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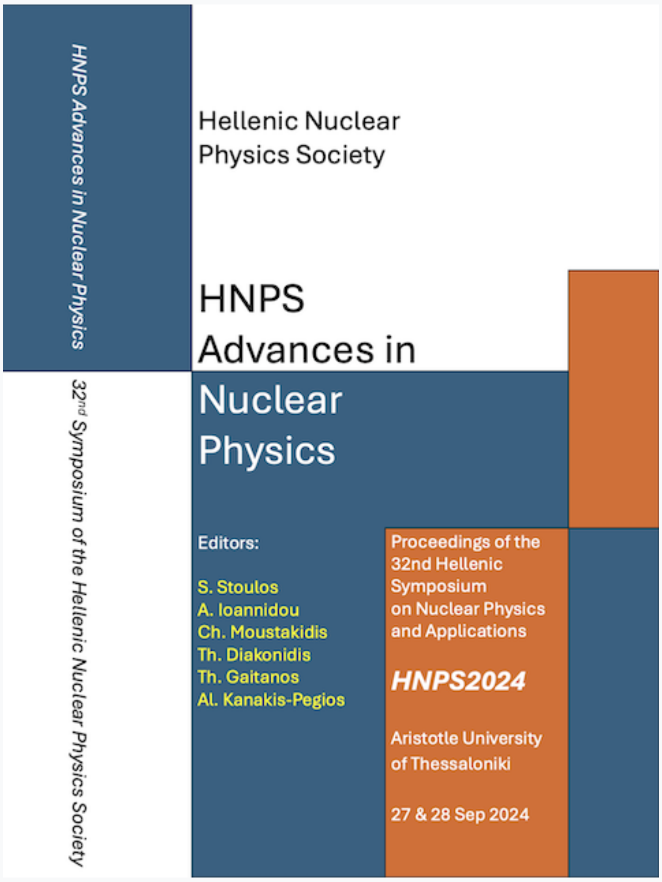

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Impact of climate change to sedimentation processes and microplastics gradients: a case study in a semi-closed deep ocean system, Lemnos basin, Greece

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Abstract The marine environment has undergone substantial changes in recent decades, due to by-products that cause pollution and end up to the marine systems mainly from the coastal zone and the drainage basins. The purpose of this work is to study environmental changes and contamination during the last century, taking into account sediment analysis as the final recipient of discharged matter at a semi-closed marine system. From the basin of Lemnos, at a depth of 1550 m, two sediment cores were sampled and analyzed, by applying gamma-ray spectrometry for radionuclides measurement and density separation/microscopic inspection for microplastic particles determination. The sedimentation rate was determined using the vertical profiles of $^{210}Pb_{ex}$ methods and validated via ^{137}Cs measurements. The ratio of $^{226}Ra/^{228}Ra$ activity concentrations was less than unity demonstrating that the main mechanism that takes place in terms of sediment dynamics is accumulation/accretion process. The microplastic particles' concentrations were measured and correlated with the increased water supply of the rivers flowing into the North Aegean, combined by the production of dense water masses. The data were also interpretred according to the impacts of climate change.such as the increase of the seawater surface temperature, the increase of the frequency of deep water formation and the increase of the sedimentation rate during the last ecades due to extreme weather events.

Keywords $^{210}Pb_{ex}$ and ^{137}Cs dating, North Aegean Sea, Lemnos basin, Sedimentation rate, microplastic particles.

INTRODUCTION

Human activities result in marine pollution which changes the physical, chemical, and biological parameters that characterize the ocean health. Due to the enhanced technological activities, there are several million tons of releases into the environment causing pollution distinctly presented as a stratigraphic signature in soils and marine sediments [1]. One of the applied methods to understand the processes related to the contaminants according to the climate conditions is the reconstruction of contaminants during the last century and their correlation with the sedimentation/accumulation processes estimated from the sediment cores [2]. The evaluation of the long term global geological processes is performed using dating methods and suitable "radio-clocks" [3].

In this work, the general goal was to observe the temporal variation of radioactivity and microplastics in Lemnos basin due to land-sea interaction mechanisms, using two sediment cores, and as dating tracers the ^{210}Pb and ^{137}Cs radionuclides. The study area, Lemnos basin, is a semi-closed system, as in the basin below the first 400 m depth, water circulation is very limited, and the deep water masses do not interact with intermediate water masses [4]. The sediment cores from Lemnos basin were collected at 1550 m depth using a box corer and they were analyzed for natural and artificial radionuclides and microparticles to investigate the anthropogenic footprint during the last century. More specifically, the radio-dating models of ^{210}Pb and ^{137}Cs were tested in the semi-closed system, the sedimentation rate was determined, the levels of radioactivity of ^{137}Cs due to the Chernobyl accident were calculated at different core depths and the sediment quality was also determined in terms of the concentration of microparticles. Another aspect of this work was the assessment of the studied deep

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basin in terms of sediment dynamics and land-sea interaction with the terrestrial part of North Greece applying a technique to study the erosion or accretion of the system using natural radionculides [5]. The activity concentrations of radionuclides and microplastic particles are correlated with the land-sea interaction phenomena between the studied basin and the inland waters of the continental part of the North Aegean. The dating of microparticles as well as of artificial and natural radionuclides was determined and validated with past extreme events and oceanographic processes.

The impact of the climate change to the seawater of ocean systems is fooprinted in larger time scales compared to its impact in the seabed since land sea interactions are related to fast extreme evemts while air-sea interactions with slow processes. As concerns the surface seawater temperatures during the 20th century, a continues rise has been observed having the year 2023 the warmest. So, the data wera also used to interpet the impact of climate change in the studies area during the last decades according to fast response proceeses (such as sedimentation/accumulation rate as observed in the seabottom of the basin), as well as to slow response processes in the sea surface (such temperature of the surface seawater).

MATERIALS AND METHODS

Lemnos basin is a steep conical depression of a maximum depth of 1550 m approximately, and is a part of the North Aegean Trough (Fig. 1). The vertical structure of the water column is characterized by the presence of three layers: the surface layer (10–50 m), which is occupied by Black Sea Waters of low temperature and salinity (30 PSU), the intermediate layer (50–400 m) which consists of Levantine Waters of higher temperature and salinity (39 PSU) and the deep water masses (>400 m), which is formed during excessivelly cold winters and is of low salinity and temperature [6]. The water circulation is affected by the Black Sea Water entering from the Dardanelles straits, by the anticyclone of Samothrace and the sinking and rising of sea water masses. The factors that affect the sedimentation in the basin are the distance from sediment supply sources, morphology and inclination of slopes, earthquake activity and deep water formation events.

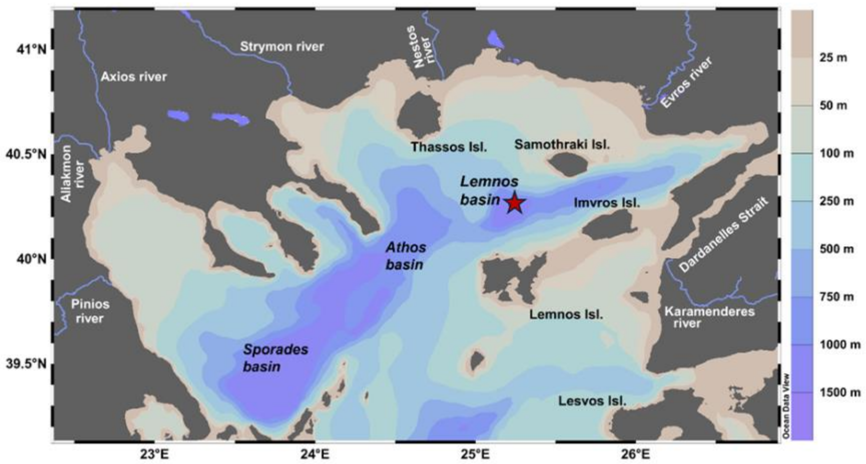

Figure 1. *Bathymetry map (m) indicating the main features (deep basins, rivers, islands and the Dardanelles Strait) of the North Aegean Sea. The star indicates the core sampling location at Lemnos Basin.*

The sediment cores were collected in 2020 by the oceanographic vessel "AEGAEO" and were recovered in cylindrical tube using the box corer, taking into consideration the geomorphologic characteristics of the seabed. With all the appropriate procedures taking place the sediment cores were sliced per 1 cm down to 15 cm, and per 2 cm below 15 cm depth, using a metallic spatula, in order to provide the samples for measurements by means of gamma ray spectrometry and microplastics determination.

The radiological analysis was carried out in the laboratory of Marine Radioactivity of the Hellenic Centre for Marine Research. All the samples were weighted, dried at 54°C, reweighted, pulverized and stored for a month in special petri (65.37 cm^3). The activity concentration of the core samples was determined via gamma-ray spectrometry using a HPGe detector, with a resolution of 1.85 keV at 1.33 MeV and a 50% relative efficiency, surrounded by a lead shield in order to reduce the ambient gamma ray background. The energy and efficiency calibration was performed using a reference source given from ALMERA proficiency tests of IAEA [7] and two background spectra were recorded during the measurement period. The spectrum analysis was carried out via the software SPECTRW and the activity concentration was calculated for nine (9) radionuclides. The uncertainties of the activity concentration were deduced according to the propagation law of uncertainties. For the calculation of the sedimentation rate the dating models of $^{210}Pb_{ex}$ (Constanf Flux:Constant Sedimentation) and ^{137}Cs were used first. Then, in order to deduce the sedimentation rate for each slice, the Constant Rate of Supply (CRS) model was applied, assuming that the $^{210}Pb_{ex}$ flux deposited to the surface of sediment mass is always constant.

The microplastic particles determination was carried out in the laboratory of the Department of Marine Sciences of University of the Aegean. The microplastic extraction from the sediment matrix was performed with density separation using a saturated solution of sodium chloride (NaCl) (ρ=1.20 g mL^{-1}). About 50 mL of each sample was transferred into a glass beaker, mixed with 200 mL of saturated NaCl solution, manually stirred, covered with aluminium foil, placed in the stirring device for 30 min and then allowed to stand for 24 h. The supernatant of each beaker was then poured off into a glass Büchner vacuum apparatus fitted with a 47 mm diameter Whatman™ GF/C filter. This density separation procedure was repeated three times for each glass beaker. Each filter was stored individually in sealed Petri-dish and kept in a glass desiccator under microscopic inspection, where it was examined for about 20 min under Nikon SMZ800 stereoscope with an attached camera to record and photograph the shape, the color, and the size of each item found on the filter. Plastic microparticles were initially visually differentiated from biological or sedimentary particles and in cases of uncertain identification the "hot needle" test was employed to verify their polymeric composition [8].

RESULTS AND DISCUSSION

The radioactivity results of this work are focused on the activity concentration of radiotracers ^{210}Pb, ^{137}Cs for the dating process, as well as of the natural radionuclides ^{226}Ra, ^{214}Pb, ^{228}Ac, ^{214}Bi and ^{40}K. The results of the dating model of $^{210}Pb_{ex}$ requires the measurement of the activity concentration of ^{210}Pb, ^{214}Pb and ^{214}Bi since the activity concentration of $^{210}Pb_{ex}$ is deduced by subtracting the activity concentration of the supported ^{210}Pb, though the average value of ^{214}Pb and ^{214}Bi, from the total ^{210}Pb activity concentration. The activity concentration of ^{210}Pb, in the first 20 cm of the sediment core varied between 165 and 450 Bq kg^{-1}, while below 20 cm it varied from 25 to 150 Bq kg^{-1}. The mean activity concentration of ^{214}Pb and ^{214}Bi varied between 11 and 36 Bq kg^{-1} at different depths in the sediment core. The mean sedimentation/accumulation rate is 0.45 $cm \cdot y^{-1}$ and was calculated from the logarithmic values of the activity concentration of $^{210}Pb_{ex}$ along with the depth of the core sediment though the slope of the graph, as depicted in Fig. 2a. According to the CRS model, the dating of the sediment core was also determined from the $^{210}Pb_{ex}$ profiles and the sedimentation/accumulation rate wass calculated for each layer of the core. The sedimentation rate varies from 0.1–0.2 cm y^{-1} from 1900 till 1940, 0.2–0.3 cm y^{-1} from 1940 to 1990 and then there is a linear increase from 2000 till reaching a maximum values of 0.48 cm y^{-1}, as depicted in Fig. 2b.

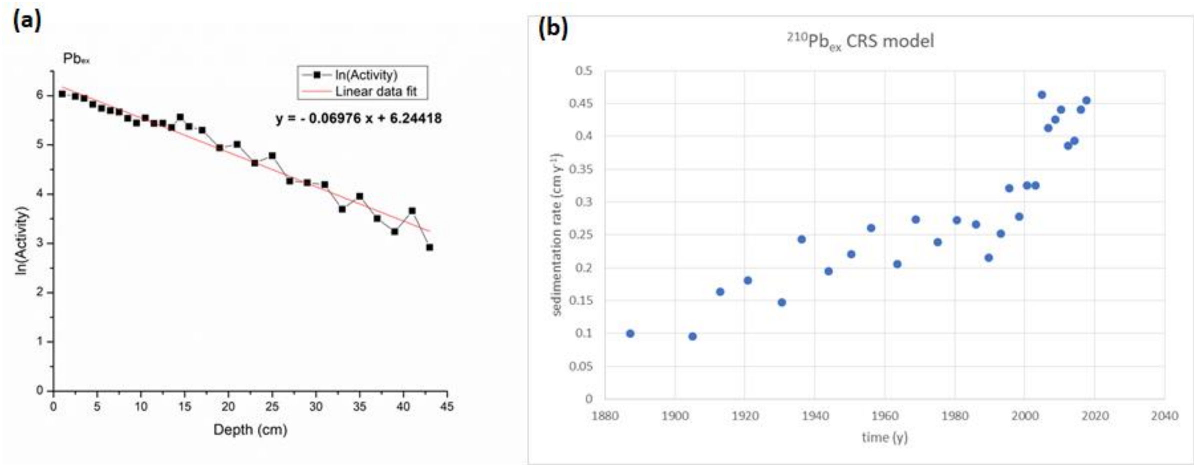

Figure 2. *(a) The representation of the logarithmic values of the $^{210}Pb_{ex}$ activity concentration along with the depth of the sediment core. (b) The averaged sedimentation/accumulation rate during the last century (CRS model of $^{210}Pb_{ex}$).*

According to the radioactivity results for ^{137}Cs, where the first significant peak of the activity concentration appears at 27 cm with an average value of 9.3 Bq kg^{-1}, the second one at 19 cm with an activity of 13.1 Bq kg^{-1} and two nearby peaks, one at 14.5 cm and the other at 12.5 cm with an average activity concentration at 11–12 Bq kg^{-1}. The average sedimentation rate using ^{137}Cs signatures at the vertical profile is around 0.37 cm y^{-1}.

Radium isotopes as natural constituents are abundant in sediments. The differentiation of ^{226}Ra/^{228}Ra activity concentration ratio or the ratio of their progenies (such as ^{228}Ac) in different geochemical fractions in the sediment is used as a tracer to study accretion and erosion processes, at the specific deep marine compartment. The calculated ratio between the ^{226}Ra and ^{228}Ac along the core varies from 0.1 to 0.4, indicating high accretion/accumulation processes in the bottom of the deep basin. The accretion process is observed possibly due to deposition of riverine "fresh" particles from intense flood events. It is evident that the sediment record from the specific deep basin provides evidence of enhanced sedimentation during the last twenty years, as a consequence of the changes in the global climate due to extreme weather phenomena. Increased rainfall intensities in short time scale are present in higher frequency the last years due to the climate change, bringing material from the land to the sea changing in terms of dynamics the marine system. Thus, the sediment discharge downwards to towards the slope of the basin is related to accumulation processes connected with the rivers discharge rather than the atmosphere, which was confirmed from the fact that there was no correlation between the activity concentration of ^{40}K nor the mean activity concentration of ^{214}Pb–^{214}Bi and ^{228}Ac, that would indicate uniformity in the origin of the samples.

After the microscopic inspection of filters and the exclusion of items resembling those of the blank filters, a total number of 36 microplastic particles was identified. Fibers were the most abundant shape with a proportion of ~60% and the length of microplastic particles ranged from 54 μm to 5526 μm, with an average length of (1111±1226) μm. The microplastic particles abundance at different depth intervals into of the core ranged between 3.3 at the slice 34–36.5 cm and 26.0 items/100 g of dry weight (d.w.) sediment at the slice 8–10 cm, with a mean abundance of (13.58±8.05) items/100 g d.w. The majority of microparticles per 100 g of dry sediment are dated between 1980 and 2000 and between 2010 and 2020. With respect to the radio-dating results, in this work, microplastic particles were found at the slice 34–36.5 cm depth down-core, corresponding to a date of ~1940, well before the large-scale production and use of plastics that dates back to ~1950 [9]. Mixing of the particles downward into the sediment via bioturbation could be a possible explanation, however several researchers [10] proposed that microplastic particlesmat vertically migrate within the sediment column via pore water.

However, observing the distribution of microplastic particles over time, from 1980 to 2010, it can be seen that in some years characterized by winters with increased river flow, the occurrence of microparticles in the sediment is higher. In the years 1982, 2001 and 2014 when there was intense flood events in the area, the abundance of microparticles also reached maximum values, possibly related to landslides and their transport from the slopes of the basin to greater depths. The abundance of microparticles also increased significantly in 1987, 1993, 2008 and 2017, when the North Aegean experienced intense heat loss and dense waters were formed during winter [11] by open-sea convective episodes or in the shallow continental shelf which were subsequently cascaded into the adjacent deep basin.

Furthermore, there was observed a significant increase at the Surface Seawater Temperature of Lemnos basin as revealed by the foundation SST time series spanning the period 1981–2024 showing a cumulative increasing trend of 2.4°C since 1981 (Fig. 3). The SST dataset (Mediterranean Sea - High Resolution L4 Sea Surface Temperature Reprocessed, [12]) includes daily (nighttime) optimally interpolated (L4) satellite-derived estimates of foundation SST –representing temperatures unaffected or minimally affected by the diurnal cycle– at a 0.05° resolution.

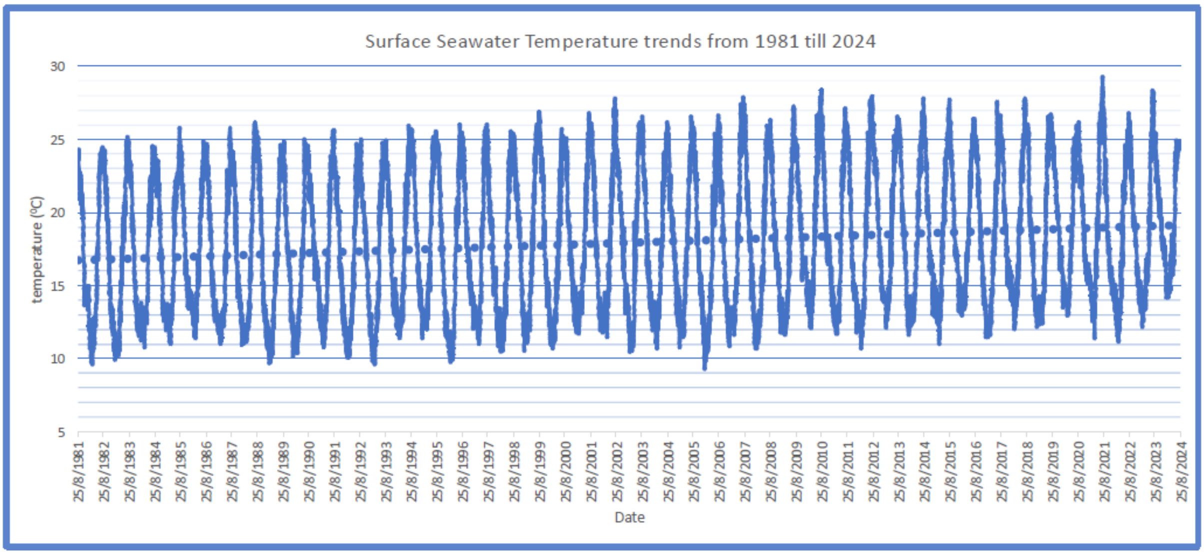

Figure 3. *Surface Seawater Temperature(SST) trends from 1981 till 2024. (The data was taken from Copernicus Marine data base)*

The changes in the surface seawater temperature is indicated as an impact of the climate change since the gradients of the global change indicators occur in the sea surface of the ocean systems in a much longer time periods than in the atmosphere (air-sea interactions). On contrary, the sediment accumulation is a faster processes due to the extreme events that occur within a very short period of time.

CONCLUSIONS

The temporal variation of the sedimentation/accumulation rate is studied in a semic-closed system, the deep Lemnos basin of the North Aegean Sea in Greece. The sedimentation rates were esimated in every cm of core depth using the $^{210}Pb_{ex}$ dating CRS method. The Lemnos deep basin has been affected by human activities since various contaminants were advected from the rivers of the North Aegean Sea. The footprint of the climate change is identified the last decades by the gradients of sedimentation rates in the basin mainly due to the land sea interactions with the North Greece. In a smaller scale the rise of sea surface temperature is also identified as an indicator of the climate change due to air–sea interaction.

Acknowledgments

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References

[1] J. Zalasiewicz, et al., Anthropocene 13, 4 (2016); doi: 10.1016/j.ancene.2016.01.002
[2] F.K. Pappa, et al., Env. Sci. Poll. Res. 25, 30084 (2018); doi: 10.1007/s11356-018-2984-0
[3] G. Eleftheriou, et al., J. Radioanal. Nucl. Chem. 316, 655 (2018); doi: 10.1007/s10967-018-5802-8
[4] C. Tsabaris, et al., J. Env. Rad. 132, 47 (2014); doi: 10.1016/j.jenvrad.2014.01.015
[5] Z.J. Dai, et al., Env. Earth Sci. 62, 1629 (2011); doi: 10.1007/s12665-010-0647-7
[6] V. Zervakis and D. Georgopoulos, Med. Mar. Sci. 3, 7 (2002); doi: 10.12681/mms.254
[7] G. Eleftheriou, et al., Appl. Rad. Isot. 206, 111234 (2024); doi: 10.1016/j.apradiso.2024.111234
[8] G. Hanke, et al., Publications Office of the European Union (2013); url: https://publications.jrc.ec.europa.eu/repository/handle/111111111/30681
[9] R. Geyer, et al., Sci. Adv. 3, 1700782 (2017); doi: 10.1126/sciadv.1700782
[10] J. Martin, et al., Sci. Tot. Env. 806, 150818 (2022); doi: 10.1016/j.scitotenv.2021.150818
[11] D. Velaoras, et al., The Physical Characteristics and Dynamics of the Aegean Water Masses. In: Anagnostou, C.L., Kostianoy, A.G., Mariolakos, I.D., Panayotidis, P., Soilemezidou, M., Tsaltas, G. (eds) The Aegean Sea Environment. The Handbook of Environmental Chemistry, vol 127. Springer, Cham; doi: 10.1007/698_2020_730
[12] Mediterranean Sea - High Resolution L4 Sea Surface Temperature Reprocessed. E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS); doi: 10.48670/moi-00173