# DETERMINATION OF SEDIMENTATION RATE IN ANZALI LAGOON OF NORTHERN IRAN USING $^{137}$Cs TRACER TECHNIQUE

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**Abstract.** One of the management tools for sediment and erosion control in the different scales from plot to watershed is informing about soil displacement process that can be obtained using fallout radionuclide spectroscopy. In recent decades, use of the radionuclides for determining sedimentation rate was common, among which Cesium ($^{137}$Cs) is the most often used. In this research, three, 4-meter long sediment cores were collected from the western part of the Anzali Lagoon. The Anzali Lagoon is one of the sediment treated ecosystems in the north of Iran. The level of $^{137}$Cs of the sediment samples was measured based on Spectrometry analysis in the Atomic Energy Organization of Iran. The grain size distribution showed that the sediment samples were mainly fine textured (Silt with low plasticity properties). The results represented that the highest amount of the $^{137}$Cs was observed in the depth of 2.4-2.7 m, which can be related to the Chernobyl disaster in 1986. An overall sedimentation rate of 8.5 cm yr$^{-1}$ (=119 kg m$^{-2}$ yr$^{-1}$) was obtained based on the $^{137}$Cs calendar of the sediment cores. This sedimentation rate is considerable, and a special arrangement is necessary to save the Lagoon.
**Keywords:** *core sampler, Anzali Lagoon, sediment color, sediment gradation, sedimentation rate*

## Introduction

The Anzali Lagoon with fresh water, located in the southern shore of Caspian Sea (Olah, 1990), is a suitable ecosystem for growing and farming aquatic organisms, so it has crucial importance from different aspects of water resources and ecosystems. The Anzali Wetland is internationally known as an important wetland for migratory birds, and it was registered as a Ramsar site in 1975 (JICA, 2005). In recent years, unfortunately, due to excess import of contaminated wastewater from urban, industrial and agricultural septic system into lagoon, it has faced with the serious risk of heavy metals. These dangerous actions along with entering garbage, water extraction from the lagoon for agricultural purposes, wastewater discharging from fish farms to the lagoon, illegal hunting and fishing, the arrival of non-native species, increase in erosion and sediment transportation of Anzali watershed, sediment deposition and other factors have treated the ecosystem of the lagoon. Because of these risks, the Ramsar Convention has included the Anzali Lagoon into Red List of Ecosystems.


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One of the main problems, which existed for long years and was found more in recent years, is sedimentation in the lagoon bottom. The studying on sedimentation rate in a water body such as Anzali Lagoon has a special importance because of the following various reasons. The suspended sediments cause decreasing of dissolved oxygen and declining in the water depth of reservoir by making turbidity in water and filling the lagoon, respectively. In sediments, the benthic and aquatic organism's habitats are damaged, the fish gills is suffered, their spawns is covered and migratory birds' habitats is disordered. By decreasing in the effective volume of the lagoon, water storage capacity will decrease and the water will overflow from that, so the adjacent area may be ponded.

As the sediments are capable to record environmental changes (Sunderland et al., 2008) and contamination entering time, so the determination of sedimentation rate by confident methods is one of the most important purposes in sediment and erosion study. This knowledge can be obtained using fallout radionuclide spectroscopy (Arata et al., 2016). An advantage of radionuclides spectroscopy is the excellence of its accuracy than conventional methods (Schuller et al., 2006). The other advantages of fallout radionuclide methods are capability of evaluation in different scales, short and long terms investigation of erosion, sediment and land use on erosion, cost-free maintenance of samples, sufficiency of a single site visit, usable under different environments and feasibility of its successful application in the world than other usual methods (Jia et al., 2012). In recent years, radiometric dating based on $^{137}$Cs and $^{210}$Pb has become an important method (Dong et al., 2013) and one of the best approaches has been using of the $^{137}$Cs (Zapata, 2002). The $^{137}$Cs is the most commonly employed radionuclide in soil (Mabit et al., 2013) that used in a different condition of agriculture and environment throughout the world. The abstraction of this element by the crop is slight and negligible (Wallbrink et al., 2002), but it is strongly adsorbed by clay particles (He and Walling, 1996) and organic matters.

The $^{137}$Cs (Cesium 137) is a radioactive element with a relatively long half-life of 30.15 years that have fallout in many countries because of nuclear weapons tests in the 1950s and early 1960s and Chernobyl catastrophic nuclear accident in 1986 (Dong et al., 2013). The regional pattern of the $^{137}$Cs deposition showed a range of 160 to 3200 Bq m$^{-2}$ that depended to latitude (García Agudo, 1998). The wide range of the $^{137}$Cs was related to atomic actions media in 1952 (Perkins and Thomas, 1980). After the Chernobyl reactor nuclear accident in 1986, for instance, large quantities of $^{137}$Cs were released into the atmosphere and a sharp peak in atmospheric fallout occurred (Estrany et al., 2010). Therefore, when a layer has the most of $^{137}$Cs radioactivity, this layer will be related to 1986 and sedimentation rate will be determined (Panayotou, 2004; Kotarba et al., 2002).

The $^{137}$Cs will form complex with particles and will represent into non-exchangeable form (Ritchie and McHenry, 1990). The $^{137}$Cs leaching from soil is low and in general, its migration in the soil by the chemical and biological process is very low and it is translocated in soil just along with colloids particles (Walling and Quine, 1992). Subsequent redistribution of that is mainly caused by physical changes such as erosion and plowing, so it can be used as a suitable mark for estimating soil erosion and sedimentation (Ritchie and McHenry, 1990; Estrany et al., 2010). The depletion of the $^{137}$Cs in soil related to reference level will show erosion and relative increase of that will represent deposition of soil.


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Considerable efforts have been directed to determine the ages of sediments and erosion by the radionuclide chronology. According to Brown et al. (1981), the results of an experiment using the $^{137}Cs$ indicated that soil movement in croplands has placed and sediments have quickly adsorbed the $^{137}Cs$. The use of the $^{137}Cs$ technique in Sri Lanka showed that, in the land with different area and utilization, this method has a high capability in estimating of erosion (Champa et al., 2010). A study in Algeria coasts has carried out from 1994 to 2004. For this aim, the $^{210}Pb$ and $^{137}Cs$ of sediments have been measured using direct counting in Gama spectrometry detector. The sedimentation rate using a concentration profile of $^{210}Pb$ and $^{137}Cs$ and CRS model was obtained 20 to 27 mm $yr^{-1}$ (Noureddine, 2010). The sediment delivery ratio in the black soil region of Northeast China within Hebei catchment was investigated by the distributions of $^{137}Cs$, $^{210}Pb$, and the grain-size of the sediments, from 1977 to 2007. The overall average deposition rate for the entire period was 22.6 mm $yr^{-1}$ and the precipitation was found to be the main factor affecting the soil erosion of the study area (Dong et al., 2013). Abbaszadeh Afshar et al. (2010) have estimated the rate of soil reformation in the western part of Iran using the $^{137}Cs$ radionuclide. The result showed that erosion and sedimentation rates were 29.8 and 21.8 ton $ha^{-1}$ $yr^{-1}$, respectively. Amini et al. (2012) have investigated the amount of sediment of Holocene in Gorgan gulf and southeastern coast of the Caspian Sea. The average of sediment at the beginning of the Holocene and at the end of that were 2.06 and 5.08 mm $yr^{-1}$, respectively. The rate of sedimentation in Anzali Lagoon was investigated by Japonica International Cooperation Agency (JICA) and the result showed that the sedimentation rate in around the lagoon was 0 to 6 mm $yr^{-1}$ (JICA, 2005).

A knowledge of sedimentation rates is often useful in planning for dredging operations. The pattern of sedimentation rates can be used to calculate when different areas will require works (Jeter, 1999). On the other hand, the conservation of ecological complex systems and profit from enormous economic, recreational and genetically resources is just subject to study and exact understanding of each wetland. Laboratory analyses of sediment cores can determine the sedimentation rates and the calendar dates associated with various depths within sediments. The aim of this research was an investigation of sediment age of the Anzali Lagoon by the $^{137}Cs$ to determine entering and displaced sediment rate at there. By understanding its annual rate, this can provide suitable planning for the lagoon conservation and the sediment management.

## Materials and Methods

### *Study area*

The Anzali Lagoon is located in the southern shore of Caspian Sea and in the Northern part of Iran between $37^0$ 25′ to $37^0$ 32′ N and $49^0$ 15′ to $49^0$ 36′ E. This water body has high importance for ecosystem because of abundant diversity of plants and animals. In the lagoon watershed with 3740 $km^2$ area, there are 27 rivers that among them, the top 10 rivers with a higher flow (*Table 1*) are the main entering rivers to the lagoon. The major volume of sediments into the lagoon is delivered by rivers that flow from upstream. The minimum and maximum mean sea level (MSL) of Anzali watershed are -26 and 3014 m, respectively. The mean annual rainfall of that is 1780 mm, 800 mm higher than evaporation. The climate in the Anzali Wetland watershed is characterized by two distinct types. The lowland area to the north between elevation (El.) -26 m to 500 m is characterized by warm temperatures, high moisture and


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abundant rainfall during the summer with a mild climate during the winter. The climate between El. 500 m to 3014 m is noticeably different from the lowland, characterized by cold temperatures, semi-humid conditions, and less rainfall.

***Table 1.*** *Mean annual flow for long-term (2002-13) for top 10 rivers of Anzali watershed*

| River | Mean flow ($m^3$ $s^{-1}$) | River | Mean flow ($m^3$ $s^{-1}$) |
|---|---|---|---|
| Ibrahim | 4.03 | Pasikhan | 18.59 |
| Pirbazar | 11.46 | Khalkaii | 4.45 |
| Siahrud | 5.52 | Siahmazgi | 4.07 |
| Shakhraz | 10.2 | Kolsar | 6.41 |
| Masouleh | 3.78 | Morghak | 3.33 |

In fact, the Anzali lagoon is one of the lakes behind the coast, which once was part of the Caspian Sea. This wetland has expanded a lot in the past but has gradually been filled by delta alluvial deposits of Sefidrud and other rivers in Rasht, Fouman and Masal areas. The area of the Anzali Lagoon during out of wet season is estimated 168 km$^2$. The Anzali Lagoon comprises four parts include western part (Abkenar), eastern part (Sheijan), center part (Hendekhale) and the southern part (Siahkishem) (*Figure 1*). The mean length of that in the east-west direct is about 30 km and in the north-south direct is about 3 km. The depth of the lagoon is in range of 2 m (in Sheijan) to 8 m (in Abkenar). The environment of the Wetland is deteriorating due to the inflow of wastewater, solid waste, and sediment from the upstream.

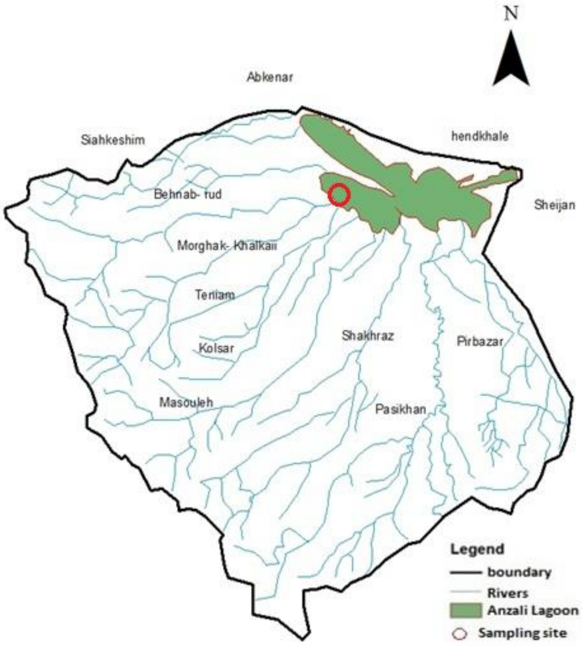


***Figure 1.*** *Anzali Lagoon watershed with entering rivers and sampling location*

## *Field sampling*

To choose the sampling site and numbers of samples, first, the sediment entering sources situation was checked and then, the locations were determined on the map. After that, based on the local investigations and consideration of limitations, such as


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accessing and sampling possibility due to the swampy condition of some sides, three places were chosen in the southern part of the lagoon (Khalkaii River) (*Figure 1*).

To investigate the local sedimentation and the soil layers properties, the sediments were sampled at 3 points in Sep 2016. The sampling was done by a piston core sampler D750. For this purpose, we sampled the sediments of the lagoon, by taking three cores, which were 11 cm in diameter and 4 m in length.

The cores are generally cut across to enable a sedimentary geologist to make a visual study of the sediments, sometimes including grain size measurements. To identify the mechanical and physical characteristics of the soil different layers, mechanical test such as direct-shear and physical tests such as relative density, humidity percent, and grain size distribution were done on sub-samples. The grain size tests was done using sieves with different meshes based on ASTM D6913 and the sediment texture was analyzed using the pipette method. The Munsell Color Chart was also used for identifying the sediment color.

The radionuclide test on all cores is not necessary because of the costs and time consuming labour. A total of 17 samples were selected from the cores horizons based on the sediment color and texture to obtain detailed information on the depositional environment. To determine the sediment age in the sampling location, from first core (BH-1), eight samples were sectioned from 0-0.5, 0.5-1, 1-1.6, 1.6-1.9, 2.2-2.4, 2.4-2.7, 2.9-3.3 and 3.3-4 m. For second core (BH-2), five samples were sectioned from 1.7-2.1, 2.1-2.4, 2.4-3, 3-3.6 and 3.6-4 m. In third core (BH-3), four samples were taken from 1.5-1.8 m, 2-2.8, 3-3.2 m and 3.3-3.5 m. In addition, some portion of the cores were clearly missing (2-2.2 m in BH-1 and 1-1.2, 1.8-2, 2.8-3 and 3.7-4 m in BH-3), which is possibly due to the loss of the sediments during sampling of the cores. In those layers, since the sediments were soft and sandy, they were difficult to sample. Finally, the dried samples were placed in special boxes.

### *Laboratory measurements*

All 17 samples were sent to the Nuclear Science and Technology Laboratory of Iran Atomic Energy Agency. To measure the $^{137}$Cs, the Gama ray spectrometer and high pure Germanium detector (HPGe) were used in an energy range of 60 KeV to 3 MeV. To analyze samples, one sample is placed under a detector device, which is connected to a counter computer. After spending 25,000 to 80,000 s, the peak point of the curve is established and on the graph in a channel with 662 Kev, the $^{137}$Cs is measured (Kachanoski and Dejong, 1984). The amount of the $^{137}$Cs was determined in Becquerel per kg of soil.

For a given depth, the time interval between the deposition date and the core sampling date is equal to the depth divided by the sedimentation rate (Jeter, 1999). This interval is subtracted from the current year in which the core was taken.

## Results and discussion

The soil particle-size distribution in *Tables 2, 3 and 4* showed that the sediment samples were mainly fine texture. The soil textures varied substantially. Nevertheless, the main soil texture in the lagoon is clayey silt. In the soil layers of BH-1 from the surface to 4 m depth, there is silt with low plasticity properties (ML). In BH-2, the soil layers of 0-3 m depth and 3-4 m depth were silt with ML and sandy silt with ML, respectively. In BH-3, the soil layers of 0-3 m depth and 3-4 m depth were silt with ML


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and clayey silt with ML, respectively. Generally, in the all depths, silt was the major portion of the sediments. Most of the sediments in the Caspian Sea coastal plain are discontinues and displaced sediments that settled in effect of different flow and waves.

***Table 2.*** *Soil layers properties in BH-1 core*

| BH-1 | | | utmX= 352254.05 | | utmY= 4143541.70 | |
|---|---|---|---|---|---|---|
| **Layers color** | **Depth (m)** | **Layer** | **Texture** | **Humidity (%)** | LL | PL |
| blue | 0-1 | Silt with low plasticity properties (ML) | Silty sand | 41.6 | | |
| green | | | Sandy silt | | | |
| | | | Sandy clay silt | | | |
| | 1-2 | | Clayey silt with biomass | 45.7 | 45.7 | 38.8 |
| | 2-3 | | No sampled | 47.3 | | |
| green | | | Clayey silt | | | |
| | 3-4 | | Sticky silt | 45.0 | 45.0 | 32.8 |
| Sample for Cs-137 test | | | LL: Liquid limit, PL: Plastic limit | | | |

***Table 3.*** *Soil layers properties in BH-2 core*

| BH-2 | | | utmX= 352444.00 | utmY= 4143848.00 | | |
|---|---|---|---|---|---|---|
| **Layers color** | **Depth (m)** | **Layer** | **Texture** | **Humidity (%)** | LL | PL |
| brown | 0-1 | Silt with low plasticity properties (ML) | Hard clay | 59.7 | N.P | N.P |
| brown | | | Silty clay | | | |
| light brown | | | Clayey silt | | | |
| light green | 1-2 | | Clay and silt with sand | 69.2 | | |
| light brown | | | Silty clay | | | |
| | | | Fine sand | | | |
| | | | Clayey silt | | | |
| [illegible] | 2-3 | | Clayey silt | 86.5 | | |
| | | | Silty fine sand | | | |
| | | | Fine sand and silt | | | |
| green | 3-4 | Sandy silt with low plasticity properties (ML) | Fine sand | 88.0 | 48.7 | 33.9 |
| black | | | Silt and clay with biomass | | | |
| | | | Fine sand | | | |
| Sample for Cs-137 test | | | LL: Liquid limit, PL: Plastic limit, NP: non plastic | | | |

*Figure 2* shows the $^{137}$Cs concentrations found at different depths in the sediment cores. The increasing trend up to the depth of 2.7 m and then decreasing trend were


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observed. The measured $^{137}Cs$ in *Figure 2* were shown that the peak of the $^{137}Cs$ radioactivity was in 2.4 to 2.7 m depth, with 9.3 Bq $kg^{-1}$. If this amount is related to the Chernobyl disaster year (1986), and the soil surface is related to sampling year (2016), the time interval between two events will be 30 years. On the other hand, by considering the middle of 2.4-2.7 m layer, we argue from given data that approximately 255 cm of sediment has been added in the last 30 years. Therefore, the sedimentation rate is determined at 8.5 cm $yr^{-1}$ (=119 kg $m^{-2}$ $yr^{-1}$ ≈20 million ton $km^{-2}$).

***Table 4.*** *Soil layers properties in BH-3 core*

| **BH-3** | | | utmX= 352688.11 | utmY= 4143809.84 | | |
|---|---|---|---|---|---|---|
| **Layers color** | **Depth (m)** | **Layer** | **Texture** | **Humidity (%)** | LL | PL |
| blue-grayish | 0-1 | Silt with low plasticity properties (ML) | Clayey silt | 52.3 | | |
| | | | Silt and fine sand | | | |
| | 1-2 | | No sampled | 45.0 | 45.0 | 36.0 |
| light blue-gra[illegible] | | | Clayey silt | | | |
| | | | No sampled | | | |
| Light pearl gray | 2-3 | | Clayey silt with organic matter | 74.3 | 46.5 | 29.7 |
| | | | No sampled | | | |
| light blue | 3-4 | Clayey silt with low plasticity properties (ML) | Clayey silt | 99.0 | | |
| dark blue | | | Clayey silt | | | |
| light blue | | | Clayey silt | | | |
| | | | Non sampled | | | |
| Sample for Cs-137 test | | | LL: Liquid limit, PL: Plastic limit, NP: non plastic | | | |

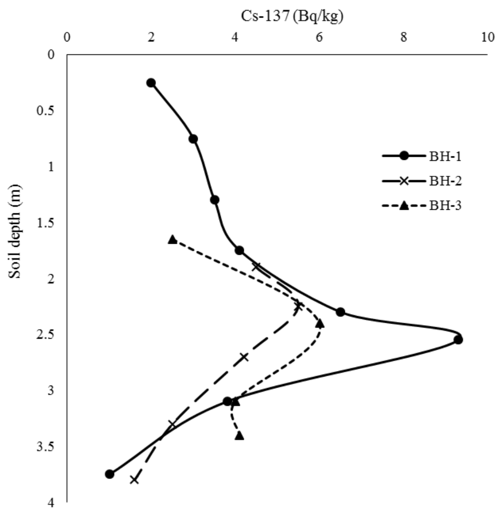


***Figure 2.*** *The vertical profiles of Cs-137 concentrations measured in three sediment cores*


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The depth distributions of the $^{137}$Cs activity and the clay percent for the sampled profiles are presented in *Table 5*. The clay particles keep strongly the $^{137}$Cs because of surface adsorption of that in soil depth (McCallan et al., 1980). The clay mineral fraction of the sediments acts as an ion exchange media and chemically fixes the cesium in place. Naturally, in an undisturbed soil, increase in soil depth will result an increase in clay percent due to leaching. In the cores (BH-1, BH-2 and BH-3), the clay percent increases with the soil depth, except 2.4-3 and 3.6-4 m in the BH-2. In addition, the $^{137}$Cs amount has a direct relation with clay percent and organic matter amount. Therefore, measuring the sediment and erosion amount using the $^{137}$Cs in soils with medium or heavy texture will represent a good result.

***Table 5.*** *Cs-137 concentration in different depth*

| Row | Sediment core | Soil depth (m) | Cs-137 (Bq Kg$^{-1}$) | Clay (%) |
|---|---|---|---|---|
| 1 | BH-1 | 0.0-0.5 | 2.0 | |
| 2 | BH-1 | 0.5-1.0 | 3.0 | |
| 3 | BH-1 | 1.0-1.6 | 3.5 | |
| 4 | BH-3 | 1.5-1.8 | 2.5 | 27.1 |
| 5 | BH-1 | 1.6-1.9 | 4.1 | 33.4 |
| 6 | BH-2 | 1.7-2.0 | 4.5 | 37.7 |
| 7 | BH-2 | 2.1-2.4 | 5.5 | |
| 8 | BH-1 | 2.2-2.4 | 6.5 | |
| 9 | BH-3 | 2.0-2.8 | 6.0 | |
| 10 | BH-1 | **2.4-2.7** | **9.3** | 34.2 |
| 11 | BH-2 | 2.4-3.0 | 4.2 | 11.1 |
| 12 | BH-1 | 2.9-3.3 | 3.8 | 33.4 |
| 13 | BH-3 | 3.0-3.2 | <4 | 34.2 |
| 14 | BH-2 | 3.0-3.6 | 2.5 | |
| 15 | BH-3 | 3.3-3.5 | 4.1 | 36.6 |
| 16 | BH-1 | 3.5-4.0 | 1.0 | 40.9 |
| 17 | BH-2 | 3.6-4.0 | 1.6 | 10.6 |

The sedimentation rate of these cores was estimated to be 8.5 cm yr$^{-1}$. Variation in sedimentation rates was conspicuously evident at depth intervals of approximately 250-350 cm in the core. The profile shows a $^{137}$Cs horizon near 400 cm depth (*Figure 3*). This marker (BH-2) can be used to calculate an average sedimentation rate as follows: (400 cm depth / 62 y between 1954 and 2016) equal to 6.5 cm y$^{-1}$. The profile also shows a $^{137}$Cs maximum near 350 cm depth. This marker (BH-3) also can be used to calculate a sedimentation rate: (350 cm depth / 53 y between 1963 and 2016) equal to 5.6 cm y$^{-1}$. In this case, the same sedimentation rate is calculated from both ways. This is not always the case, however, because events such as unusual floods could occur between the years 1954 and 1963, causing the two calculations to differ.

The total amount of radioactivity deposited on the earth's surface depends on the atmospheric concentration of radioactivity and the amount of rainfall. On the other hand, average siltation rate in lagoons and reservoirs can also be estimated if the $^{137}$Cs peak is noticeable in the vertical distribution of this radionuclide in bottom-sediment core samples. As Iran located in the middle of Asia with the approximately 80 mBq cm$^{-2}$, it could be inferred that Iran is a normal condition of use of radionuclides and with regard to these cases, it is concerned to utilize this isotope.


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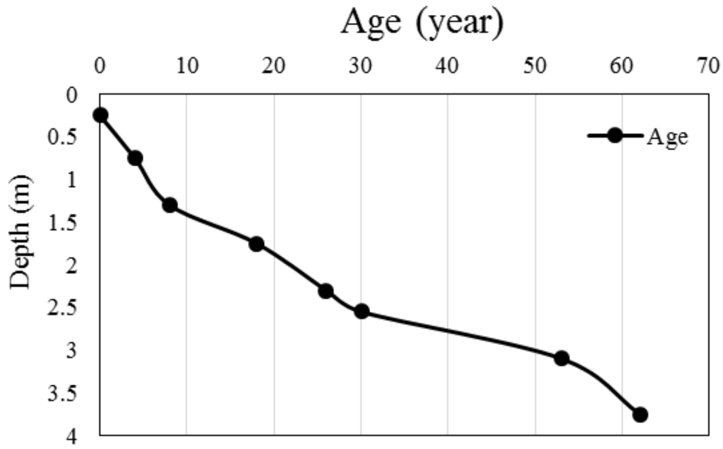


***Figure 3.*** *The age of sediment cores by Cs-137 chronolog*

## Conclusion

To survey sedimentation rate in Anzali Lagoon, Iran, a research was conducted in 2016 by coring from sediment in the southern part of the lagoon. The grain size distribution, liquid limit, and colors of the sediments were determined in soil laboratory. The $^{137}$Cs of the samples was also measured in Nuclear Science and Technology Laboratory of Atomic Energy of Iran. The result showed that the sediments were often Silt with low plasticity properties (ML) and green, light brown and blue colors. The highest amount of the $^{137}$Cs was observed in 2.4-2.7 m depth, which can be related to 1986 (Chernobyl accident). Therefore, the sedimentation rate was obtained as 8.5 cm $yr^{-1}$, which is high. The established rates of sediment accumulation confirm that sedimentation conditions in the Anzali Lagoon are fairly intensive and can cause declining in the lagoon water depth. In this regard, the water quality of the lagoon will be affected, which needs to investigate in future works. So, special arrangements should be considered to save the lagoon and protect its value.

## REFERENCES

[1] Abbaszadeh Afshar, F., Ayoubi, S., Jalalian, A. (2010): Soil redistribution rate and its relationship with soil organic carbon and total nitrogen using $^{137}$Cs technique in a cultivated complex hill slope in western Iran. – Journal of Environmental Radioactivity 101: 606-614.

[2] Amini, A., Moussavi, R., Lahijani, H., Mohboubi, A. (2012): Holocene Sedimentation Rate in Gorgan Bay and Adjacent Coasts in Southeast of Caspian Sea. – Journal of Basic and Applied Scientific Research 2(1): 289-297.

[3] Arata, L., Meusburger, K., Frenkel, E., A'Campo-Neuen, A., Iurian, A., Ketterer, M. E., Mabit, L., Alewell, C. (2016): Modelling Deposition and Erosion rates with Radio Nuclides (MODERN), Part 1: A new conversion model to derive soil redistribution rates from inventories of fallout radionuclides. – Journal of Environmental Radioactivity 162-163: 45-55.

[4] Brown, R. B., Cutshall, N. H., Kling, G. F. (1981): Agricultural Erosion Indicated by $^{137}$Cs Redistribution: I. Levels and distribution of $^{137}$Cs activity in soils. – Soil Science Society of America Journal 41: 33-37.


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1701_13371347

[5] Champa, K., Dissanayake, A. P., Mahawatte, B. K., Abeynayake, C., Weerasekera, T. S. B. (2010): Use of Cesium-137 technique for the assessment of soil erosion in two selected sites in Uma Oya Catchment in Sri Lanka. – World Congress of Soil Science, Soil Solutions for a Changing World. Brisbane, Australia.
[6] Dong, Y., Wu, Y., Zhang, T., Yang, W., Liu, B. (2013): The sediment delivery ratio in a small catchment in the black soil region of Northeast China. – International Journal of Sediment Research 28: 111-117.
[7] Estrany, J., Garcia, C., Walling, D. E. (2010): An investigation of soil erosion and redistribution in a Mediterranean lowland agricultural catchment using Cesium-137. – International Journal of Sediment Research 25(1): 1-16.
[8] García Agudo, E. (1998): Global distribution of Cs-137 inputs for soil erosion and sedimentation studies. – In: Global distribution of $^{137}Cs$ inputs for soil erosion and sedimentation studies (IAEA-TECDOC--1028). International Atomic Energy Agency (IAEA) 117-121. Vienna, Austria.
[9] He, Q., Walling, D. E. (1996): Interpreting particle size effects in the adsorption of $^{137}Cs$ and unsupported $^{210}Pb$ by mineral soils and sediments. – Journal of Environmental Radioactivity 30(2): 117-137.
[10] Jeter, H. W. (1999): Determining the Ages of Recent Sediments Using Measurements of Trace Radioactivity. – Workshop of the Nuclear Regulatory Commission, Region 1, June 1999, in Baltimore, Maryland, USA: 21-28.
[11] Jia, Y., Wang, Z., Zheng, X., Han, L. (2012): Estimation of soil erosion in the Xihanshui River Basin by using 137Cs technique. – International Journal of Sediment Research 27: 486-497.
[12] JICA. (2005): The Study on Integrated Management for Ecosystem Conservation of the Anzali Wetland in the Islamic Republic of Iran. – Vol 2. Nippon Koei Co.
[13] Kachanoski, R. G., Dejong, E. (1984): Predicting the temporal relationship between soil Cs-137 and erosion rate. – Journal of Environmental Quality 13(2): 301-304.
[14] Kotarba, A., Lokas, E., Wachniew, P. (2002): $^{210}Pb$ dating of young Holocene sediments in high-mountains lakes of the Tatra Mountains, Geochronometria. – Journal on Methods and Applications of Absolut’s Chronology 21: 73-77.
[15] Mabit, L., Meusburger, K., Fulajtar, E., Alewell, C. (2013): The usefulness of $^{137}Cs$ as a tracer for soil erosion assessment: a critical reply to Parsons and Foster. – Earth Sci. Rev 127: 300-307.
[16] McCallan, M. E., O’Leary, B. M., Rose, C. W. (1980): Redistribution of Caesium-137 by Erosion and Deposition on an Australian Soil. – Australian Journal Soil Resource 18: 119-128.
[17] Noureddine, A. (2010): Evaluation of the sedimentation rate with $^{210}Pb$ and $^{137}Cs$ using the CRS model and estimation of the total inventory of sediment in the Algerian Coast. – Journal of Oceanography 1(2): 47.
[18] Olah, J. (1990): Pollution in the Anzali Lagoon catchment preliminary assessment. – FAO, Rome 1-23.
[19] Panayoto, K. (2004): Geomorphology of the Minnamurra river estuary, southeastern Australia: evolution and management of a barrier estuary. – Ph.D. thesis, School of Geosciences, University of Wollongong.
[20] Perkins, R. W., Thomas, C. W. (1980): Worldwide fallout. – In: Hanson, W. C. (ed.) Transuranic elements in the environment. USDOE/TIC-22800. US DOE, Washington, DC. 53-82.
[21] Ritchie, J. C., McHenry, J. R. (1990): Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review. – Journal of environmental quality 19(2): 425-472.
[22] Schuller, P., Iroumé, A., Walling, D. E., Mancilla, H. B., Castillo, A., Trumper, R. E. (2006): Use of Beryllium-7 to Document Soil Redistribution following Forest Harvest Operations. – Journal of Environmental Quality 35: 1756-1763.


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DOI: http://dx.doi.org/10.15666/aeer/1701_13371347

[23] Sunderland, E. M., Cohen, M. D., Selin, N. E., Chmura, G. L. (2008): Reconciling models and measurements to assess trends in atmospheric mercury deposition. – Environmental Pollution 156(2): 526-35.
[24] Wallbrink, P. J., Belyaev, V., Golosov, V. N., Sidorchuk, A. S., Murray, A. S. (2002): Use of radionuclide, field based and erosion modeling methods for quantifying rates and amounts of soil erosion processes. – CSIRO Land and Water consultancy report.
[25] Walling, D. E., Quine, T. A. (1992): The use of Cs-137 measurements in soil erosion surveys. Erosion and sediment transport monitoring programs in river basins. – Oslo symposium.
[26] Zapata, F. (2002): Handbook for the Assessment of Soil Erosion and Sedimentation Using Environmental Radionuclides. – The Netherlands: Kluwer Academic Publishers.


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