



Original article

Assessment of the bioaccumulation pattern of Pb, Cd, Cr and Hg in edible fishes of East kolkata Wetlands, India



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ARTICLE INFO

Article history:

Received 7 August 2021

Revised 10 September 2021

Accepted 13 September 2021

Available online 17 September 2021

Keyword:

Bioaccumulation

Heavy metals

Fishes

Water

Sediments

Wetland

ABSTRACT

Waste water fed pisciculture is nowadays a common feature in aquaculture belts across the globe. East Kolkata Wetlands (EKW) a nature's wonder where waste water fed natural aquaculture belts is active for more than 70 years now and is efficiently operating as a natural waste management system. The peri urban wetland is also a site of international importance and is listed in Ramsar. Field and lab-based investigations were carried out using three commonly edible carp variety of fishes such as Rohu (*Labeorohita*), Catla (*Catla catla*) and Nile Tilapia (*Oreochromis niloticus*) collected from ponds (bheries) of the wetland located on the eastern fringes of Kolkata, India. The lab-based analysis revealed the presence of toxic metals such as Cr, Pb, Cd and Hg in the samples with the seasonal order of accumulation being monsoon > post-monsoon > winter > pre-monsoon in the successive years of 2016, 2017 and 2018. Bio-accumulation of toxic heavy metals in fishes follows the order Tilapia > Rohu > Catla where as the bioaccumulation pattern of toxic metals shows the trend Pb > Cd > Cr > Hg across all the seasons and years. The ambient media was also investigated to understand in detail the bioaccumulation pattern at different trophic levels of the ecosystem. Water and sediments were analyzed to evaluate the contamination of toxic heavy metals from point and non-point sources. Current study shows the observed bioaccumulation pattern of the toxic heavy metals in one of the fragile ecosystems that raises an important question of environmental safety in the food we intake on daily basis.

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1. Introduction

Waste water-fed aquaculture systems had a long history due to their humongous potential of converting city's sewerage and

drainage wastewater flows into treated surface waters; thus reducing environmental pollution (Edwards, 2000; Bunting and Little, 2005). East Kolkata Wetlands (EKW), world's largest single stretch aquaculture system located on the eastern fringes of metropolitan city of Kolkata, India is nothing short of an ecological marvel. EKW displays a bouquet of ecosystem services from microclimate regulation to livelihood generation, especially through agriculture and pisciculture services. It happens to be one among the largest single-stretched waste-water fed aquaculture belts (locally known as *bheries*) in the world (Raychaudhuri et al., 2008). The fragile ecosystem presents a unique case study of being an archetype of resilient eco-culture in the world. Wastewater fed aquaculture acts as a sustainable and promising avenue of livelihood generation for

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Peer review under responsibility of King Saud University.



Production and hosting by Elsevier

<https://doi.org/10.1016/j.sjbs.2021.09.039>

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developing economies such as India and Bangladesh that are abundantly blessed with freshwater and marine resources. Informal cultivation of fishes and crops in wastewater has been in vogue across Asia since ages (Edwards, 2005a, 2005b). However, increasing urban spaces, agricultural activities, pollution of ecosystems, industrialization, oil-spills, overfishing have left an indelible mark on aquaculture sector. This has led to an imbalance in cost-demand proportions across the world and loss of valued consumers (Edwards, 2005a, 2005b, Little and Bunting, 2005). Changing represent sea-level temperature and increase in mean sea level temperature bears a potential threat to aquaculture and fish stocks around the world. Oil spills, bleaching of coral reefs, natural disasters such as tsunamis, overfishing, and unsustainable aquaculture practices across the world are taking a serious toll on fish reserves. Besides, pesticides, industrial effluents and heavy metals are also a major nuisance leading to the deterioration of pisciculture mainly in developing economies such as India. Fishes constitute an important portion of the people inhabiting in lower Gangetic delta. Easy availability of large variety of fishes, that are rich in omega fatty acids, protein and low density lipoprotein are key factors for healthy heart. Therefore, it quickly forms a feasible solution. However, fishes are more prone to water pollution and bioaccumulation due to direct contact with water. Even smaller concentrations of heavy metal if consumed repeatedly by fishes might wreak havoc in human body. Heavy metal concentration in fishes are being studied by ecologists across the globe (Dhanakumar et al., 2015; Hosseini et al., 2015; Jia et al., 2017; Ahmed et al., 2019).

In this paper, we have discussed bioaccumulation of toxic heavy metals as a potential threat to aquaculture practices in East Kolkata

Wetlands, a site of international importance. Almost all the components of environment have been compromised as a result of ecological imbalance which is an effect of the multitude of causal factors during the greater part of last century (Masindi and Muedi, 2018). Heavy metal toxicity has devastating implications on the ecological health of ecosystems (Farombi et al., 2007) particularly natural aquatic systems i.e. freshwater and marine. Atmospheric deposition, geological erosions, volcanic eruptions as well as anthropogenic activities are the pathway of entry of heavy metal into ecological space and eventually biological systems. Heavy metals easily dissolve into the aqueous medium and transports through biological matrix into the living organisms (Das et al., 2007). The presence of toxic metals in aquatic organisms at large has been investigated and confirmed by environmental toxicologists (Dutta et al., 2017; Dutta et al., 2016; Joystu et al., 2017; Dutta et al., 2019). Environmental toxicants in ambient media lead to bioaccumulation in fish body through osmosis as well as through diet and water uptake. Persistent trace metals such as As, Pb, Cr, Cd, and Hg has known human health implications.

2. Material and methods

2.1. Study area

East Kolkata Wetlands is a designated Ramsar site located in the south-eastern fringes of Kolkata, an important city of Indian sub-continent, and is often termed as 'gateway of east' (22°25' to 22°40' N and 88°20' to 88°35' E). The current study area map is

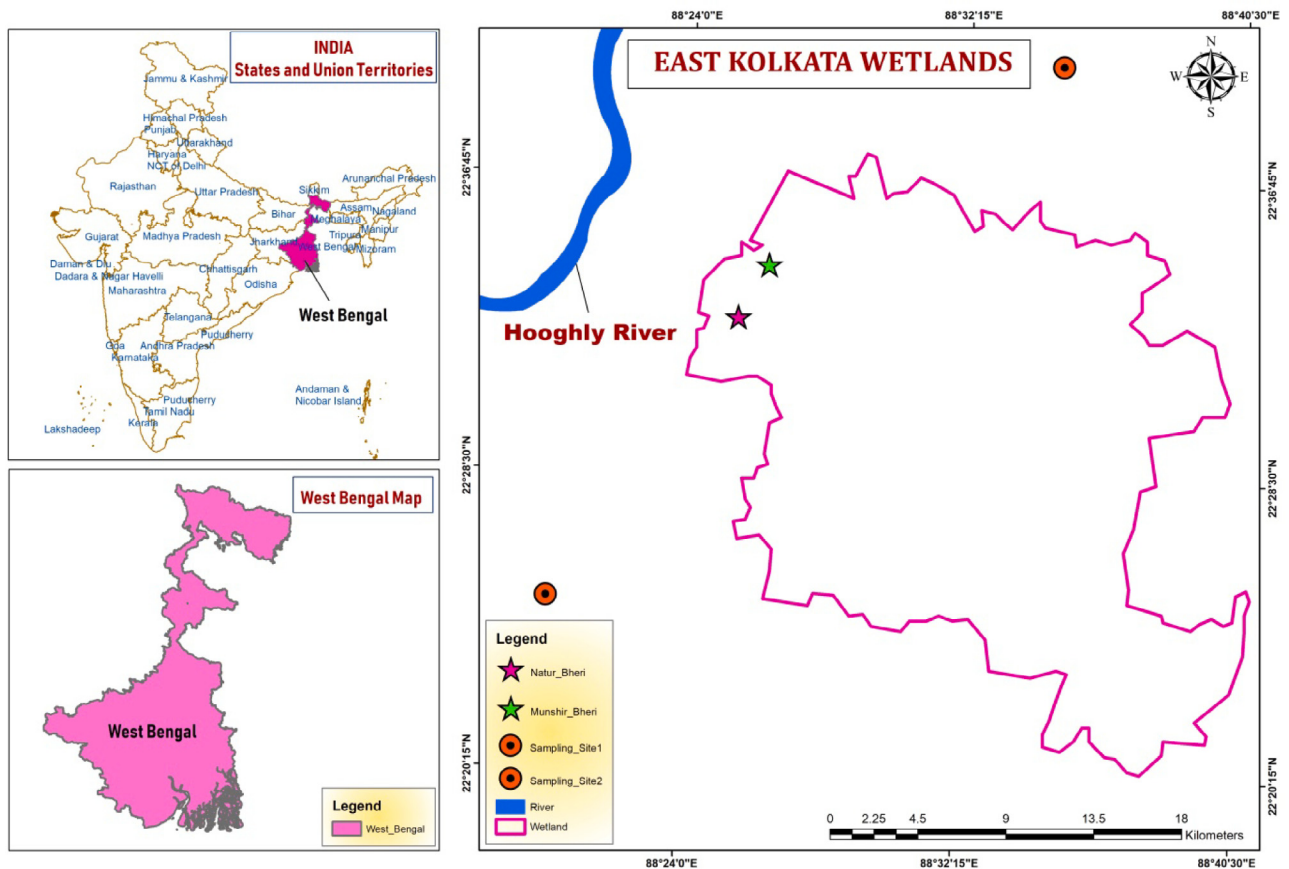


Fig. 1. Map of East Kolkata Wetlands, a designated Ramsar Site of East India.

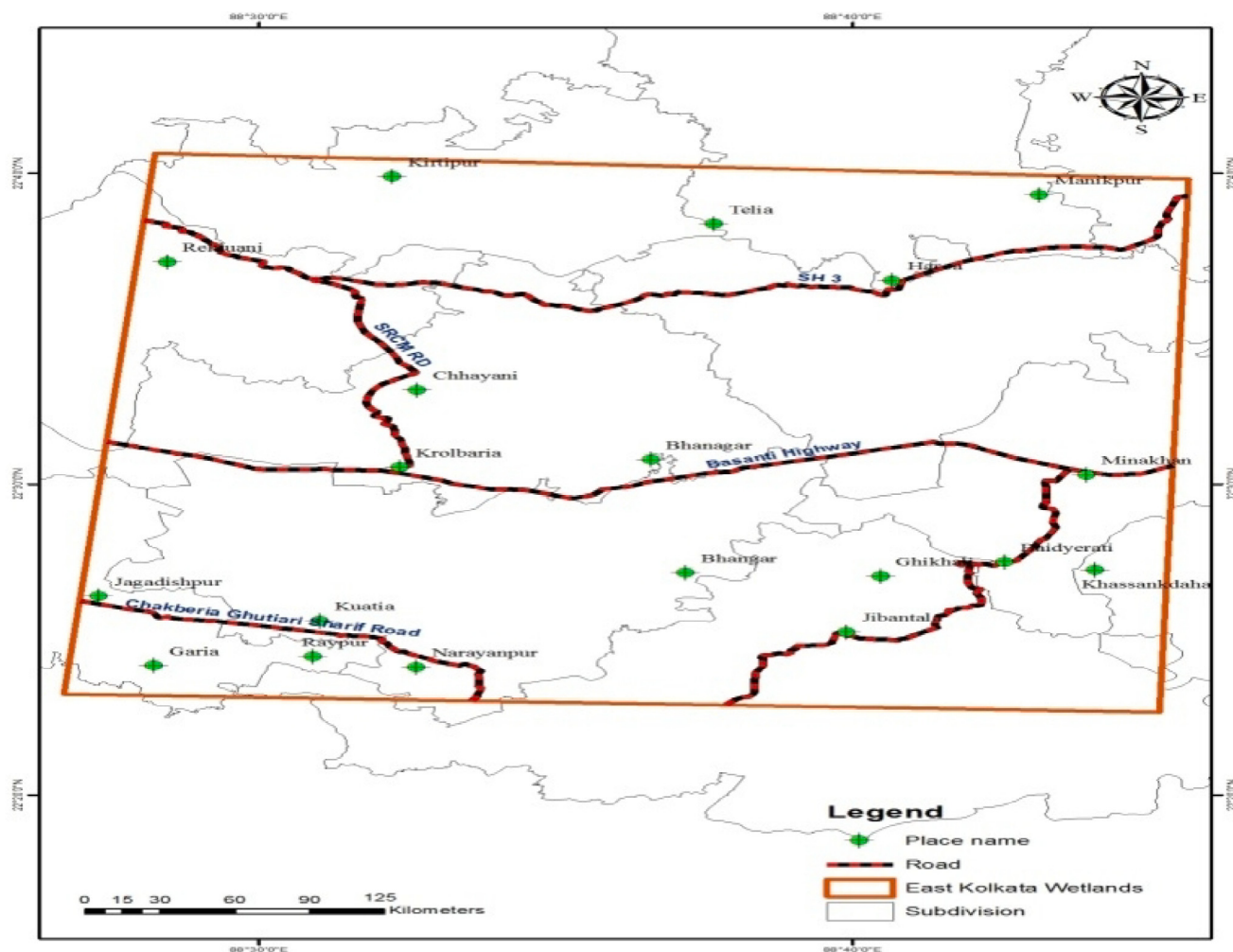


Fig. 2. Base map of the Study Area.

Table 1
Land use status in Eastern Kolkata Wetlands area (Kundu et al., 2008).

Land	Area (in hectare)
Water body-oriented Area	5852
Agricultural Area	4718
Farming Area	602
Urban/Rural Settlements	1326
	(91 ha (Urban)
	1235 ha. (Rural))

described in (Fig. 1) and the base map of the study area is shown in (Fig. 2). The land-use status of EKW is detailed in Table 1.

Out of the total area under EKW, 45.93% area is engineered for the purpose of livelihood generation activities. It is a complex ecological network of natural and man-made wetlands locally known as *bheries*. The ponds are shallow flat bottomed wastewater fed lagoons and varies in depths (50–150 cm) as per intended breeding species with approx. 40–50 ha in size. It is a prime site for bioremediation activity (Dutta et al., 2016). This unique group of wetlands receives the city’s sewage and organically treats it with the help of oxygen, sunshine and microbial action and leads to conversion into productive fish habitat. EKW is an ecologically dynamic

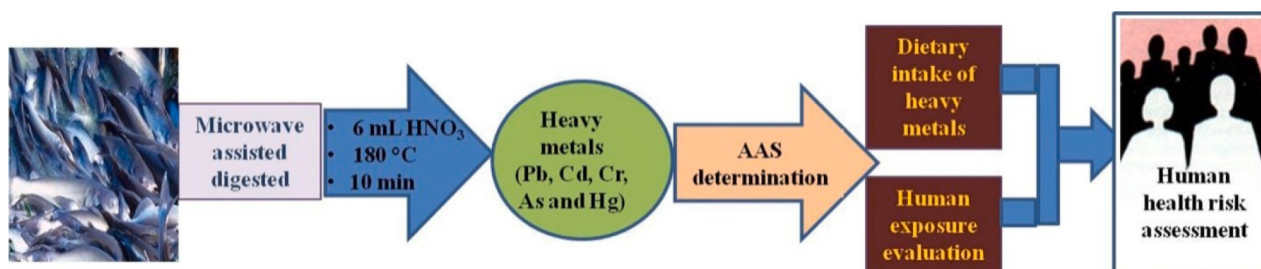


Fig. 3. Methodology of Heavy Metal Assessment in fish samples collected from East Kolkata Wetlands.

ecosystem with respect to primary production and being a humongous reservoir of phytoplankton acting as the backbone of food chain. The wetlands are ably maintained by her evangelists; farmers and fisher folk who constitute the primary stakeholders of the region.

2.2. Hydrological analysis

The analysis of dissolved heavy metals in surface water for this study was done by following the protocols laid down by Chakraborti et al., (Chakraborti et al., 1987). Analytical blank was prepared and treated with reagents. Chemical Analyses was done using Atomic Absorption Spectrophotometer (AAS;Perkin-Elmer Model: 3030).

2.3. Sediment analysis

The sampling of surface soil and sediments was done as per the standardized procedure outlined by Malo (Malo, 1977). The resulting solutions were analyzed further using AAS as done for water and fish species.

2.4. Sampling of fish specimens

Carp variety of fishes such as Rohu (*Labeorohita*), Catla (*Catla catla*), and Nile Tilapia (*Oreochromis niloticus*) were collected from EKW bheries. 50 specimens of each species with uniform height and weight were selected. The protocol as laid down by (Nadkarni, 1984; Matusiewicz and Sturgeon, 1989; Denoyer, 1992) was followed. Analysis was done with the help of AAS. The

methodology of heavy metal assessment in fish specimens is illustrated with the help of a flowchart detailed in (Fig. 3).

3. Results and discussion

3.1. Heavy metal analysis in fish species

Toxic heavy metal bioaccumulation pattern was studied for selected fish species cultivated in bheries of EKW for the four seasons namely, pre-monsoon, monsoon, post-monsoon, and winter for three consecutive years namely 2016, 2017 and 2018. The trace metals selected for the purpose were Pb, Cd, Cr, and Hg. The graphical representation of the analysis is demonstrated in (Figs. 4–6).

The results reveals that the accumulation trends have increased over the three years and monsoon season shows maximum accumulation trends followed by Post-Monsoon (PoM), Winter (W), and Pre-Monsoon (PM) respectively. The seasonal accumulation trend shows the same pattern over the three years. The leaching of nutrients from the surrounding ambient media (water and soil) and the run-off from adjoining industrial and highly urbanized areas along with admixture of wastewaters from point and non-point sources is a probable reason for these results. Post-Monsoon runoff and leaching contribute to the continuing problem followed by winter. The accumulation is least in Pre-Monsoon owing to low rainfall, high evaporation rates, soil dryness, and lesser rates of heavy metal dissolution in surrounding waters. Fish uptakes heavy metals in their gills, fins, and muscles through osmosis leading to precipitation in the body parts. The bioaccumulation pattern of toxic heavy metals in commonly consumed fishes

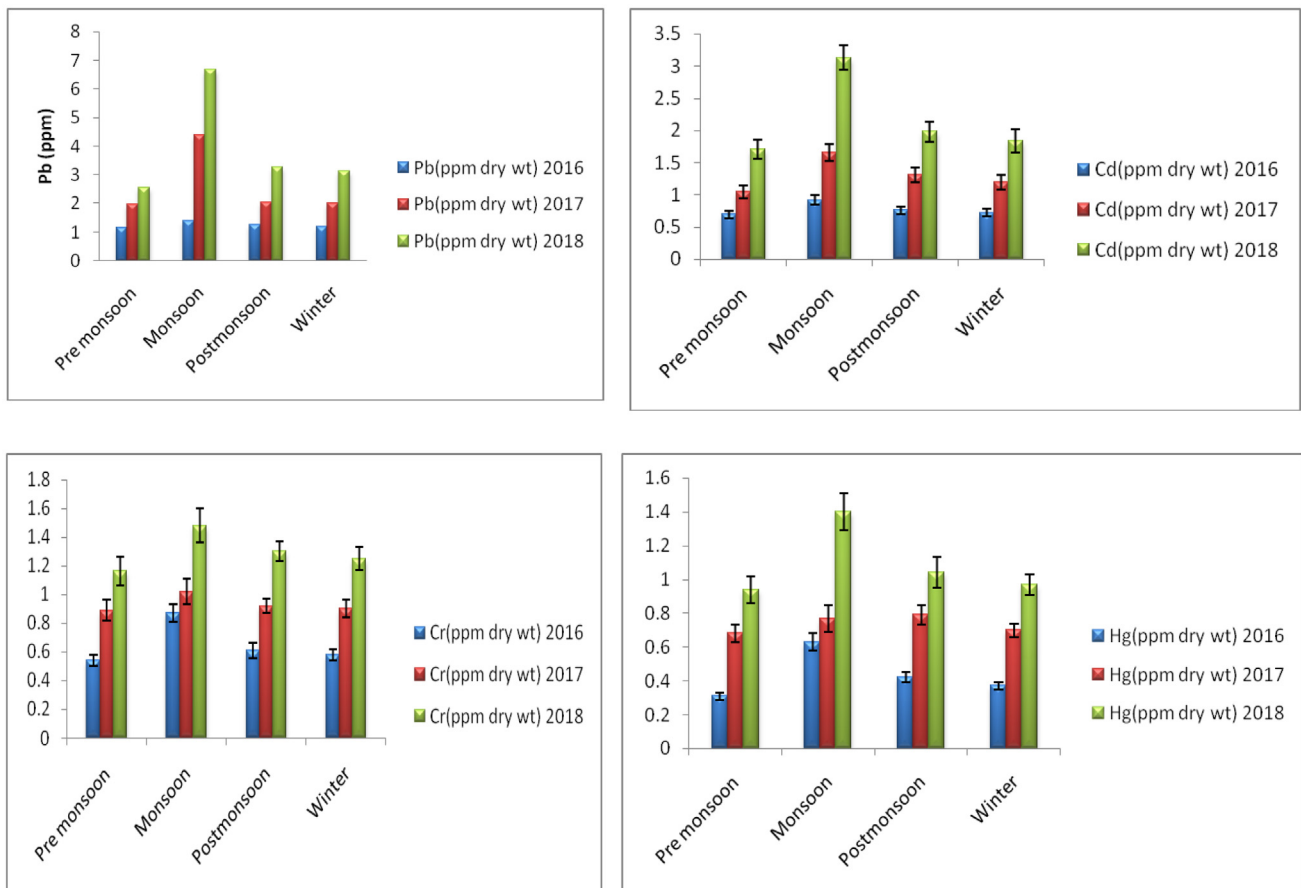


Fig. 4. Bioaccumulation of Pb, Cd, Cr & Hg in Labeo sp. in 2016, 2017 and 2018.

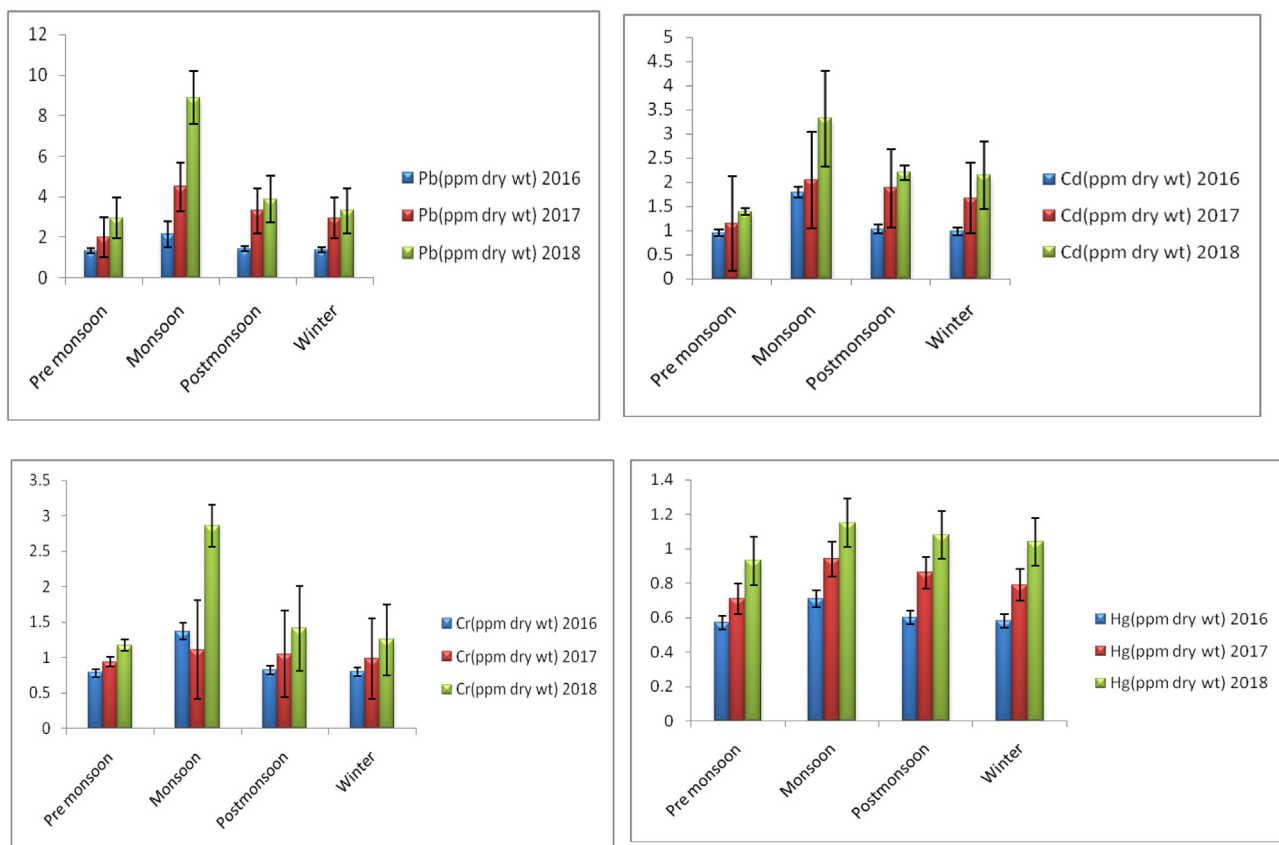


Fig. 5. Bioaccumulation of Pb, Cd, Cr & Hg in *Oreochromis sp.* in 2016, 2017 and 2018.

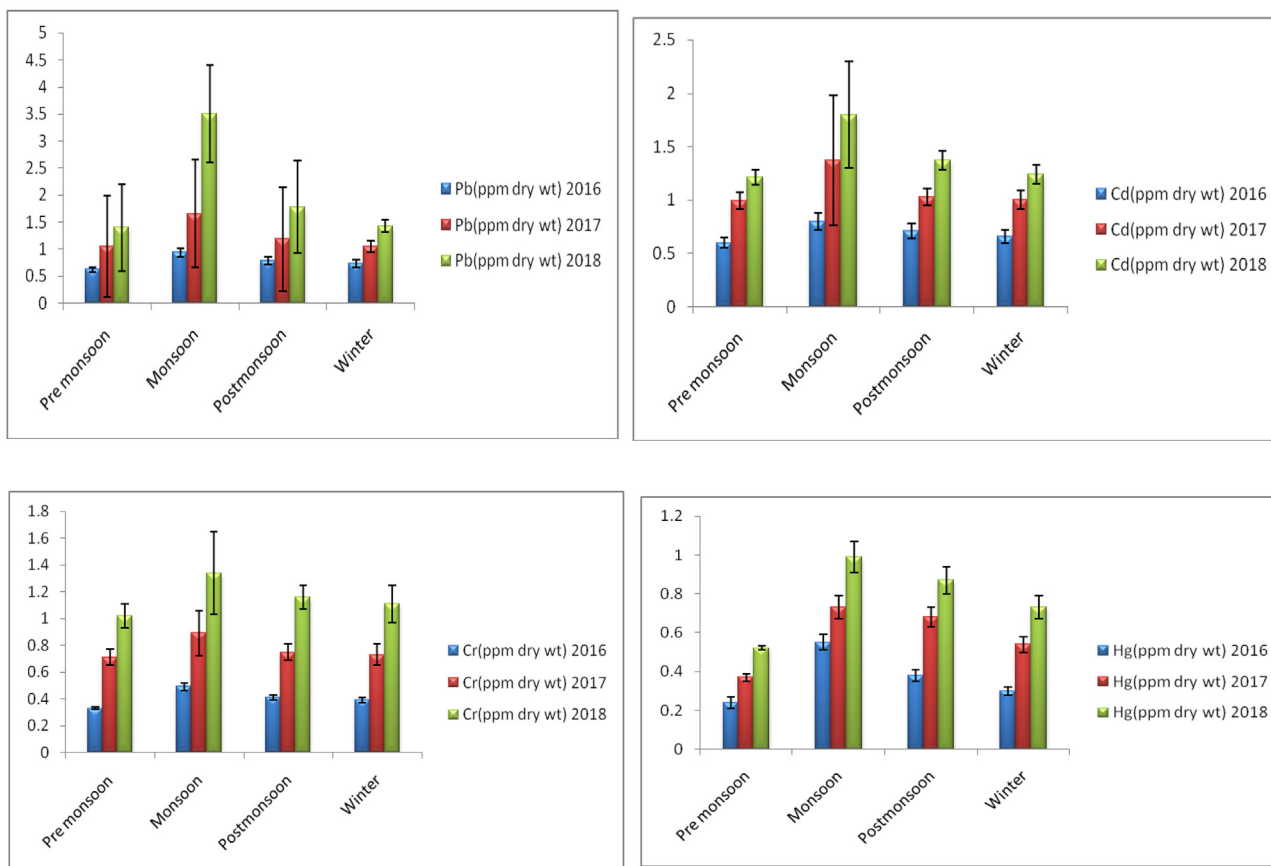


Fig. 6. Bioaccumulation of Pb, Cd, Cr & Hg in *Catla sp.* in 2016, 2017 and 2018.

Table 2
Bioaccumulation pattern of heavy metals in commonly consumed fishes across four seasons of the year 2016.

Name (Fish species)	Season during 2016	Pb (ppm dry wt.)	Cd (ppm dry wt.)	Cr (ppm dry wt.)	Hg (ppm dry wt.)
Rohu (Labeorohita)	Pm	1.16 ± 0.10	0.69 ± 0.05	0.54 ± 0.04	0.31 ± 0.02
	M	1.40 ± 0.12	0.92 ± 0.07	0.87 ± 0.06	0.63 ± 0.05
	Pom	1.26 ± 0.11	0.76 ± 0.06	0.61 ± 0.05	0.42 ± 0.03
	W	1.20 ± 0.10	0.72 ± 0.06	0.58 ± 0.04	0.37 ± 0.02
Tilapia (Oreochromis niloticus)	Pm	1.34 ± 0.11	0.95 ± 0.07	0.78 ± 0.06	0.57 ± 0.04
	M	2.16 ± 0.63	1.79 ± 0.11	1.37 ± 0.12	0.71 ± 0.05
	Pom	1.43 ± 0.12	1.03 ± 0.09	0.82 ± 0.06	0.60 ± 0.04
	W	1.39 ± 0.11	0.98 ± 0.08	0.80 ± 0.06	0.58 ± 0.04
Catla (Catlacatla)	Pm	0.62 ± 0.05	0.60 ± 0.05	0.33 ± 0.01	0.24 ± 0.03
	M	0.94 ± 0.08	0.80 ± 0.08	0.49 ± 0.03	0.55 ± 0.04
	Pom	0.79 ± 0.07	0.71 ± 0.07	0.41 ± 0.02	0.38 ± 0.03
	W	0.74 ± 0.07	0.66 ± 0.06	0.39 ± 0.02	0.30 ± 0.02

*pre-monsoon (Pm), monsoon (M), post-monsoon (Pom), winter (W).

Table 3
Bioaccumulation pattern of heavy metals in commonly consumed fishes across four seasons of the year 2017.

Name (Fish species)	Season during 2017	Pb (ppm dry wt.)	Cd (ppm dry wt.)	Cr (ppm dry wt.)	Hg (ppm dry wt.)
Rohu (Labeorohita)	Pm	1.98 ± 0.21	1.05 ± 0.10	0.89 ± 0.07	0.68 ± 0.05
	M	4.38 ± 1.56	1.66 ± 0.13	1.02 ± 0.09	0.77 ± 0.08
	PoM	2.05 ± 0.99	1.31 ± 0.11	0.92 ± 0.05	0.73 ± 0.06
	W	2.00 ± 0.99	1.19 ± 0.12	0.90 ± 0.06	0.70 ± 0.04
Tilapia (Oreochromis niloticus)	Pm	2.02 ± 0.99	1.14 ± 0.98	0.94 ± 0.07	0.71 ± 0.09
	M	4.49 ± 1.21	2.05 ± 1.00	1.11 ± 0.70	0.94 ± 0.10
	PoM	3.31 ± 1.11	1.88 ± 0.81	1.05 ± 0.61	0.86 ± 0.09
	W	2.96 ± 1.01	1.67 ± 0.73	0.98 ± 0.57	0.79 ± 0.09
Catla (Catlacatla)	Pm	1.05 ± 0.93	0.99 ± 0.08	0.71 ± 0.06	0.37 ± 0.02
	M	1.66 ± 0.99	1.37 ± 0.61	0.89 ± 0.17	0.73 ± 0.06
	PoM	1.19 ± 0.96	1.03 ± 0.08	0.75 ± 0.06	0.68 ± 0.05
	W	1.05 ± 0.11	1.00 ± 0.09	0.73 ± 0.08	0.54 ± 0.04

*pre-monsoon (Pm), monsoon (M), post-monsoon (Pom), winter (W).

Table 4
Bioaccumulation pattern of heavy metals in commonly consumed vegetables and fishes across four seasons of the year 2018.

Name (Fish and Vegetables)	Season during 2018	Pb (ppm dry wt.)	Cd (ppm dry wt.)	Cr (ppm dry wt.)	Hg (ppm dry wt.)
Rohu (Labeo rohita)	Pm	2.54 ± 0.25	1.71 ± 0.15	1.6 ± 0.1	0.94 ± 0.08
	M	6.67 ± 1.57	3.13 ± 0.19	1.48 ± 0.12	1.4 ± 0.11
	Pom	3.27 ± 1.11	1.98 ± 0.16	1.3 ± 0.07	1.04 ± 0.09
	W	3.13 ± 1.14	1.83 ± 0.18	1.25 ± 0.08	0.97 ± 0.06
Tilapia (Oreochromis niloticus)	Pm	2.96 ± 0.99	1.39 ± 0.07	1.17 ± 0.08	0.93 ± 0.14
	M	8.89 ± 1.3	3.32 ± 0.99	2.86 ± 0.3	1.15 ± 0.14
	Pom	3.89 ± 1.15	2.2 ± 0.15	1.41 ± 0.6	1.08 ± 0.14
	W	3.31 ± 1.12	2.14 ± 0.7	1.25 ± 0.5	1.04 ± 0.14
Catla (Catla catla)	Pm	1.4 ± 0.8	1.21 ± 0.07	1.02 ± 0.09	0.52 ± 0.01
	M	3.51 ± 0.9	1.8 ± 0.5	1.34 ± 0.31	0.99 ± 0.08
	Pom	1.78 ± 0.86	1.37 ± 0.09	1.16 ± 0.09	0.87 ± 0.07
	W	1.43 ± 0.12	1.24 ± 0.09	1.11 ± 0.14	0.73 ± 0.06

Table 5
Seasonal and Annual Variation of toxic heavy metal accumulation in selected species of fishes in East Kolkata Wetlands.

Variable	Species	F _{cal}				F _{crit} when (p < 0.05)
		Pb	Cd	Cr	Hg	
Between Seasons	Labeo rohita	4.09	4.12	14.78	5.70	4.75
	Oreochromis niloticus	3.44	8.68	3.08	21.57	4.75
	Catla catla	3.01	9.42	17.00	30.41	4.75
Between Years	Labeo rohita	8.68	23.77	160.58	49.20	5.14
	Oreochromis niloticus	6.18	12.99	4.52	200.43	5.14
	Catlacatla	7.34	50.89	368.73	64.20	5.14

across four seasons of the year 2016, 2017, and 2018 is further evaluated in (Table 2–4).

Seasonal and Annual Variation of heavy metal accumulation in selected species of fishes in East Kolkata Wetlands is discussed in

(Table 5). F_{crit} and F_{cal} values were analyzed for all three fish species. When F_{cal} > F_{crit}, the results are highly significant. However F_{cal} < F_{crit}, the results are not significant at (p < 0.05). Highly significant results over the seasons, as well as the years, indicate that

Table 6
Seasonal and Annual Variation of toxic heavy metal accumulation in water.

Variable	Component	F _{cal}				F _{crit} when (p < 0.05)
		Pb	Cd	Cr	Hg	
Between Seasons	Water	18.74	24.75	29.18	5.93	4.75
Between Years		7.26	8.51	20.13	13.61	5.14

Table 7
Seasonal and Annual Variation of toxic heavy metal accumulation in sediments.

Variable	Component	F _{cal}				F _{crit} when (p < 0.05)
		Pb	Cd	Cr	Hg	
Between Seasons	Sediments	19.81	25.34	10.69	16.59	4.75
Between Years		7.67	15.31	8.79	20.11	5.14

heavy metal levels are higher than normal values and need immediate attention and continuous monitoring of the ecosystem concerned.

3.2. Analysis of toxic heavy metals in ambient media (water and sediments)

ANOVA was performed to analyze the bioaccumulation trends in ambient media. Heavy metal leaching and dissolution also play a key role in toxic heavy metal dynamics in the aquatic ecosystem (Table 5). Highly significant values over the seasons, as well as the years, are an indication of the fact that how heavy metals interact with the ecological profile of our study area. Heavy metals have natural affinity to remain locked in sediment compartments due to active precipitation tendencies. With time and monsoonal flow, heavy metals break away from sediments and dissolve in aqueous medium. It is further transported into the biological systems (aquatic plants and animals) leading to ecological toxicities at different trophic levels of the food chain (Zoumis et al., 2001). Rapid urbanization and rampant industrialization activities provoke the rapid increase in concentration of heavy metals along with the sediments of river banks especially in developing economies where the environmental management aspects in the industrial sector are still in its' infancy (Chen et al., 2004). The analysis of variation of heavy metal accumulation across the seasons and years in water and sediments is discussed in (Table 6) and (Table 7). The results reveal that when $F_{cal} \geq F_{crit}$ at (P < 0.05), it is highly significant indicating the toxic heavy metal accumulation much beyond the recommended limits. However, when $F_{cal} \leq F_{crit}$ at (P < 0.05), the results are not significant indicating no significant contamination beyond recommended limits.

This is alarming and points to the fact that ecological interplay of EKW is severely compromised. Industrial effluents and monsoonal run-off from surrounding urban-spaces are the major contributors of the heavy metals in ambient media. Mercury is an important and the most toxic of all the heavy metals with documented toxicological effects on human health. The source of Pb, Cd, and Cr are majorly the vehicular exhaust, automobile emissions, pesticides, tanneries in the adjoining areas, electroplating industries, dye and paint factories as well as glass and ceramic workshops. One of the major objectives of the present research is to evaluate the composite health index map for EKW which is a designated Ramsarsite of east India located in the state of West Bengal and detect the vulnerable stations among the selected sites. The entire discussion leads to conclude that in terms of wetland health status the order is Captain Bhery > MollarBhery > NaturBhery as depicted in (Fig. 7).

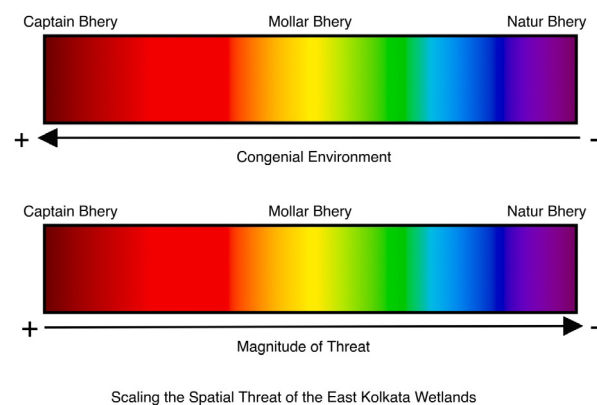


Fig. 7. Assessment of Magnitude of threat and vulnerability quotient of sampling stations of EKW.

Wetlands are among the world’s most prolific ecosystems with a large bouquet of ecosystem services. Wetlands are nature’s kidneys that regulate the toxic pollutants and helps in purification of the ecosystem congenial to flora and fauna as well as the environment as a whole. The peri-urban wetlands such as EKW also provides buffer between terrestrial and nearby marine environment; trapping and stabilizing sediments, nutrients, and several types of conservative pollutants (Dutta et al., 2017; Dutta et al., 2016; Dutta et al., 2019). Thus, helping to maintain the soil health and water quality optimal for consumption in agriculture as well as domestic activities. It is therefore pertinent to understand the significance of wetlands as primary service providers to terrestrial as well as coastal populations. It is further crucial to record the health parameters that act as ecosystem indicators. The current study is an approach in this direction to evaluate the health of the Ramsar Site which is consistently under threat from anthropogenic stress factors and human interferences by taking into consideration three sampling stations i.e. Natur Bhery, Mollar Bhery as well as Captain Bhery.

Pronounced spatio-temporal variations were observed in Natur Bhery leading to its proximity to industrial townships, roads as well as effluent channels from leather complex followed by Mollar Bhery and Captain Bhery. The adverse impact of bioaccumulation of toxic heavy metals i.e. Pb, Cd, Cr, and Hg is also a major reason behind the increasing magnitude of threat on the biodiversity of the area. On contrary to composite health index for EKW, if a

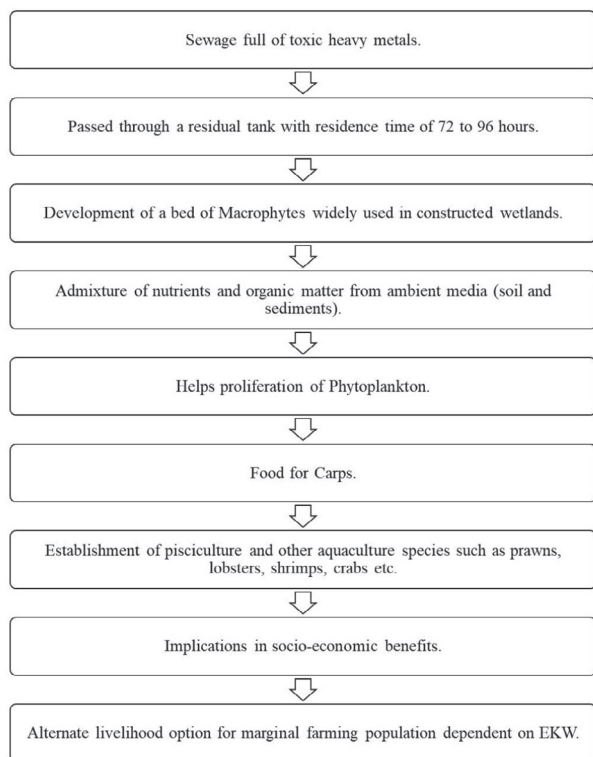


Fig. 8. Sustainable Management Model for EKW, a Ramsar Site of India.

reverse order of assigning vulnerability/risk is considered for the selected stations, the order would be just the opposite to the above i.e., Natur Bhery > Mollar Bhery > Captain Bhery as highlighted in (Fig. 7). The health of wetlands can be improved through minimal anthropogenic interferences and proper conservation of natural flora and fauna. Studies all over the world have revealed that wetlands chemically, physically, and biologically eliminate pollutants, sediments, and nutrients from water flowing through them (Kadlec and Wallace, 2009; Seo et al., 2013; Shaffer et al., 2015). In context to the present research program, it is therefore of utmost importance to carry out mass scale afforestation program with local indigenous wetland flora which would add positive feedback to the health of EKW. It is further important to arrest the influx of toxic industrial effluents to regulate toxic heavy metal accumulation in EKW thus ensuring wetland sustainability.

A self-explanatory Sustainable Management Model for EKW is further proposed as a part of the research work in (Fig. 8) below which makes a blueprint for the sustainability of the Ramsar Site in coming times if implemented by the policymakers of the state. This model aims to balance ecology and society keeping falling economy as a fulcrum of development in a post-COVID world. Diversification of income umbrella of the stakeholders while helping them own their business can reduce vulnerabilities and risks of these communities residing within and around the periphery of EKW, a designated Ramsar site of India. This model would ensure zero tolerance to the exploitation of the Ramsar site while assisting in restoration of biodiversity. Land use and land cover (LULC) assessment studies have pointed out the random degradation of EKW during the last decade which might have an irreversible impact on flora and fauna of the region which is also ascribed to be the 'wetlands of international importance'. The available ecotoxicological documentation of the selected toxic heavy metals in

scientific literature conclusively points to the fact that the threats due to heavy metal toxicity are rapidly evolving around the globe in the absence of reasonable attentions by the policymakers.

4. Conclusion

Wetlands are integrated systems that display crucial interplay of ecological factors. EKW was designated as a Ramsar site on August 19, 2002. East Kolkata Wetlands, the current study area also points to similar perilous future if immediate environmental management interventions are not taken for long-term sustainable conservation of this unique group of wetlands. Our results with respect to the concentration of toxic heavy metals in fishes ring alarm bell with respect to ecological health of these wetlands. The persistence and the degree of heavy metal toxicity in ambient media (water and sediments) depends on a bouquet of factors such as water flow, water speed, frequency of tides, monsoonal run-off and same is true for EKW as well. The bulk of monsoonal run-off received by EKW from point and non-point sources is a main source of heavy metal load in the ambient media. High monsoonal run-off in consonance with lowering of pH levels lead to acidification. This increases dilution factor of toxic heavy metal in ambient media. The heavy metal locked up in sediment compartments undergo heavy dissolution in water and ultimately to the bodies of fishes increasing the recommended levels of consumption as proposed by WHO. This is the high time to consider the scopes of fish consumption from perspectives of ecotoxicology and environmental safety. Therefore, the current study investigated the concentrations of heavy metals in muscles of fishes to the internal organs or other body parts which are preferably not consumed. It would be nonsensical to propose radical technological changes in aquaculture practices in the area due to bleak socio-economic conditions of the stakeholders concerned during a post-Amphan Super-Cyclone setup. The authors propose local government backed knowledge dissemination facilities and proper coordination among the fish farmers can be a feasible alternative. Diversion of monsoonal influx of waste water and preliminary treatments before being used for aquaculture practices would largely reduce the pollution loads too. Wise use of wetlands would bring massive returns in long term with respect to development of green economy, in parallel with mainstream socio-economic development.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledge the support and assistance of respective authorities as well as field and lab staffs during the lab analysis. This project was supported by Researchers Supporting Project number (RSP-2021/5) King Saud University, Riyadh, Saudi Arabia.

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