163.7	856.1	376.8						
S.D	26.2	68.7	71.6						
Range	1123.8 - 1185.9	738.2 - 897.6	321.3 - 501.9						
C.V (%)	2.3	8.0	19.0						

^{238}U-and ^{232}Th-series isotopes commonly occur together in nature; the $^{232}Th/^{238}U$ mass ratio is around 3.5 in almost all natural systems [36]. AR mean value in earth crust is 1.2 [37]. The ^{228}Ra (^{232}Th) /^{238}U AR mean value in the sediment core was higher than 1.2. $^{238}U/^{226}Ra$ ARs show disequilibria (AR $\neq$1) in the ^{238}U chain at the first layer and the deepest four in the sediment core, where were found AR values between 1.3 and 1.7. This behavior may be explained by their differential ion mobility [6]. ^{228}Ra (^{232}Th) /^{226}Ra AR mean value in the core was 1.8, higher than AR=1.1 reported by (Evans 1997) in most environmental samples. Usually this AR is applied to assess the conservation of the proportion within ^{232}Th and ^{238}U decay series. Thereby, in this sediment core the expected proportion could not been observed.

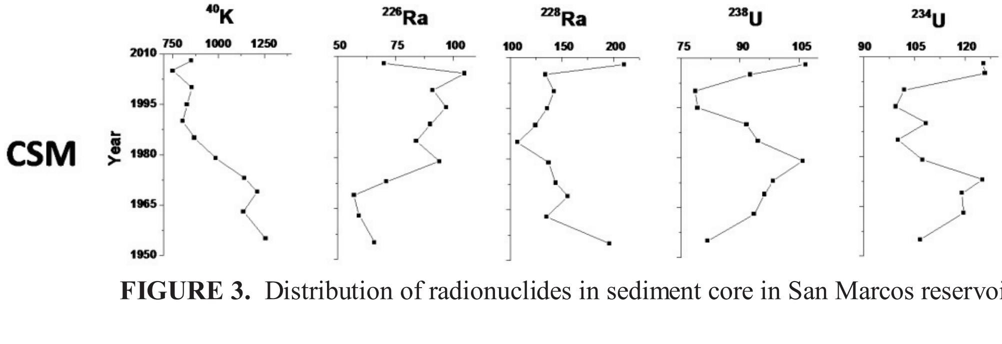

FIGURE 3. Distribution of radionuclides in sediment core in San Marcos reservoir.

Luis L Leon reservoir collects water that comes from the Rio Conchos basin. Its elongated shape has a length of approximately 12 km. Its relatively recent construction from a rough relief area but with a steady stream of water, produces a reservoir bottom of abundant vegetation including trees, which are now submerged. The vegetation and the topography may play the role of filtering the solutions and suspended material in the water flowing along the reservoir.

Both entrance and northern sediment cores (ECLLL and NCLLL) extracted from Luis L. Leon reservoir show a non-monotonic distribution of $^{210}Pb_{exc}$ concentration with depth, but they have an exponential decreasing. The CRS model dating was applied for them. $^{210}Pb_{tot}$ activities ranged from 48 to 59 Bq kg^{-1}, and 41 to 55 Bq kg^{-1} for ECLLL and NCLLL, respectively (Figure 4). The $^{210}Pb_{exc}$ inventory in ECLLL and NCLLL were estimated to be 194 ± 5 and 179 ± 3 Bq m^{-2}, respectively. The age calculated for the deepest layer of the ECLLL was down to the year 1976, whereas for the NCLLL it was 1971. The maximum ^{137}Cs activity concentration was found around 1989 in both cases, which suggest the acceptance of the dating model applied in this reservoir by the radioisotope concentration of the Chernobyl accident fallout. The sedimentation rates in ECLLL are correlated with rainfall (0.708 $p<0.001$) but not in the case of NCLLL. This could be related to the variability of the annual water discharge from the dam, producing changes in the sedimentation rates near dam wall.

U_{nat} concentrations were one order of magnitude higher in SMS and CSM than in sediments from the Luis L. Leon reservoir area. Activity concentrations of U_{nat} isotopes were higher in ECLLL than in NCLLL and SLLL (Table 4), suggesting that radionuclides are transported by the different streams reaching the reservoir. This feature suggests that radioisotopes are filtered from the water by the reservoir accidents, preventing their further transport downstream to the Rio Conchos.

^{232}Th, ^{238}U, ^{226}Ra ACs did not show difference between NCLLL and SLLL, suggesting that the core taken in this point could retain the features of the Luis L. Leon surface lithology; the difference in ^{40}K concentration in these samples is due to low content of feldspar in NCLLL.

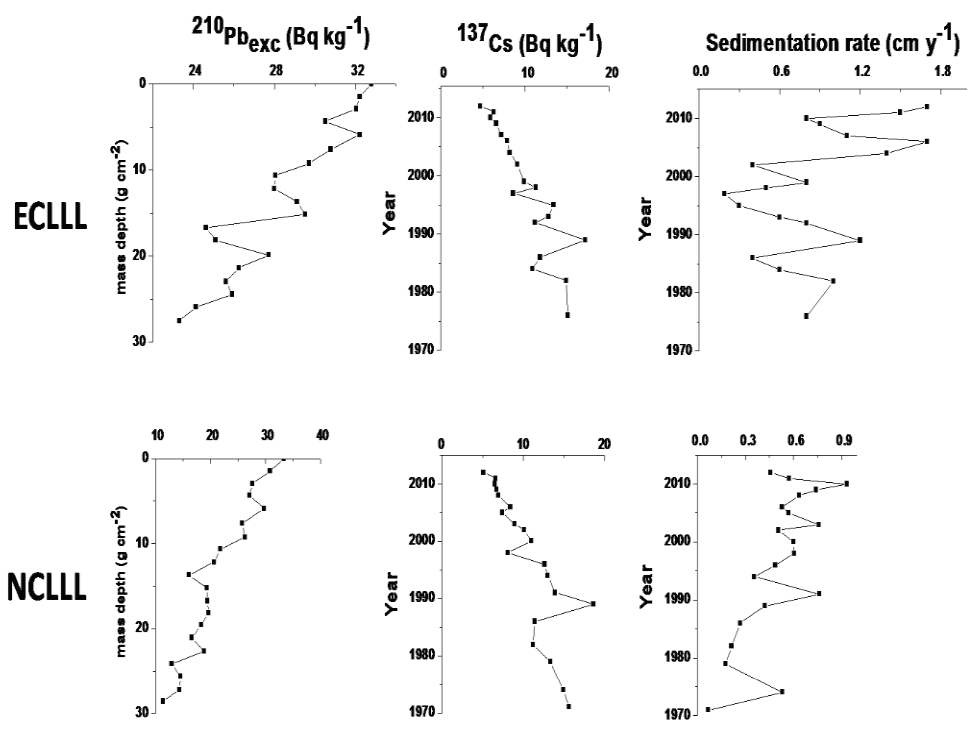

FIGURE 4. ^{210}Pb, ^{137}Cs concentration activities and sedimentation rate profiles in sediment core in Luis L. Leon reservoir. ECLLL means entrance and NCLLL Northern Core.

TABLE 4. Comparison of radionuclide concentrations among core and surface sediments at Luis L Leon reservoir area. Different letter means that significant difference exists. Letter A means higher concentration.

	^{228}Ra	^{238}U	^{226}Ra	^{40}K	^{137}Cs
ECLLL	A	A	A	A	A
NCLLL	B	B	A	B	A
SLLL	B	B	A	A	B

Only ACs values of ^{40}K were above the reference values established by [38] (400 Bq kg^{-1}) (Table 5). The high concentration of potassium corresponds to the feldspar appearing in the diffraction patterns.

Activity concentrations were homogenous in both sediment cores, the lower ACs were found in NCLLL. ^{228}Ra(^{232}Th)/^{238}U AR in ENLLL, NCLLL and surface sediments were about one, as in the upper earth crust. ^{234}U/^{238}U ARs are alike in both sediment core (1.1 – 1.2) indicating equilibrium between isotopes. The same may be observed for ^{226}Ra/^{238}U AR.

The radionuclide concentrations in both sediment cores did not show high temporal variability (C.V <20%). ^{238}U and ^{234U} showed almost the same behavior in both sediment cores, the concentrations of these radionuclides from certain depth to the bottom of the cores is almost constant (Figure 5).

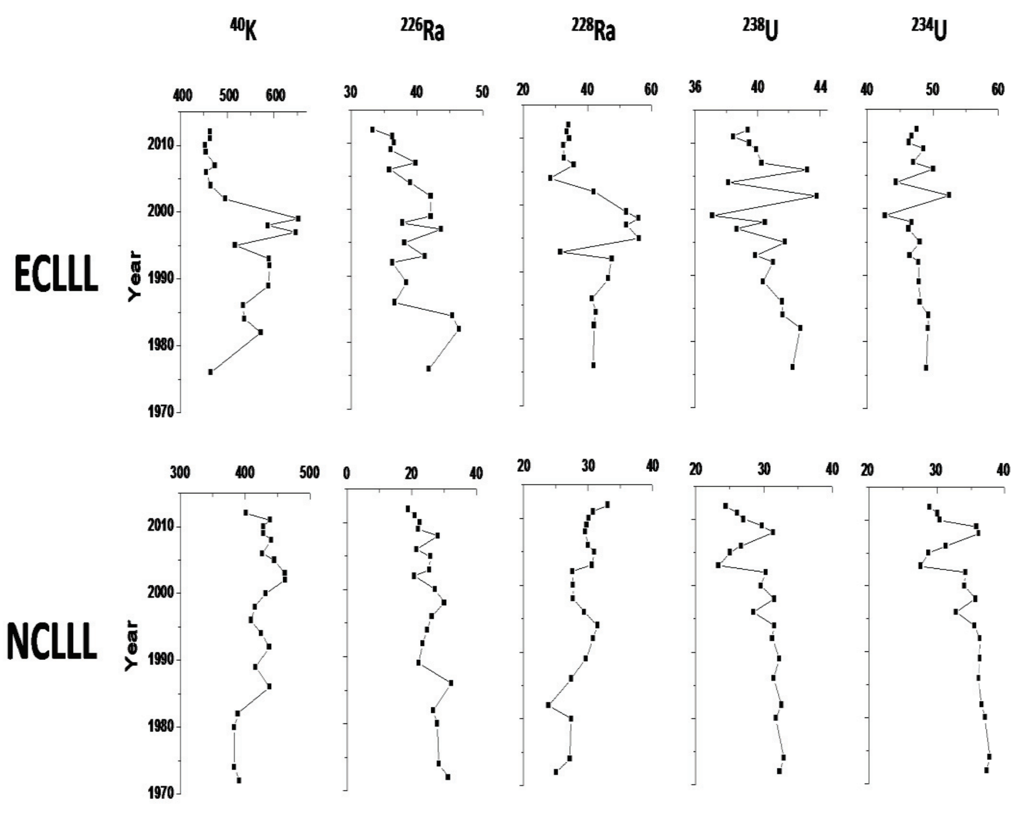

FIGURE 5. Distribution of radioisotopes in sediment core in Luis L. Leon reservoir.

TABLE 5. Statistics of radionuclide concentrations and AR in Luis L. Leon area.

ECLLL	^{40}K	^{226}Ra	^{232}Th	^{238}U	^{234}U	$^{228}Ac/^{238}U$	$^{238}U/^{226}Ra$	$^{226}Ra/^{228}Ra$	$^{234}U/^{238}U$
Mean	526.4	29.3	41.2	40.5	47.6	1.0	1.0	0.9	1.2
S.D	68.1	4.6	8.6	1.8	2.1	0.1	0.1	0.2	0.03
Range	452.3-652.5	33.3-46.4	28.5–56	37.1-43.8	42.7-52.5	0.8-1.1	0.8-1.1	0.6-1.2	1.1-1.2
C.V (%)	12.9	15.7	20.9	4.4	4.4	10.0	10.0	20.0	10.0
NCLLL									
Mean	422.2	25.3	29.0	29.5	33.9	1.4	1.0	0.7	1.2
S.D	23.7	3.7	2.2	3.0	3.3	0.3	0.2	0.2	0.02
Range	383.2-461.7	18.9-32.1	23.9-32.94	23.4-32.9	27.6-37.8	0.8-2.0	0.8-1.4	0.4-1.3	1.1 1.2
C.V (%)	5.6	14.7	7.7	10.2	9.6	22.4	16.6	25.8	1.9
SCLLL									
Mean	517.4	26.6	29.0						
S.D	101.6	4.3	5.2						
Range	352.8-659.1	18.1-31.1	24.3-38.7						
C.V (%)	19.6	16.1	17.8						

CONCLUSIONS

Variations in radionuclide concentrations with depth in all sediment cores provided information about the behavior of these in three sediment cores from two different reservoirs, and the way that they are transported or mobilized in the environment.

U_{nat} concentrations in San Marcos area sediments are affected by the erosion or lixiviation of the rocks from the natural deposits.

U_{nat} concentrations were one order of magnitude higher in SMS and CSM than in sediments from the Luis L. Leon reservoir area. These results suggest that erosion and weathering products of rocks from Victorino uranium deposit in the San Marcos area, that are assumed to be responsible of observed uranium concentration values in groundwater of the Chihuahua-Sacramento Valley [16], we conclude that at least in recent times do not reach the low Rio Conchos subbasin.

The non-anthropogenic or natural origin from San Marcos area uranium contents suggest that the natural mean concentration of U (2.3 mg kg^{-1}) in Luis L. Leon area may be considered as the Natural Concentration Level in the Rio Conchos basin.

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