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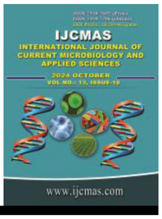

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Hydrobiological Studies of Arasalar Estuary: Emphasis on Heavy Metal Pollution

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ABSTRACT

Estuaries serve as crucial ecosystems, acting as natural filters for pollutants and providing important habitats for aquatic life. However, human activities such as industrialization, urbanization, and agricultural expansion have significantly impacted these ecosystems, resulting in the contamination of estuaries with harmful substances like heavy metals. The Arasalar estuary, located in Karaikal, South India, is one such vulnerable environment facing heavy metal pollution. This study investigates the hydrobiological characteristics of the Arasalar estuary, with a specific focus on the bioaccumulation of hazardous heavy metals in commercially important aquatic species. Heavy metals such as copper, zinc, cadmium, mercury, and lead are known to pose significant risks to aquatic organisms, disrupting ecosystems and affecting food safety. The research highlights the long-term effects of these metals, which bioaccumulate in aquatic species, leading to toxic levels that threaten biodiversity and human health. Through systematic sampling and analysis, this study provides critical data on metal concentrations in the estuary, offering insights into the ecological health of the region. The findings underscore the urgent need for pollution management strategies to safeguard aquatic ecosystems and ensure the sustainability of local fisheries. This research contributes to broader efforts in environmental monitoring and the global understanding of estuarine health, addressing key issues related to pollution and ecosystem resilience.

Keywords

Estuaries, bio-monitoring crucial, aquatic ecosystems, coastal aquaculture

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Introduction

Estuaries play a critical role in coastal aquaculture, serving as natural filters for suspended materials and pollutants. However, human activities have significantly altered the concentration of various substances in these ecosystems, making prolonged bio-monitoring crucial. Many aquatic organisms have the ability to accumulate heavy metals, which poses significant threats to the environment. Metal contamination in aquatic ecosystems has become a growing concern due to the persistence of these metals, which can be harmful to aquatic life (Nriagu and Sprague, 1987; Verma *et al.,* 2005).

With increasing industrialization, urbanization, and population growth, environmental pollution has become a global issue, affecting all life forms. Among the various types of pollution, aquatic pollution is particularly alarming, as water is essential for all forms of life. Heavy metals, such as copper, zinc, cadmium, mercury, and lead, are among the most hazardous pollutants in aquatic systems (Zyadah and Abdel-Bakey, 2000; Lliopoulou-Georguadaki and Kotsanis, 2001).

While some of these metals, such as copper and zinc, are necessary for metabolic functions in small quantities, others like lead and mercury have no known biological role and are toxic to organisms at even low concentrations (Nriagu, 1996; Sanders, 1997).

Bioaccumulation of metals occurs when organisms take in more metals than they can excrete, leading to toxic levels that can harm their health and the overall ecosystem (Burman and Lal, 1994). This process, compounded by the long half-life and non-biodegradable nature of heavy metals, further exacerbates the issue of environmental pollution (Pitter, 1999). The increasing use of metals in agriculture, industry, and chemical processes has intensified the risk of metal contamination in aquatic ecosystems, especially in estuaries and coastal environments (Mason, 1996; Lodhi *et al.,* 2006).

Given the crucial role fisheries play in global food security, supplying protein to millions, the impact of metal contamination is especially concerning. The Food and Agriculture Organization (FAO) reported that in 2008, global fisheries production reached 146 million tonnes, with a record value of $103 billion.

However, overfishing, pollution, global warming, and poor fish stock management continue to threaten the sustainability of this vital industry (FAO, 2008). By 2030, FAO forecasts a seafood shortage of 40 million tonnes if current trends continue. In light of these concerns, this research focuses on determining the bioaccumulation levels of hazardous metals in commercially important species from the Arasalar River estuary in Karaikal, South India.

Materials and Methods

Study Area

The study was conducted in the Arasalar estuary, located on the east coast of India, in the Bay of Bengal (Lat. 79°52'N, Long. 10°55'E). The Arasalar River originates from the Cauvery River in Kabisthalam, Thanjavur district, and flows through various regions to form an estuary at Karaikal, Puducherry.

Collection and Preparation of Samples

Water, sediment, and biological samples were collected seasonally (pre-monsoon, monsoon, post-monsoon, and summer) from July 2010 to June 2011. Surface water samples were collected using pre-cleaned, acid-washed polypropylene bottles and filtered using Millipore filters (0.45 µm). Sediment samples were collected using a Petersen's grab and transferred to clean polythene bags. The hermit crab (*Clibanarius infraspinatus),* clam (*Meretrix casta*), and mullet fish (*Mugil cephalus*) were collected from the estuary by hand-picking and netting. Soft tissues, including gill, digestive gland, liver, and muscle, were extracted from the organisms for metal analysis.

Heavy Metal Analysis

The concentration of heavy metals (copper, zinc, cadmium, and chromium) was analyzed in water, sediment, and the tissues of collected organisms. Water samples were pre-concentrated using the Ammonium Pyrrolidane Dithio Carbamate (APDC)-Methyl Iso-Butyl Ketone (MIBK) extraction method described by Brooks *et al.,* (1967).

Sediment and tissue samples were digested using a hydrochloric acid-nitric acid-perchloric acid mixture (10:5:1 ratio) at 300°C following Dalziel and Baker's method (1983). The resulting solutions were analyzed using Atomic Absorption Spectrophotometry (AAS) to determine the concentrations of the heavy metals. Results were expressed in µg/g of dry weight.

Acclimatization of Organisms

The collected organisms were acclimated to laboratory conditions for 10-15 days in glass aquaria with estuarine water. Water quality parameters, including temperature, dissolved oxygen, salinity, and pH, were monitored and maintained within optimal ranges (APHA, 1992).

Toxicity Studies

Acute toxicity tests were performed to determine the lethal concentrations (LC50) for each metal after 96 hours of exposure using methods described by Finney (1971). Sublethal concentrations (10% and 30% of LC50) were used for chronic toxicity tests, where organisms were exposed for 30 days. Mortality rates and physiological changes were recorded.

Results and Discussion

Physico-chemical Parameters

The physico-chemical parameters of water and sediments revealed notable variability in heavy metal concentrations. Copper (Cu) in water ranged from 1.31 µg/L in May 2011 to 2.64 µg/L in November 2010, with sediment concentrations between 4.6 µg/g and 14.4 µg/g, showing an increase during monsoons. Zinc (Zn) levels in water fluctuated from 4.12 µg/L to 8.4 µg/L, while sediment concentrations ranged from 12.1 µg/g to 20.61 µg/g. Cadmium (Cd) in water varied between 0.05 µg/L and 0.13 µg/L, with sediment levels between 1.1 µg/g and 3.7 µg/g. Chromium (Cr) concentrations in water ranged from 0.54 µg/L to 1.26 µg/L, while sediment levels varied from 3.2 µg/g to 8.37 µg/g (Table 1; Fig. 1-9).

Heavy Metal Concentrations in Water and Sediments

The concentrations of heavy metals in water and sediments showed significant variation. Copper (Cu) levels in water ranged from 1.31 µg/L in May 2011 to 2.64 µg/L in November 2010, with sediment concentrations between 4.6 µg/g and 14.4 µg/g, peaking during monsoons. Zinc (Zn) concentrations in water fluctuated between 4.12 µg/L and 8.4 µg/L, and in sediments, they ranged from 12.1 µg/g to 20.61 µg/g. Cadmium (Cd) levels in water were between 0.05 µg/L and 0.13 µg/L, while sediment concentrations varied from 1.1 µg/g to 3.7 µg/g. Chromium (Cr) in water ranged from 0.54 µg/L to 1.26 µg/L, with sediment levels between 3.2 µg/g and 8.37 µg/g. (Table 2 & 3; Fig. 10-13).

Bioaccumulation in Aquatic Organisms

Bioaccumulation of heavy metals in aquatic organisms varied across species and tissues, with the highest levels generally observed during the monsoon season. In hermit crabs (*Clibanarius infraspinatus*), the hepatopancreas showed the greatest accumulation of copper (Cu), zinc (Zn), cadmium (Cd), and chromium (Cr), with significant variations in metal concentrations across different tissues. This elevated accumulation during monsoon suggests a seasonal influence on metal uptake. In clams (*Meretrix casta*), the digestive gland was the primary site of metal accumulation, with Cd reaching as high as 7.3 µg/g and Zn at 56.2 µg/g, particularly during monsoon. Similarly, in fish (*Mugil cephalus*), the liver was the organ where the highest levels of Cu, Zn, Cd, and Cr were detected, also peaking during the monsoon season. These findings highlight the tendency for metals to concentrate in specific tissues, especially during periods of increased environmental exposure such as the monsoon, posing potential health risks to these organisms and, by extension, the ecosystems they inhabit.

Lethal Concentrations (LC50)

The lethal concentration (LC50) data revealed cadmium (Cd) to be the most toxic heavy metal among those tested across various aquatic species. Hermit crabs demonstrated the highest sensitivity to cadmium, with an LC50 value of 5.3 ppm over a 96-hour exposure period, meaning that this concentration of Cd was lethal to 50% of the hermit crabs within that time frame. Clams, while slightly more resilient, also showed significant vulnerability to cadmium, with an LC50 value of 7.4 ppm. Fish, similarly affected by cadmium toxicity, had an LC50 value of 6.1 ppm over 96 hours, making cadmium the most dangerous heavy metal to aquatic organisms in this study. These results underscore cadmium's high toxicity across species, suggesting that even relatively low concentrations can be lethal to marine life, especially over prolonged exposure periods.

Histological and Morphological Changes

Significant tissue damage was observed in organisms exposed to heavy metals, especially cadmium. In hermit crabs, clams, and fish, exposure led to cell disintegration, necrosis, and vacuolization, with the most severe effects observed in the gills, digestive glands, and muscle tissues. This study highlights the severe impact of heavy metals on the Arasalar estuary ecosystem, particularly during monsoon periods when the highest concentrations were observed. The accumulation of metals in sediment and bioaccumulation in aquatic organisms underline the potential long-term ecological risks.

The hydrobiological parameters of the Arasalar estuary, particularly the physico-chemical characteristics and the concentration of heavy metals, exhibit distinct seasonal variations. These variations are primarily driven by the rainfall patterns, particularly the heavy monsoons from October to December, which influence water temperature, pH, salinity, and the concentration of dissolved oxygen and nutrients like phosphate, nitrate, and silicate.

Table.1 Physico-chemical parameters in Arasalar estuary (for Rainfall, Temperature, pH, Salinity, etc.)

Parameters	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
	2010						2011					
Rainfall (mm)	19.3	293.1	224.6	85.5	551.8	348.8	31.2	20.4	1.2	0.33	21.5	23.8
Atmosphere (°C)	32.6	29.5	30.1	27.1	26.1	26.3	30.4	31.2	32.4	33.5	34	34.3
Water (°C)	30.4	28.3	28.4	25.7	25.3	25.1	29.1	30.2	31.1	31.6	31.5	31.8
pH	8.1	7.9	7.8	7.6	7.6	7.5	7.7	7.8	7.8	8.1	8.4	8.2
Salinity (ppt)	26.1	26.8	23.1	24.6	21.4	20.5	23.1	23.6	26.1	28.6	32.1	31.1
Dissolved oxygen (ml/l)	3.1	3.9	4.9	4.6	5.3	5.1	4.6	4.7	4.4	3.9	2.8	2.9
Silicate (µg/l)	33.1	49.6	51.2	54.6	84.3	85.1	72.1	56.2	39.1	14.2	24.1	25.1
Total phosphorus (µg/l)	0.75	1.14	1.17	0.98	1.21	1.14	0.91	0.83	0.71	0.32	0.64	0.59
Nitrate (µg/l)	4.97	8.97	8.19	7.91	8.69	8.41	7.67	6.95	4.81	2.47	3.41	3.11

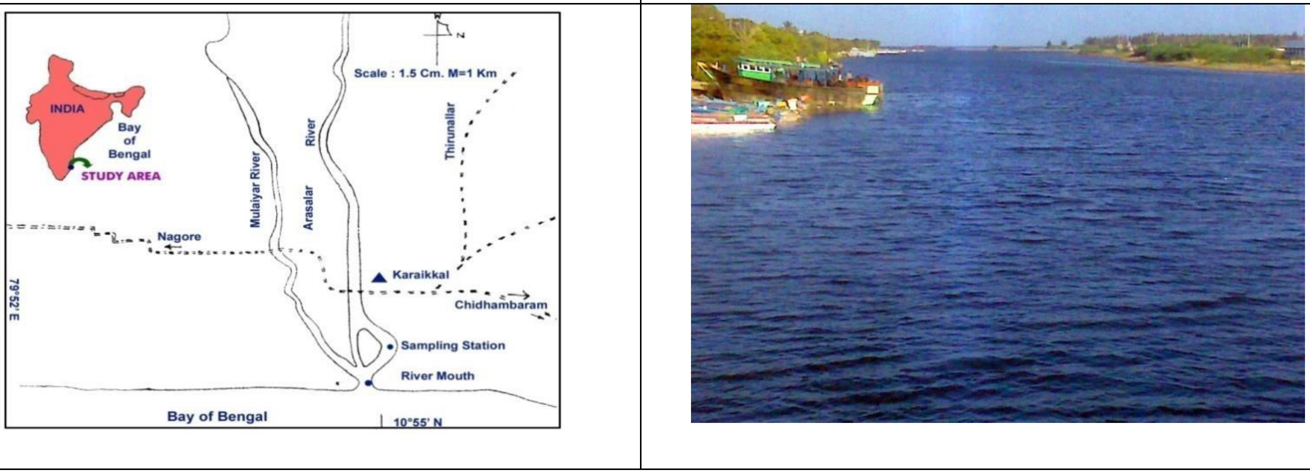
Table.2 Distribution of heavy metal copper (µg/g) in Arasalar estuary

	July 2010	Aug. 2010	Sept. 2010	Oct. 2010	Nov. 2010	Dec. 2010	Jan. 2011	Feb. 2011	March 2011	April 2011	May 2011	June 2011
Water (µg/l)	1.36	2.37	2.29	2.61	2.56	2.64	1.76	1.98	2.04	1.14	1.31	1.66
Sediment (µg/g)	4.9	6.4	8.9	12.9	14.4	14.1	11.6	11.2	8.2	4.6	5.1	5.7

Table.3 Distribution of heavy metal zinc (µg/g) in Arasalar estuary

	July 2010	Aug. 2010	Sept. 2010	Oct. 2010	Nov. 2010	Dec. 2010	Jan. 2011	Feb. 2011	March 2011	April 2011	May 2011	June 2011
Water (µg/l)	4.3	7.2	6.9	8.03	8.14	7.98	5.6	4.85	4.13	4.2	4.6	5.14
Sediment (µg/g)		16.9	17.4	17.2	18.4	20.61	16.8	15.7	14.6	12.1	12.16	14.1

Figure.1



Map showing the study Area

Photograph of Arasalar Estuary

Figure.2

Fig. 1: Rainfall recorded during 2010 to 2011 in the study area

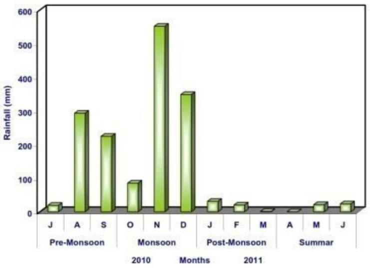


Fig.2: Monthly changes in atmospheric temperature during 2010 to 2011 in the study area

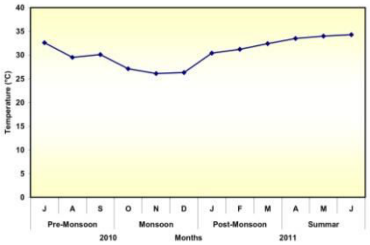


Fig. 3: Monthly changes in water temperature during 2010 to 2011 in the study area

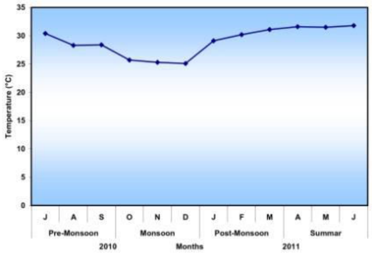


Fig.4: Monthly changes in the pH during 2010 to 2011 in the study area

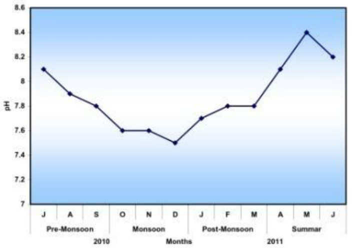


Fig.5: Monthly changes in salinity during 2010 to 2011 in the study area

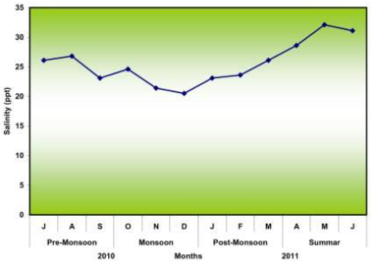


Fig.6: Monthly changes in dissolved oxygen during 2010 to 2011 in the study area

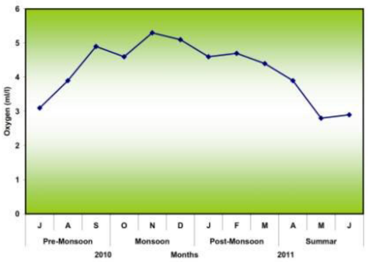


Fig. 7: Monthly changes in the silicate content during 2010 to 2011

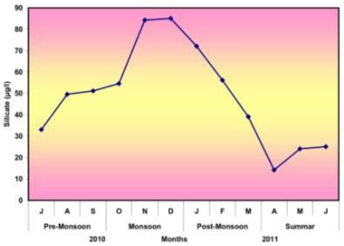


Fig.8: Monthly changes in the total phosphate content during 2010 to 2011 in the study area

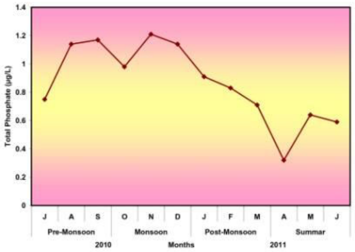


Fig. 9: Monthly changes in the nitrate content during 2010 to 2011 in the study

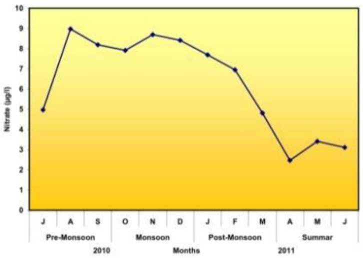


Figure.3

Fig.10: Monthly variations of heavy metal copper concentration of water (µg/l) and sediments (µg/g) of Arasalar estuary

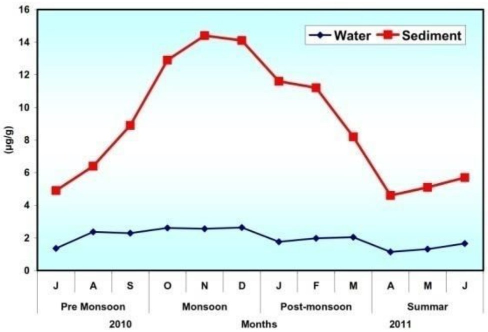


Fig.11: Monthly variations of heavy metal zinc concentration of water (µg/l) and sediments (µg/g) of Arasalar estuary

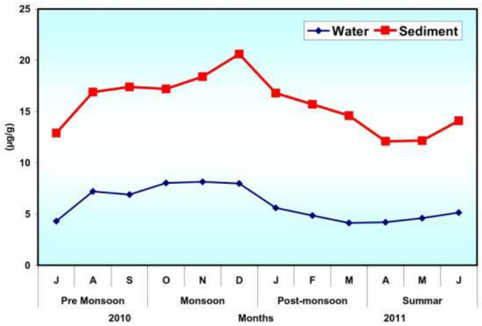


Fig.12: Monthly variations of heavy metal cadmium concentration of water (µg/l) and sediments (µg/g) of Arasalar estuary

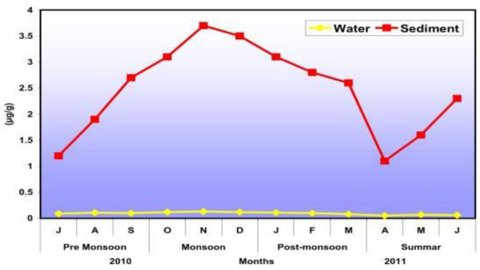
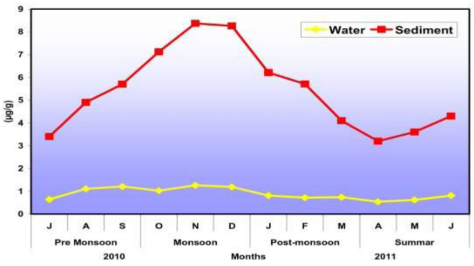


Fig.13: Monthly variations of heavy metal chromium concentration of water (µg/l) and sediments (µg/g) of Arasalar estuary



Physico-chemical Parameters

The observed seasonal variations in temperature, pH, and dissolved oxygen in the Arasalar estuary are consistent with studies conducted in other Indian estuaries. For example, Damotharan *et al.,* (2010) reported similar seasonal fluctuations in the Point Calimere coastal waters, where temperature and salinity levels were closely linked to the monsoonal patterns. The dilution effect of rainfall on salinity levels during the monsoon is well-established by earlier studies, such as Knauer and Martin (1973), which discussed how the inflow of freshwater affects the concentrations of trace metals and salinity in coastal regions.

Heavy Metal Pollution

The accumulation of heavy metals in the sediments and aquatic organisms of the Arasalar estuary, particularly zinc and copper, mirrors findings from other coastal regions of India. For example, Krishna kumar *et al.,* (1990) documented significant bioaccumulation of trace metals in marine flora and fauna along the Karnataka coast, which closely aligns with the current study's findings of elevated metal concentrations during the monsoon season. The high levels of metals in sediment during the monsoon can be attributed to increased runoff, as observed by Cuadras *et al.,* (1981) in their study of copper and zinc accumulation in hermit crabs near Barcelona.

Bioaccumulation in Aquatic Organisms

Bioaccumulation of metals in the tissues of organisms such as fish, crabs, and clams is a significant concern. Studies like Lakshmanan and Nambisan (1983) highlighted similar trends in bivalve mollusks, where bioaccumulation varied seasonally and was particularly high during periods of increased metal influx.

In addition, Krishnamurti and Nair (1999) examined metal concentrations in shrimps and crabs from the Thane-Bassein creek system, further supporting the results of the current study which identified high metal accumulation in the hepatopancreas of crabs during the monsoon season.

Toxicity and Histological Effects

The histological changes observed in the aquatic organisms of the Arasalar estuary, particularly the damage caused by cadmium, are consistent with findings from other studies. Koca *et al.,* (2008) investigated the genotoxic and histopathological effects of water pollution on fish species in Turkey, documenting similar tissue damage, including necrosis and cellular degeneration, in organisms exposed to heavy metal contamination. Furthermore, Girija (1987) reported structural damage to gill tissues of *Tilapia mossambica* exposed to pesticides and metals, providing further evidence of the toxic effects of cadmium and other metals on aquatic life.

Ecological Implications

The long-term ecological risks posed by heavy metal pollution are supported by previous studies such as Forstner and Prosi (1978), who emphasized that heavy metal pollution in freshwater and estuarine ecosystems can lead to biomagnification, adversely affecting multiple trophic levels. The importance of continued monitoring, as highlighted by Goldberg (1978) in his "Mussel Watch" study, is underscored by the need to track the accumulation of metals over time and prevent further ecological degradation.

The study highlights the significant impact of heavy metal pollution on the Arasalar estuary, particularly during the monsoon when metal concentrations in water and sediments peak. Although the estuary is not yet highly contaminated, the presence of metals like zinc, copper, cadmium, and chromium poses a potential threat to the ecosystem's health. Continued monitoring and management are essential to prevent further contamination and ensure the sustainability of aquatic life in the estuary.

Reporting Standards Statement

The authors pledge adherence to recognized reporting standards (for example, CONSORT for randomized trials, PRISMA for systematic reviews and meta-analyses, STROBE for observational studies, ARRIVE for animal studies, etc.).

Author Contribution

D. Kandasami: Investigation, formal analysis, writing—original draft.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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