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A 50-Year Meta-analysis review of metal pollution in sediments of the N. Saronikos Gulf, Salamina Straits.

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Abstract Saronikos Gulf encounters the highest environmental challenges due to heavy metal contamination, among Greece's coastal areas. In the present study fourteen scientific papers published from 1974 to 2024 were chosen, from online databases, for meta-analysis review. The mean values of heavy metals were calculated per decade, while the ecological status of the area was estimated via the application of the Pollution Loading Index (PLI). Integrated comparisons that would enhance Saronikos Gulf's management and sustainable development were made possible by the reassessment of the data cited in the literature.

Keywords: Heavy metals; Saronikos Gulf; Ecological assessment

1. Introduction

The first environmental studies of heavy metals in marine sediments were conducted in the early 1970s in the Saronikos Gulf (Papakostidis et al., 1975; Griggs et al., 1976; Grimanis et al., 1977; Griggs et al., 1978; Scoullos et al., 1977). Half a century since the initial research on the pollution of Saronikos sediments caused by heavy metals, the information and understanding of coastal pollution in the region have been increasing significantly (Karageorgis et al., 2020; Gkaragkouni et al., 2021; Gkaragkouni et al., 2024). Thus, the current work provides a review of studies on heavy metals pollution in Saronikos Gulf over the last fifty years, between 1974 and 2024. The Pollution Loading Index (PLI) proxy was used to estimate the pollution that heavy metals pose to marine sediments. Particularly, the magnitude of environmental change due to human activities in the area was assessed using GIS mapping techniques.

2. Materials and methods

2.1. Study area

The Saronikos Gulf, home to Greece's capital, Athens, and largest port, Piraeus, has been a highly human-impacted area for 2500 years. It is surrounded by urban and industrial areas, with Elefsina and Keratsini Bays receiving effluents from industrial, shipping, and domestic waste. Environmental pressures include Piraeus Port, a Fertilizer Plant, shipyards, the Naval Station, abandoned ships, and the Athens Sewage Outfall (ASO). The ASO was replaced in 1995 by a Wastewater Treatment Plant, which began operating as a secondary treatment plant in 2004 located on Psyttalia island.

2.2. Meta-analysis review dataset and analysis

The current review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Al-Mutairi et al., 2021). To collect the fourteen published studies on heavy metal pollution in marine sediments of Saronikos Gulf keyword searches were conducted on electronic databases including Scopus, Web of Science, Science Direct and Google Scholar. Searches within references were also conducted. The above-mentioned studies were eligible to meta-analysis review if they presented quantitative and composition data of total concentrations of heavy metals contamination in surficial marine sediments of the Saronikos Gulf and were published in English. Total digestion was used in the fine sediment fraction (from <55μm in the earlier studies to < 62μm at the most recent ones). Articles with insufficient or incomplete data on pre-established data were excluded.

2.3. Environmental indices

The calculation of the Pollution Loading Index (PLI) introduced by Tomlinson et al., 1980 offers an estimation of the environmental burden due to overall multi-metal pollution and was estimated per decade. It should be noted though that the metals used and the sediment sampling design differ per decade depending on the available data.

3. Results and discussion

3.1. Geochemical composition

The mean values of main heavy metals available from the previous studies per decade are presented in Table 1.

Table 1. Average element values as estimated by various researchers in Saronikos Gulf (metals in ppm, Corg in %).

Element	1970s	1980s	1990	2000	2010
C_{org}	2.0	2.3	1.9	1.8	1.3
As		375.3	118.6	27.6	15.3
Cr		270.94	323.20	208.90	122.4
Cu			186.56	96.28	45.81
Mn			705.65	312.52	377.5
Ni			105.94	98.61	60.93
Pb			376.86	135.45	51.38
Zn	1255.2	683.13	844.00	326.23	121.6

As can be seen from Table 1, organic carbon and metal values hold their higher levels in the decade of 1990 whilst they present lower values in the most recent deposited sediments.

3.2. Environmental Indices

In Figure 1, the subareas of the Saronikos Gulf are highlighted where PLI values hold their maximum levels in every decade according to available data, for the decades 1980s, 1990s, 2000s and 2010s, respectively. PLI wasn't calculated below 1 for any sampling site of the entire area with an exception at the south Attica coastal zone. As can be seen, the most affected sites include the Port of Piraeus, Salamina Straits, Elefsina Bay and the island of Psyttalia. It seems that the highly impacted area expanded from earlier to the most recent decades and the Salamina Straits with the west Attica coast is mostly affected during the four decades.

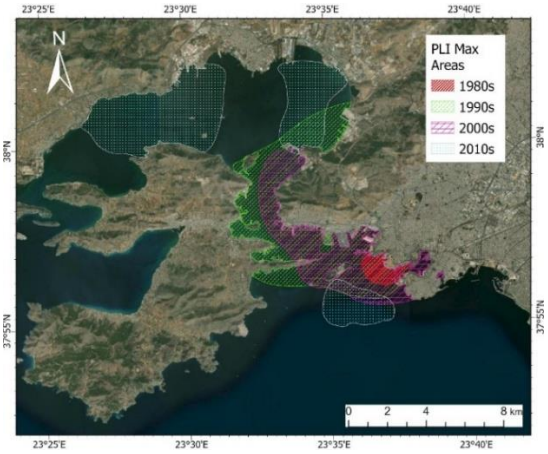

Figure 1. PLI maximum values distribution in surficial sediments of Saronikos Gulf calculated from studies conducted in the area during the 1980s, 1990s, 2000s and 2010s.

4. Conclusions

The Saronikos Gulf has attracted the focus of scientists for the past five decades, as it is regarded as the most contaminated marine region in Greece. The most impacted areas according to PLI values comprise the Salamina – Perama straits, around the Psyttalia (Wastewater Treatment Plant) and Athens Sewage Outfall and to a lesser extent Elefsina Bay. A decreasing pollution trend was also recorded in most recent deposited sediments. This study's findings can enhance the environmental management strategy in coastal and shallow marine sedimentary processes, although further research is needed to understand pollutants' dynamics.

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