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Assessment of heavy metals retention in sediments and mangroves along the Saurashtra coast, Gujarat

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Abstract

This study aimed to investigate the impact of heavy metal pollution on the mangrove ecosystem on the Gujarat coast, which is facing pressure due to rapid industrialization. The concentrations of 5 heavy metals, including Pb^{+2}, Cd^{+2}, Zn^{+2}, Cu^{+2}, Fe^{+2} and Mn^{+2}, were measured in the sediments and tissues of 4 mangrove species, *Avicennia marina* (Family: Acanthaceae), *Rhizophora mucronata* (Family: Rhizophoraceae), *Ceriops tagal* (Family: Rhizophoraceae) and *Aegiceras corniculatum* (Family: Primulaceae), in 8 habitats along the coast of Gujarat, India. The results indicated that the sediments in the study sites had relatively high heavy metal accretion (Pb+2 > Cu^{+2} > Fe^{+2} > Zn^{+2} > Mn^{+2} > Cd^{+2}), but *A. marina* selectively accumulated only Cu (3.59 ppm) and Zn (0.63 ppm), while avoiding other heavy metals. The morphology of the plants did not show any visible impact from heavy metals stress. These findings highlight the significance of comprehending how industrial pollution affects mangrove ecosystems and the potential processes by which these plants can adapt to survive in such settings. Another advantage of mangroves is their capacity to absorb pollutants from many environments. Mangrove stems play a major role in absorbing pollutants.

Keywords

Adaptation, Coastal habitat, Heavy metal, Mangroves, Pollution

Introduction

Coastal regions are crucial for economic growth and development because they offer a variety of ecological services, such as transportation, recreation and fishing. The health and welfare of both people and marine life are now in danger as a result of major environmental degradation and ecological disasters brought on by growing urbanization and industrialization. These activities have resulted in environmental catastrophes and ecological deterioration on a global scale. Urban landscapes have changed and the atmosphere, soil, sediments, groundwater and marine ecosystems, including all micro- and macro-organisms, have all been impacted by industrial pollution and misuse of natural resources. Along with biodiversity loss, falling fisheries and increasing vulnerability to natural catastrophes like hurricanes and tsunamis, the deterioration of coastal ecosystems has also resulted due to negative effects of anthropogenic activity (1). Mangrove is a shrub or tree that grows mainly in coastal saline or brackish water. Mangroves grow in an equatorial climate, typically along coastlines and tidal rivers. They have special adaptations to take in extra oxygen and remove salt, which allow them to tolerate conditions that would kill most plants. In this way, mangrove ecosystems are essential for preventing erosion along coastlines and preserving intertidal soil (2). Mangroves are a vital ecosystem that offers essential services to humans and the biosphere, including commercial and forest products, pollution reduction and protection from natural disasters (3). They are uniquely adapted to survive in harsh and hostile conditions, such as muddy soil, tidal interference and extreme weather conditions. Mangroves are essential for their commercial and forestry goods, for reducing pollution and for their role in protecting against natural disasters. After the devastation caused by regular cyclones and tsunamis in Asian nations, the necessity to safeguard mangroves has only lately come to light (4).

Thus, mangrove conservation and restoration are essential to preserve the priceless services that the ecosystem provides. (5).

One of the soil sediments that can hinder plant growth is heavy metals, which are more likely to be found in higher concentrations in polluted soils. High concentrations of heavy metals in soil can impair various physiological processes as well as the development and production of crops. Additionally, it has been discovered that heavy metals have an impact on complete food webs in marine environments (6, 7).

As pollutants, heavy metals are widely dispersed throughout the ecosystem and are naturally present in the earth's crust. Heavy metal concentrations in the environment can rise as a result of human activities. Numerous studies have concentrated onetals including copper, mercury, arsenic, zinc and others (8). Heavy metals are a big global problem since they are not easily broken down and continue to be present in wastewater treatment. Numerous sources, including mining, rubbish disposal, electrical accessories, paints, ash, pesticides and the disposal of radioactive materials, produce numerous pollutants, including lead, cadmium, chromium, mercury, zinc, arsenic, uranium, selenium, gold, silver, copper and nickel etc., are frequently employed in the petrochemical, paper, leather tanning and engineering fields (9-12).

Materials and Methods

2.2. Soil sample (Pre monsoon)

Samples were collected from different 8 district on Gujarat coast. The soil samples were collected from a depth of 10 cm with the help of a digger. The samples were dried in sunlight and crushed using a motor pester. The sundried and crushed soil samples weighing 12.5 g were added to in 100 mL iodine solution contained in the volumetric flasks. Further, 25 mL of Diethylene tri amine Penta-acetic acid (DTPA) solution was added to the mixture. The mixture was shaken continuously for 2 hrs on a shaker at 70 to 80 oscillations per min and filtered through acid-washed distilled water rinsed Whatman No.1 filter paper. The filtrate was then collected in the plastic bottles. Heavy metals analysis done by atomic absorption spectrophotometer (AAS) including range of 210 -230nm (13).

2.3. Plant samples

Plant samples containing leaves and stems were collected from 8 location of Gujarat coast. The samples were washed with tap water for 5 min for the purpose of cleaning leaves and stems. The samples were then dried in oven and were powdered using a mixer. Plant sample weighing 0.5 g was added in a conical flask (corning, 100 mL capacity) and 10 to 12 mL of Di acid mixture (1 perchloric + 4 nitric acids, 1:4 ratio) was added to it. The mixture was kept on a hot plate to digest until the residue turned colourless. The residue was cooled down and diluted with distilled water. It was filtered through Whatman filter paper no.1 filter paper. (14).

2.3 Bioconcentration factor

In order to determine chemical residuals in plants, the bioaccumulation of environmental contaminants was measured by bioconcentration factors (BCFs). Formula of Bioconcentration factor BCF = Cbiota/Csoil, where heavy Cbiota is planted with high levels of metal (leaves or stems) and Csoil is a Sedimentary heavy metal concentration in soil (15, 16).

Results and Discussion

Table 1 shows the concentration of six heavy metals (Cu^{+2}, Zn^{+2}, Cd^{+2}, Fe^{+2}, Pb^{+2} and Mn^{+2}) in 4 mangrove species (*Avicennia marina, Rhizophora mucronata, Ceriops tagal* and *Aegiceras corniculatum*) from 8 different locations. The values are expressed in µg/gm and represent the mean value of triplicate samples.

The results of bioaccumulation of the heavy metal concentration analysis in the mangrove species indicate

Table 1. Heavy metals (Cu^{+2}, Zn^{+2}, Cd^{+2}, Fe^{+2}, Pb^{+2} and Mn^{+2}) concentration in 4 different species at different locations

Location	**Plant species**	**Heavy metals concentration (µg/gm)**					
		Cu^{+2}	**Zn^{+2}**	**Cd^{+2}**	**Fe^{+2}**	**Pb^{+2}**	**Mn^{+2}**
Jodiya	*Avicennia marina*	0.36	0.42	0.01	1.11	1.38	0.53
	Rhizophora mucronata	0.46	0.42	0.02	0.79	4.5	0.54
	Ceriops tagal	0.36	0.60	0.01	0.95	2.75	0.3
	Aegiceras corniculatum	0.25	0.54	0.01	1.26	1.8	0.44
Sikka	*Avicennia marina*	0.73	0.47	0.01	1.43	2.26	0.53
	Rhizophora mucronata	0.28	0.54	0.01	1.3	5.54	0.55
	Ceriops tagal	0.13	0.36	0.01	1.13	0.51	0.65
Rozi	*Avicennia marina*	0.42	0.60	0.03	1.11	1.47	0.44
Kachchh	*Avicennia marina*	0.49	0.54	0.02	0.92	1.67	0.44
Bhavnagar	*Avicennia marina*	0.73	0.35	0.02	1.73	4.69	0.31
Diu	*Avicennia marina*	0.44	0.63	0.01	3.03	1.11	0.26
Porbandar	*Avicennia marina*	0.75	0.29	0.01	2.24	5.67	0.35
Dwarka	*Avicennia marina*	0.64	0.14	0.02	1.54	3.8	0.77

(Heavy metals (µg/gm) each value indicates mean value of triplicate samples) that the levels of heavy metals vary across different locations and species. Among the 4 species, *Avicennia marina* showed the highest concentration of heavy metals in all eight locations, while *Ceriops tagal* and *Aegiceras corniculatum* showed the lowest concentration in most of the locations.

In terms of specific heavy metals, lead (Pb+2) showed the highest concentration in most of the locations, followed by iron (Fe^{+2}) and zinc (Zn^{+2}). On the other hand, cadmium (Cd+2) showed the lowest concentration in all locations. The variation in heavy metal concentration across different locations could be due to differences in anthropogenic activities and the level of pollution in the surrounding areas.

Overall, the results suggest that the mangrove species, particularly *Avicennia marina*, are capable of accumulating heavy metals and their concentration can vary significantly across different locations.

Therefore, the use of mangroves for phytoremediation purposes should be carefully assessed based on the heavy metal concentration in the surrounding area (17, 18).

The results presented in Table 2 show that the concentrations of heavy metals varied among different locations. The highest concentrations of Cu+2 was found in *Aegiceras corniculatum* samples from Jodiya, while the lowest concentrations of Cu+2 were found in *Avicennia marina* samples from Dwarka. Zn+2 concentrations were highest in *Avicennia marina* samples from Sikka, while the lowest concentrations of Zn+2 were found in *Avicennia marina* samples from Rozi.

Cd+2 concentrations were generally low in all samples, with the highest concentration found in *Aegiceras corniculatum* samples from Jodiya. Fe+2 concentrations were highest in *Avicennia marina* samples from Kachchh, while the lowest concentrations were found in *Avicennia marina* samples from Dwarka. Pb+2 concentrations were highest in *Avicennia marina* samples from Porbandar and Bhavnagar, while the lowest concentrations were found in *Avicennia marina* samples from Rozi and Dwarka. Mn+2 concentrations were highest in *Rhizophora mucronata* samples from Jodiya and Sikka, while the lowest concentrations were found in *Avicennia marina* samples from Rozi and Dwarka.

The highest concentrations of heavy metals were found in *Aegiceras corniculatum* and *Avicennia marina* samples, while *Rhizophora mucronata* and *Ceriops tagal* samples generally had lower concentrations (19, 20).

Table 3 shows the results of a principal component analysis (PCA) of heavy metals in sediments of eight natural habitats of *Avicennia marina*. The PCA reduces the dimensionality of the data by identifying underlying patterns and correlations among the heavy metals. The table shows the scores of each location on the first 2 principal components (PC1 and PC2). PC1 explains 90.908% of the total variance and PC2 explains 8.3044% of the variance. The cumulative variance of the first 2 principal components is 99.2142%.

PC1 is the dominant component, accounting for 90.9% of the total variance in heavy metal concentrations.

Table 3. Principal component analysis of heavy metals in sediments of 8 natural habitats of *Avicennia marina*

Location	PC 1	PC 2
Jodiya	0.14081	0.14886
Rozi	0.14498	0.13751
Sikaa	0.2356	0.10749
Kachchh	0.16303	0.028669
Bhavnagar	0.51985	-0.16463
Diu	0.15961	0.9418
Porbandar	0.64117	-0.13421
Dwarka	0.41261	0.391
Eigen value (variation between two measurement)	11.3601	1.03774
%Variance	90.908	8.3044
Cumulative variance (%)	**90.908**	**99.2142**

Table 2. Heavy metals (Cu^{+2}, Zn^{+2}, Cd^{+2}, Fe^{+2}, Pb^{+2}, Mn^{+2}) concentration in the soil collected from the 8 locations

Location	Species	Heavy metal concentration (µg/gm)					
		Cu^{+2}	**Zn^{+2}**	**Cd^{+2}**	**Fe^{+2}**	**Pb^{+2}**	**Mn^{+2}**
Jodiya	*Avicennia marina*	2.69	0.62	0.02	2.30	0.64	0.54
	Rhizophora mucronata	1.91	0.34	0.02	1.65	0.32	2.13
	Ceriops tagal	2.52	0.33	0.01	1.39	0.41	1.57
	Aegiceras corniculatum	5.59	0.45	0.03	2.25	0.02	1.38
Rozi	*Avicennia marina*	0.32	0.30	0.01	0.46	0.35	0.32
Sikka	*Avicennia marina*	0.33	0.75	0.02	1.79	0.28	0.47
	Rhizophora mucronata	1.00	0.44	0.02	1.65	0.15	2.61
	Ceriops tagal	0.74	0.64	0.02	1.63	0.24	0.26
Bhavnagar	*Avicennia marina*	3.59	0.28	0.03	2.42	0.31	2.24
Diu	*Avieecnnia marina*	2.03	0.45	0.02	2.36	0.03	0.64
Kachchh	*Avicennia marina*	2.27	0.39	0.02	2.85	0.66	2.24
Porbandar	*Avicennia marina*	0.35	0.33	0.02	2.12	0.32	1.03
Dwarka	*Avicennia marina*	0.17	0.45	0.02	0.84	0.32	0.84

(Heavy metals (µg/gm) Each value indicates the mean value of triplicate samples)

It is positively correlated with all heavy metals except for cadmium, which has a negative correlation. The high positive loading of copper, zinc, iron and lead on PC1 indicates that these metals share a common source or have similar geochemical behavior. Therefore, PC1 represents a general measure of metal pollution.

PC2 accounts for 8.3% of the total variance in heavy metal concentrations. It has a high positive correlation with manganese and a negative correlation with copper, zinc, iron and lead. This suggests that PC2 is primarily influenced by manganese and is less affected by other heavy metals. Therefore, PC2 likely represents a more specific measure of manganese pollution.

The PCA results suggest that human activities may be contributing to the heavy metal contamination of the sediments in these natural habitats *of Avicennia marina*. The findings may be useful for environmental management and conservation efforts in these areas (21).

The results indicate (Table 4) a strong positive correlation between the heavy metal concentrations in *Rhizophora mucronata* and *Ceriops tagal* at Jodiya habitat (r=0.979**), as well as at Sikka habitat (r=0.995**). This suggests that these two plant species have a similar uptake and accumulation of heavy metals in their tissues. A similar pattern was also observed between *Ceriops tagal* and *Aegiceras corniculatum* at Jodiya habitat (r=0.931**), which further supports the idea of similar metal uptake and accumulation patterns. However, the correlation between *Rhizophora mucronata* and *Aegiceras corniculatum* was slightly weaker at Jodiya habitat (r=0.856*) and not statistically significant at Sikka habitat (r=0.894*). This suggests that there may be some differences in the ability of these plant species to accumulate heavy metals in their tissues, which could be due to differences in their physiology or habitat preferences.

Additionally, the correlation between heavy metal concentrations in *Ceriops tagal* at Sikka habitat and the other plant species was relatively weak and not statistically significant. This may be due to differences in the availability and uptake of heavy metals at different habitats, or differences in the metal tolerance of different plant species (21).

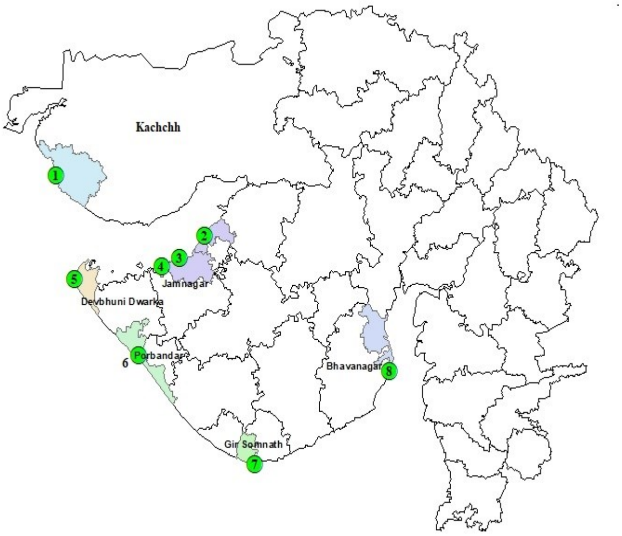

Fig. 1. S Study area: 1] Kachchh (Jakhau), 2] Jodiya (Jamnagar), 3] Sikka (Jamnagar), 4] Rozi(Jamnagar), 5] Dwarka, 6] Porbandar (Subhashnagar), 7] Gir Somnath (Diu-Union territory- Vanakbara), 8] Bhavanagar(Lakhanaka).

The provided Fig. (A) shows the bioconcentration factors (BCFs) of heavy metals in various mangrove plant species at different locations. Based on the data presented, it can be observed that the BCFs of heavy metals vary across different plant species and locations. In general, *Rhizophora mucronat*a and *Ceriops tagal* have higher BCFs for most of the studied heavy metals compared to *Avicennia marina* and *Aegiceras corniculatum* and *Ceriops tagal* are more efficient in accumulating heavy metals in their tissues than the other 2 plant species. In terms of location, the highest BCFs for most of the heavy metals were observed in the Rozi and Bhavnagar sites, while the lowest BCFs were observed in the Kachchh and Porbandar sites. This could be due to differences in the availability of heavy metals in the soil and water, as well as differences in the physiology and metal uptake mechanisms of the plant species in different locations (21). Fig. (B) showed the Bioconcentration Factors (BCFs) of heavy metals in three mangrove plant species (*Avicennia marina, Rhizophora mucronata* and *Ceriops tagal*) in the Sikka location. The heavy metals analyzed were Cu+2, Zn+2, Cd+2, Fe+2, Pb+2 and Mn+2. The Bioconcentration Factor (BCF) is the ratio of the concentration of a heavy metal in a plant to the concentration of that metal in the surrounding environment (usually sediment or water).

BCF values greater than one indicates that the plant is accumulating the metal, while values less than one indicate that the plant is not accumulating the metal. Based on the data presented, it can be observed that the BCF values for the different heavy metals vary among the 3 plant species. For instance, the BCF values for Cu+2 and

Table 4. Results of Pearson's Correlation analysis of heavy metals concentration at 2 habitats with 3 plant species.

Pearson's Correlation	*Rhizophora mucronata* (Jodiya)	*Ceriops tagal* (Jodiya)	*Aegiceras cor-niculatu m.* (Jodiya)	*Rhizophora mucronata* (Sikka)	*Ceriops tagal* (Sikka)
Rhizophora mucronate (Jodiya)	1				
Ceriops tagal (Jodiya)	.979**	1			
Aegiceras corniculatum. (Jodiya)	.856*	.931**	1		
Rhizophora mucronata (Sikka)	.995**	.989**	.894*	1	
Ceriops tagal (Sikka)	.184	.184	.628	.253	1

(**Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level. (Heavy metals (µg/gm) Each value indicates mean value of triplicate samples

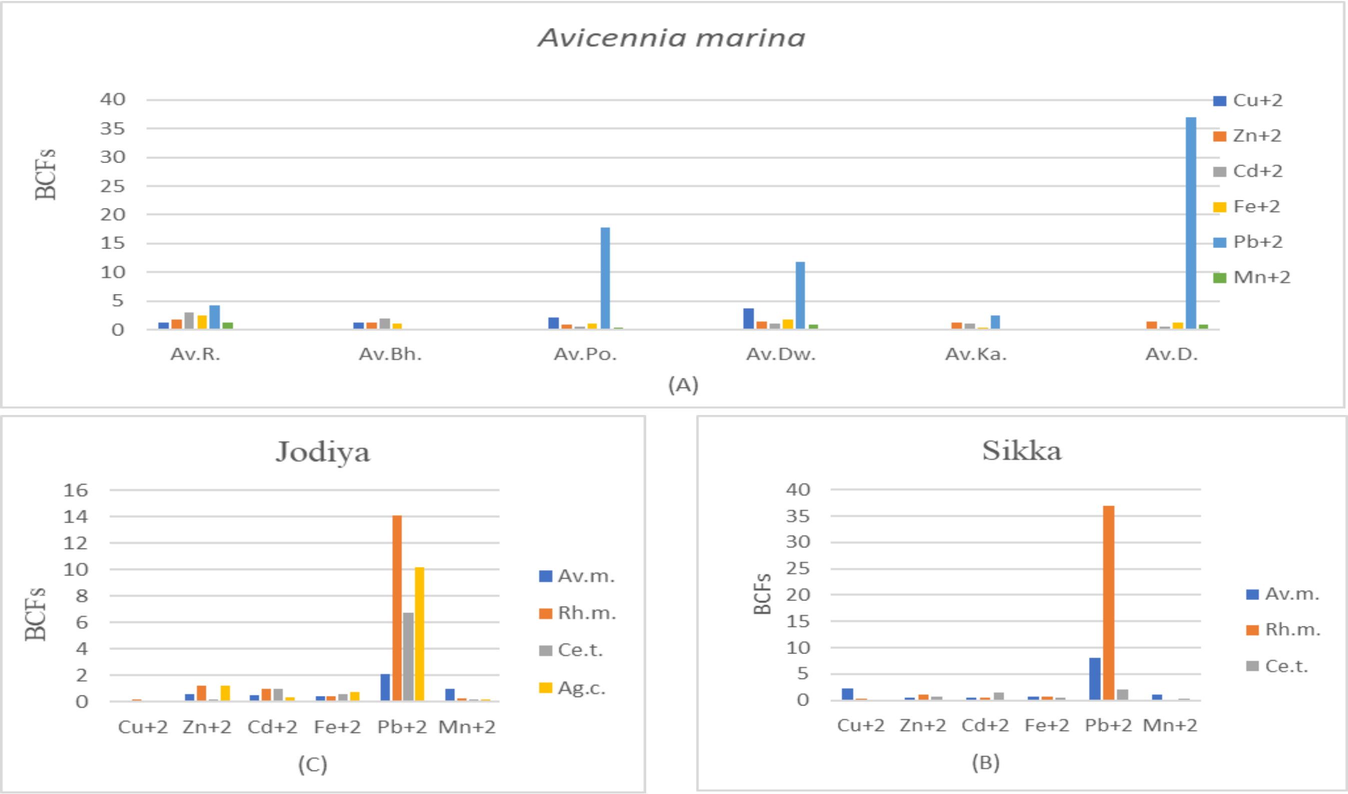

Fig. 2. BCF value of mangroves at three different locations.

Zn+2 was highest in *Rhizophora mucronata*, while the BCF values for Cd+2 and Fe+2 were highest in *Ceriops tagal*. *Avicennia marina* shows the highest BCF values for Pb+2 and Mn+2.

The Fig. (C) showed the Bioconcentration Factors (BCFs) of heavy metals in 4 mangrove plant species (*Avicennia marina, Rhizophora mucronata, Ceriops tagal* and *Aegiceras corniculatum*) in the Jodiya location. The heavy metals analyzed were Cu+2, Zn+2, Cd+2, Fe+2, Pb+2 and Mn+2.The BCF values for the different heavy metals vary among the 4 plant species. For instance, the BCF values for Cu+2 is highest in *Aegiceras corniculatum*, while the BCF values for Zn+2, Cd+2 and Fe+2 is highest in *Rhizophora mucronata*. *Avicennia marina* shows the highest BCF values for Pb+2, while *Ceriops tagal* shows the highest BCF values for Mn+2. The variations in BCF values among different plant species could be due to differences in the physicochemical properties of the sediment, as well as the uptake and accumulation mechanisms of the heavy metals in different plant species. Additionally, it is worth noting that the BCF values of different heavy metals can also vary within the same plant species.

Conclusion

The study was carried out on heavy metal concentrations of mangrove plant parts and also for habitat; on the most significant analysis was shown on the mangrove sample. In mangrove habitats their heavy metal concentration is varied; Copper, Zinc and Cadmium are low in concentration in comparison to Iron and Lead. *A. marina* has successfully adapted itself to this stress condition with a mechanism for selective uptake of only necessary minerals. Furthermore, the metal content in different plant parts. Metals distribution in sediments was affected by inputs from natural as well as anthropogenic sources at all stations along the estuary.

Anthropogenic additions through mining discharges from upstream regions of the estuary and via the water flow significantly affected the sediment contamination with respect to iron mainly. A speciation study revealed that high concentrations of lead in the bioavailable segments of sediments can cause harmful effects on the sediment-associated biota and degrade the quality of the estuarine environment conservation of saline plants can be reduced the heavy metal concentration on the coast. *A. marina* can be used for plantation programs in contaminated soils for the long-term sustainable functioning of the estuarine ecosystem. BCFs factor amplifies that Pb^{+2} is high in all sites, indicating that mangroves all accrue heavy metals in coastal habitat with pollutant site.

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Authors' contributions

Lab Work support and help was provided by KJG and KBD. The whole research work was carried out under the able guidance of SJV.

Compliance with ethical standards

Conflict of interest: No conflict of interest.

Ethical issues: None.

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