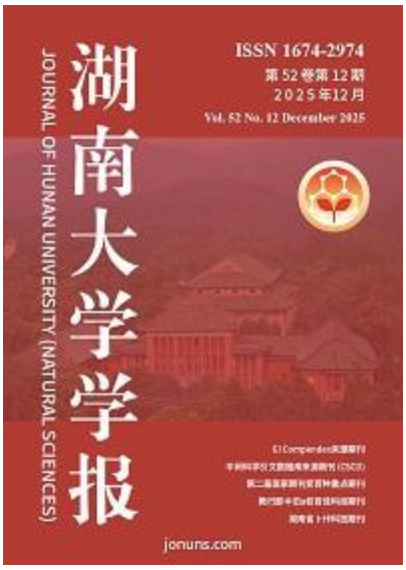

Journal of Hunan University
(Natural Sciences)

Vol. 52 No. 12
December 2025

Available online at
https://jonuns.com

Open Access Article

https://doi.org/10.55463/issn.1674-2974.52.12.15

Examination of Po - 210 in Halophila Stipulacea in Aqaba Gulf – Jordan

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Article history
Received: November 11, 2025
Revised: December 24, 2025
Accepted: January 8, 2026
Published: January 30, 2026

Abstract: This study investigates whether the activity concentrations of polonium-210 (^{210}Po) in the seagrass *Halophila stipulacea* (Forsk.) collected from different sites in the Gulf of Aqaba (Red Sea) can be used as an indicator of genotoxicity in the region. The research adopts a novel approach by employing seagrass as a natural bioindicator to explore the relationship between environmental radiation exposure to ^{210}Po and potential genetic damage in marine ecosystems.

Samples were collected from five sites characterized by different levels of anthropogenic activity in order to identify spatial patterns of radionuclide accumulation and associated environmental risks. The activity concentrations of ^{210}Po in *Halophila stipulacea* were determined using high-resolution alpha spectrometry. The results reveal clear spatial variability in ^{210}Po accumulation across the study area.

The highest activity concentration (mean ± SD) was recorded at the Old Phosphate Port (27.16 ± 1.52 Bq/kg), while the lowest value was observed at the Marine Science Station (12.44 ± 0.76 Bq/kg). Intermediate activity concentrations were measured at other industrially influenced sites, namely Big Bay (16.30 ± 0.97 Bq/kg), Tala Bay (20.10 ± 1.19 Bq/kg), and the Fertilizers Factory site (21.47 ± 1.41 Bq/kg).

The findings provide an overview of ^{210}Po accumulation in *Halophila stipulacea* within the Gulf of Aqaba and highlight its potential use as a bioindicator of environmental radioactive pollution. The observed spatial distribution of ^{210}Po may reflect varying degrees of anthropogenic impact and suggests a possible link between radionuclide exposure and genomic instability in the studied marine environment.

Keywords: Halophila stipulacea; Seagrass; Polonium-210; Environmental pollution; Alpha spectrometry; Genotoxicity.

亚喀巴湾（约旦）海草 *Halophila stipulacea* 中钋-210（Po-210）的研究

摘要：本研究探讨了从约旦亚喀巴湾（红海）不同采样点采集的海草 *Halophila stipulacea*（Forsk.）中钋-210（^{210}Po）活度浓度是否可作为该地区遗传毒性水平的指示指标。研究采用了一种新颖的方法，将海草作为天然生物指示物，用以揭示环境中 ^{210}Po 放射性暴露与海洋生态系统潜在遗传损伤之间的关系。

为识别放射性核素累积的空间分布特征及其相关环境风险，本研究在五个具有不同人类活动强度的采样点采集样品。采用高分辨率 α 能谱法测定 *Halophila stipulacea* 中 ^{210}Po 的活度浓度。结果表明，不同采样点之间的 ^{210}Po 累积水平存在显著的空间差异。

最高的活度浓度（平均值 ± 标准差）出现在老磷矿港（27.16 ± 1.52 Bq/kg），最低值则出现在海洋科学站（12.44 ± 0.76 Bq/kg）。其余受工业活动影响的采样点表现出中等水平的活度浓度，分别为大湾（16.30 ± 0.97 Bq/kg）、塔拉湾（20.10 ± 1.19 Bq/kg）以及化肥厂区域（21.47 ± 1.41 Bq/kg）。

研究结果系统地揭示了亚喀巴湾 *Halophila stipulacea* 中 ^{210}Po 的累积特征，表明其可作为环境放射性污染的有效生物指示物。^{210}Po 的空间分布特征反映了不同程度的人类活动影响，并暗示放射性核素暴露与研究区域海洋生态系统基因组不稳定性之间可能存在关联。

关键词：*Halophila stipulacea*；海草；钋-210；环境污染；α 能谱法；遗传毒性

1. Introduction

The marine environment is essential for the maintenance of global biodiversity and the regulation of the Earth's ecological stability. This is achieved through maintaining the balance of producing Oxygen and absorbing Carbon Dioxide that affects climate change. Which plays a critical role in habitats of marine life as a part of the biological richness on Earth. Therefore, marine pollutants in various forms, such as heavy metals, oil, plastics, and chemicals adversely affect the health of marine species by causing physical harm, disrupting reproductive processes, and modifying feeding behaviors [1].

Monitoring the marine environment is very important to track the contamination levels from different sources and the disadvantages affect marine life. This will help the decision makers to establish policies to minimize pollution and control their sources.

Research works have been done to study the contamination related to heavy metals and radiation levels in different environments, because of their negative effect on the living organisms and ecosystems [2-5]. Besides, reports showed changes in the natural exposure levels in the globe by a factor of three [6]. One of the main sources of radioactive residues is nuclear fuel cycle activities. As well as industrial processes that include industrial minerals, mining, and non-nuclear fuels production like gas and oil [7].

The present study chooses the Aqaba Gulf since it is the only port in Jordan, where all economic activities; importing oil, exporting goods, fishing, and other industrial activities are wide, diverse, and active. Aqaba Gulf is remarkable in the wide existence of coral reef systems on different sites on it. Halophila stipulacea (Forsk) is a small tropical seagrass that belongs to the Hydrocharitaceae family (Figure 1). It is widely spread in the Red Sea and Indian Ocean [8-10].

Polonium-210 is one of the most toxic natural radionuclides [11]. It enters the marine environment through the deposition from the atmosphere at the water surface related to both the decay of Rn-222 gas and the decay of Ra -226 at the sea floor. As well as from the anthropogenic components accumulate through the sediment discharging sources and river water [12].

Figure 1: Halophila stipulacea (The authors' elaboration)

Po-210 tends to accumulate in marine biota with particularly high levels observed in brown algae [13-14]. Mat Catal et al. [15] in their study showed that Po-210 is recognized as a significant contributor to the natural radiation dose within marine ecosystems.

In the northern Gulf of Kuwait, concentration factors for Po-210 in brown algae (Sargassum) have been found with high concentrations exceeded the values recommended by the IAEA [16]. These macroalgae effectively concentrate radionuclides, facilitating their transfer to higher trophic levels within the marine food web. Therefore, marine organisms can serve as effective bioindicators of radionuclide contamination in the surrounding marine environment [17].

Alam and Mohamed in their study presented a baseline assessment of Po-210 accumulation in marine organisms. The findings indicated that all studied marine species accumulated Po-210 radionuclide at high concentrations due to its solubility in seawater and strong affinity for organic matter. Therefore, Po-210 represented a primary source of natural radiation exposure for most marine life [18].

The importance of this study lies in the fact that, to date, it is the first in the region to measure the activity concentrations of Po-210 in Halophila stipulacea seagrass to be considered as a pollution bio-indicator in the marine environment. Halophila stipulacea seagrass was chosen in particular because of its wide distribution in the Gulf of Aqaba. The findings contribute valuable baseline data and highlight the significance of seagrass-based monitoring for costal environmental protection.

2. Materials and Methods

2.1 Sample Collection

Five different sites on the Gulf of Aqaba on the Red Sea were selected to collect the widespread *Halophila stipulacea* seagrass, as shown in Figure 2. These sites are listed in Table 1 with their specific locations. They are varied in human activities, they were chosen for comparison reasons, especially Marine Science Station which is considered as a green area, protected a way from pollutants and industrial activities. *Halophila stipulacea* samples were collected using grab samplers at different depths ranging from 3m to 6m below the sea surface. Collected samples were packed carefully and transported to the physics laboratory/Yarmouk University directly after collection.

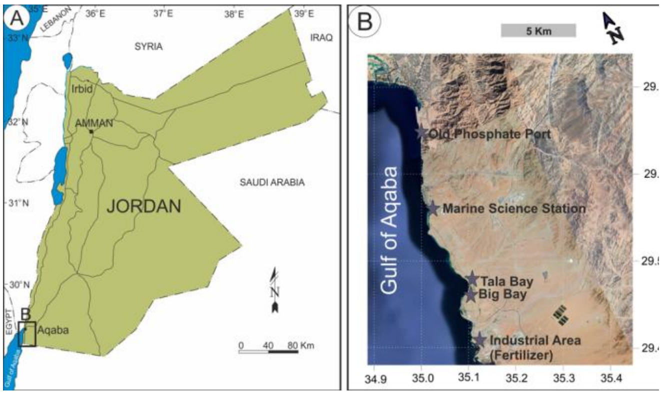

Figure 2 (A and B): Map and Locations of the sampling sites (The authors' elaboration).

Table 1: *Halophila stipulacea* seagrass samples sites, and locations (The authors' elaboration).

Sample #	Site	Location
1	Marine Science Station	N 29° 27' 29.66" E 34° 58' 35.92"
2	Old Phosphate Port	N 29° 30' 42.35" E 34° 59' 50.88"
3	Tala Bay	N 29˚ 24' 34.16" E 34˚ 58' 44.62"
4	Big Bay	N 29° 24' 33.56" E 34° 58' 39.29"
5	Fertilizers Factory	N 29° 22' 45.93" E 34° 58' 36.64"

2.2 Sample Preparation and Spectroscopy Measurements

The collected samples were labeled and washed carefully using distilled water to remove any unnecessary materials or suspended particles. The next step was drying the samples away from the sunlight in a ventilated area to get red from any moisture. The samples were grounded, homogenized to get 70-120 μ mesh sieve, stored in a suitable container, and transported to the nuclear chemical laboratory at Jordan Atomic Energy Commission (JAEC).

Alpha spectroscopy was used to detect the existence of Po-210 and measure their activity concentrations. For this reason, 2.0 g of each sample prepared was used after adding 0.1 g of Po-209 with known energy and activity as a chemical recovery through the nuclear chemical treatments. The samples were chemically treated using distilled water and acids, according to a specific protocol done by JAEC according to the International Atomic Energy Agency. Three acids were employed in the digestion procedure: hydrofluoric acid (HF, 49%), nitric acid (HNO_3, 69%), and hydrochloride acid (HCl, 37%). Nitric and hydrochloric acids were used for general dissolution and digestion of the samples, whereas hydrofluoric acid was specifically applied to facilitate the decomposition of silica-containing matrices. The sample was digested sequentially with HF, HNO_3, and HCl, using 15 ml of each acid per digestion step [19].

The treated solution was continually stirred using a hot plate and heated up to 80 C° to insure homogeneity. Finally, Po isotopes (Po-210 and Po-209) were plated on a silver disk to start counting emitted alpha particles from these radionuclides.

Canberra 7401, USA alpha spectroscopy model was used to detect and count alpha particles. The instrument is provided with Gennie-2000, Canberra, USA software for analysis purposes. The spectroscopy consists of a Passivated Implanted Planner Silicon (PIPS) detector (15% relative efficiency and 20 keV energy resolution) [20]. A multi-standard source, Canberra, A450-20AM, USA was used for calibration purposes. Each sample was detected and counted for approximately two days, about 170,000 s to get reliable uncertainty values according to the description in the nuclear application series 12 reported in the analytical quality of IAEA [21]. The average value obtained for the recovery was about 80%.

The value of the Minimum Detectable Activity (MDA) in the experiment was measured using the definition of Curie [22]. It was found about 0.25 mBq/g in 5.0 g of the sample.

2.3 Equations and Calculations

Po-210 activity concentrations (in Bq/kg) in the samples were calculated using Equation (1) [21]. The calculations take into consideration all the factors and corrections that affect the activities' values.

$$A = \frac{A_T \bullet m_T}{m_s} \bullet \left(\frac{R_{GA} - R_{BA}}{R_{GT} - R_{BT}}\right) \bullet f_T \bullet f_{2-Po} \bullet f_{3-Po} \qquad (1)$$

where A, and A_T are the activity concentrations for Po-210 and Po-209, respectively. The m value represents the mass of the tracer solution (T) and the mass of the mass of the samples detected (s). R values represent the counting rates for gross (G) and Blank (B) for both Po-210 (A) and Po-209 (T), respectively. The factors (f_T, f_{2-Po}, and f_{3-Po}) correct the results considered the time interval starting from sampling to separation to measurement date. For more information Abdallah, et al. study explained these factors in detail [19].

3. Results

Po-210 radionuclides were detected in seagrass samples at all surveyed sites, indicating the presence of measurable radiological inputs across the study area. The activity concentrations of Po-210 (in Bq/kg, dry wt.) quantified in the seagrass samples, together with their associated (MDA), are presented in Table 2. These values provide a comparative basis for evaluating spatial variations in radionuclide accumulation within the sampled seagrass.

The results were ranged between12.44±0.76 Bq/kg and 27.16±1.52 Bq/kg with an average value equals 21.26±2.48 Bq/kg. The minimum value was found on the Marine Science Station site as expected and the maximum activity concentration of Po-210 was found on the Old Phosphate Port. The two closed industrial sites (Tala Bay and Big Bay) got activity concentration values of 20.10±1.19 Bq/kg and 16.30±0.97 Bq/kg, respectively. While the Fertilizers Factory site had 21.47±1.41 Bq/kg activity concentration (as shown in Figure 3).

Table 2: The activity concentrations (A) and MDA* of Po-210 radionuclide in the *Halophila stipulacea* seagrass grown in Aqaba Gulf-Jordan (The authors' elaboration).

Sample	Site	A (Po-210) (Bq/kg, dry wt.)	MDA (Bq/kg)
1	Marine Science Station	12.44±0.76	0.27±0.3
2	Old Phosphate Port	27.16±1.52	0.17±0.6
3	Tala Bay	20.10±1.19	0.25±0.3
4	Big Bay	16.30±0.97	0.23±0.6
5	Fertilizers Factory	21.47±1.41	0.36±0.8
	Average	21.26±2.48	
	Range	12.44-27.16	

MDA*: Minimum Detectable Limit.

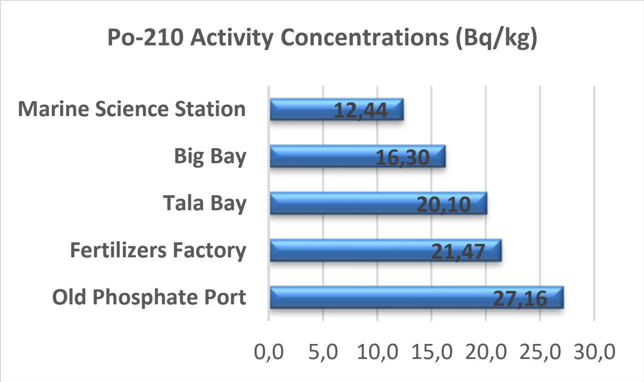

Figure 3: Po-210 activity concentrations in the present work (The authors' elaboration).

4. Discussion

The spatial variation in Po-210 radionuclide activity concentrations among the sampling sites reflects clear differences in environmental exposure and anthropogenic influence. Marine Science Station site exhibited the minimum activity concentrations, consistent with its designation as a protected green area with restricted human access. The absence of industrial or commercial activity in the vicinity likely contributes to its relatively low radiological burden, supporting the notion that undisturbed coastal habitats maintain naturally low background levels. In contrast, Old Phosphate Port demonstrated the highest activity concentrations, aligning with its proximity to intensive human activities, particularly facilities involved in phosphate export and related operations. Phosphate-rich materials are known to contain elevated levels of naturally occurring radionuclides, and their handling, transport, and processing can enhance environmental dispersion. The elevated levels measured at Old Phosphate Port therefore likely result from cumulative industrial inputs, reaffirming the sensitivity of seagrass as bioindicator for detecting radiation-related contamination along impacted coastline. These findings highlight the value of seagrass monitoring for identifying localized hotspots of radiological pollution and for informing environmental management strategies in industrialized coastal regions.

Al Khateeb and Alomari in their study [23] investigated the level of DNA damage in *Halophila stipulacea* seagrass samples collected from the same sites in the present work. The study focused on DNA damage as a pollution bioindicator in the study area. They found the minimum DNA damage was found in samples collected from the Marine Science Station (MSS) site, and the maximum DNA damage was in the Old Phosphate Port, and the moderate values were in the other industrial sites (Big Bay, Tala Bay, and Fertilizer Factory industrial sites). The obtained results of the Po-210 activity concentrations in the present work agreed and emphasized the clear association between DNA damage and the activity concentration of Po-210 radioisotope.

Azzam et al. [24] in their study reported that ionizing radiation (such as alpha particles in our study) can affect plant tissues causing interaction with the components of the cell, resulting in several damages: proteins, lipids, and the acids of the nucleus. Which is convenient with our findings.

The concentrations of the target radionuclide (Po-210) measured in the current study were compared with previously reported values from assorted studies listed in Table 3. Comparative studies were conducted in various countries worldwide, involving different species of seaweed, highlighting how geographical location and species-specific uptake influence radionuclide accumulation in marine ecosystems.

The measured concentrations in this experiment were found to be higher than those reported in Kalpakkam coast, Bay of Bengal [25] and Point Calimere Coast (Palk Strait), India [26] studies, which is attributed to the differences in sampling locations, environmental conditions, or bioaccumulation capacities of the studied organisms. In contrast, the values reported in the Red Sea, Sudan study [14] was significantly higher than those obtained in the present work, due to elevated background radiation levels, human activities, or increased anthropogenic input in those regions. These variations highlight the influence of local environmental factors and species-specific accumulation patterns, emphasizing the need for site-specific assessments when evaluating radionuclide contamination in marine ecosystems. Where results reported in Finavarra, Ireland [27], Greenland [28], Northern Gulf (The ROPME Sea Area, RSA) [29], Red Sea, Sudan [30], France [31], and Syrian coast [13] were consistent with the present work results.

Table 3: Comparison of Po-210 activity concentrations in various seaweed species from the study area with previously reported values from different regions.

#	Location	Species	A(Po-210) [Bq/kg, dry wt.]	Ref.
1	Aqaba Gulf, Red Sea	Halophila stipulacea	12.44 - 27.16	Present Study
2	Finavarra, Ireland	Brown seaweed Species	2.6-14.9	[27]
		Red seaweeds Species	6.2-23.2	
3	Greenland	F. vesiculosus	7.7–19.6	[28]
4	Kalpakkam coast, Bay of Bengal	Seaweeds	2.09 - 8.21	[25]
5	Northern Gulf (The ROPME Se Area, RSA)	Sargassum boveanum	22.5–25.6	[29]
		Sargassum oligocystum	20.2–22.5	
6	Red Sea, Sudan	Favites	38.7	[14]
		Brown algae, Cystoseria sp.	32.6	
7	Point Calimere Coast (Palk Strait), India	Seaweeds (brown algae)	2.8	[26]
		Sargassum wightii Padina parvula	2.9	
8	Syrian coast	Red Jania longifurca alga	27.43	[13]
9	Port Sudan	Seagrass	22.7	[30]
		Algal species	13.7-36.4	
10	France	F. vesiculosus	3.0–21.7	[31]

5. Conclusions

Halophila stipulacea seagrass was collected and examined to detect the existence of Po-210 at five different sites at the Gulf of Aqaba-Jordan. Alpha Spectroscopy with high resolution was used to count the activity concentrations. Po-210 was found in all samples with varied values. The results obtained showed that waste (e.g. phosphate, fertilizers, and other products related to human activities) released to the marine system has an environmental impact on the marine organisms.

The innovation of the present work lies in its use of seagrass as bioindicator of genotoxic risk, a biological matrix that remains largely underexplored in radiological monitoring literature. Previous studies have largely focused on sediment, water, or macroalgae, the present study demonstrates that seagrass serves as sensitive and ecologically indicator of localized radiological contamination. Moreover, by combining radionuclide measurements with site-specific environmental characterization, this study offers a more integrated assessment framework than those typically reported. As such, the findings contribute new evidence supporting the expansion of seagrass-based monitoring programs in regions affected by industrial activities.

Future research should focus on developing long-term monitoring datasets to better understand temporal trends in Po-210 radionuclide accumulation within seagrass and to evaluate how these patterns respond to fluctuations in industrial activity. Controlled experimental studies investigating the direct genotoxic effects of individual radionuclides on seagrass tissues would provide valuable insight into underlying causal mechanisms.

Declarations

Author Contributions

Conceptualization, Manal J. Abdallah and Wesam M. Al Khateeb; methodology, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; software, Sajedah M. Alameer; validation, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; formal analysis, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; investigation, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; resources, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; data curation, Sajedah M. Alameer.; writing—original draft preparation, Manal J. Abdallah and Wesam M. Al Khateeb; writing—review and editing, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; visualization, Manal J. Abdallah, Wesam M. Al Khateeb, and Sajedah M. Alameer; supervision, Manal J. Abdallah; project administration, Manal J. Abdallah. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data is contained within the article.

Acknowledgements

The authors would like to thank Dr. Mohammed Al-Qudhah from Department of Earth and Environmental Sciences at Yarmouk University for kindly providing the maps of the locations where the samples were collected.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, all authors have met ethical and legal standards of research and publication, and we are committed to presenting our findings transparently and objectively.

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Manuscript Information

Word count: 5,820 words (excluding references).

Peer-Review Record

Fast-track status: Not fast-tracked.
First-round reviews received: 3 reports.
Revision cycles completed: 3 rounds.
Final version submitted: January 8, 2026

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