Indus river estuary: an assessment of potential risk of contaminants and ecosystem susceptibility

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Abstract

The Indus River is proclaimed as second most plastic-polluted rivers of the world. This river is the principal river of Pakistan and supplies freshwater for agriculture and human consumption. Its terminus into the northern Arabian Sea creates a unique ecosystem that supports a variety of aquatic organisms. In this study we have evaluated the heavy metal concentration in fishes sampled from the IRE. Muscle tissues from five fish species of ecologically and economically important were sampled and the concentrations of cadmium ($0.125\text{--}1.025\text{ }\mu\text{g g}^{-1}$, 0.93 ± 0.33), lead ($0.250\text{--}2.560\text{ }\mu\text{g g}^{-1}$, 0.92 ± 0.86), arsenic ($4.178\text{--}6.337\text{ }\mu\text{g g}^{-1}$, 4.24 ± 2.13) and mercury (BDL– $0.116\text{ }\mu\text{g g}^{-1}$, 0.05 ± 0.04) were found to be beyond optimum level. We determined the pollution load index which indicated that the IRE pollution exhibits significant seasonal oscillations. In addition to the heavy metal assay we note the frequent appearance of abnormal fishes caught in the IRE, which validates the pollution load. Multivariate approaches, canonical correspondence analysis and cluster analysis, were used to evaluate the relationships among environmental variables that influence metal concentration. This study is the first to document heavy metals detected from fishes inhabiting in IRE and highlights concerns regarding the need for management measures.

Highlights

- We examined heavy metals in commercial and ecological valuable fishes in the Indus River Estuary (IRE) for the first time.
- Multivariate approaches were used to determine the efficacy of environmental parameters to predict heavy metal concentration.
- We described the presence of fish abnormalities as a result of contamination in the IRE.
- We observe that the mechanism of action of organism health and food contamination in the IRE is poorly understood.

Keywords Heavy metals · Pollution load index · Water quality · Contamination · Fish abnormalities · Indus River Estuary

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1 Introduction

Fishing practices and increases in the release of untreated industrial and domestic wastes has impacted riverine, estuarine, coastal environments, especially in developing countries. The Indus River a principal river of Pakistan and is the second most polluted river of the world [2]. Various factors contributed to this level of pollution, primarily industrial development along the river basin in upper areas of the country, rampant population increases, and lack of regulation and enforcement of environmental policies. The Indus River Estuary (IRE) serves as nursery grounds for a variety of aquatic organisms and these are vulnerable to untreated industrial wastes released into the IRE in Lahore, Faisalabad and Sialkot (Panhwar et al. [1]; Dawn, 12. 2019 [2]). Additionally, WWF-Pakistan reported that plastic waste greatly impacts coastal beaches, and is notably heavy at Karachi's Clifton beach, while other beaches along the coastal belt are also impacted by plastic waste. In this context, several attempts have been taken to ban non-biodegradable polythene bags, but these efforts are resisted by manufacturing entities. We note that informed consumers can change their lifestyle choices by prioritising the environment and health of their fellow citizens over convenience (Dawn, 10. 2019, 26, [2]). In 2016 a judicial commission was constituted to provide a report on water quality of the Indus River, and the commission affirmed that not only municipal contamination but also power plant activity near or on river basin has increased water temperature and created oxygen depletion zones at various parts of the River (Judicial Commission on Water, [3]). Additionally, pesticides from agricultural application have added more contamination into drinking water. Aquatic pollutants can reach to top consumers (human) through the food chain (water, fishes, and human). Greater concentrations of heavy metals are found in the estuary ecosystem and enter the food chain through feeding by benthic species. Accumulation of metal in fish species depends on distribution, habitat preferences, feeding habits, trophic level, age, size, metal exposure period, and homeostatic regulation activity [4]. Heavy metals, such as zinc (Zn), iron (Fe) and copper (Cu) are important for fish metabolism while lead (Pb), cadmium (Cd), mercury (Hg) and others have unknown functions in biological systems. Metabolic activity plays an important role in the bioaccumulation of metals in aquatic organisms [5, 6]. Some aquatic organism can play vital role in understand ecosystem as they indicate ecosystem health (Parmar [7]; [8] for this purpose macrophytes, microorganisms (phytoplankton and zooplankton), invertebrates, and fish are highly sensitive to the

heavy metals pollution [9, 10]. A comprehensive review on the Keenjhar lake on the Indus River basin documented (Qamer et al. [11]).

In this study, we determine (I) metal concentration (As, Cd, Pb, Hg) in the muscle tissue of commercially exploited species, (II) evaluate the intensity of metal released during rain and dry seasons, and (III) delineate influence of the physicochemical factors to provide a better understanding of the environmental risk with reference to the to human consumption and safety guidelines of the FAO and WHO.

2 Material and methods

2.1 Fish sampling protocols

Fish specimens were collected by using estuarine set bag net (ESBN) fixed at the mouth of IRE from 2017–2018 (Fig. 1). Fish specimens were immediately put on ice in insulated coolers. These were then processed in the laboratory: each fish species was identified with the aid of published taxonomic keys. Fishes of high ecological and economical importance were selected for analysis and frozen until processing.

2.2 Fish muscles digestion process

Fish samples were thawed and then rinsed with deionized water to remove surface adherents that could have adsorbed metals. Morphometric measurements were taken and fish were dissected by using stainless steel instruments to avoid any contamination. Total weight of the muscles was also obtained after the removal of organs and bones. The sample was ground using a mortar and pestle. We digested 2 g of muscle tissue in 25 ml nitric acid headed to (100 °C) until a clear light-yellow solution was obtained. The mixture was then cooled to room temperature. After cooling, the sample was filtered with Whatman No. 42 filter paper. The filtrate was transferred to a volumetric flask. We added 25 ml of distilled water and then for the analysis of Mercury and Arsenic, MSH was used. For lead and cadmium flame atomic absorption spectrophotometer was used.

2.3 Water quality parameters

A portable hydro lab HL-4, USA with different snodes inside was used to recorded in situ water quality variables (temperature, oxygen, salinity, conductivity and pH) at each sampling site.

Fig. 1 Red dotted area is mouth of the Indus River Estuary where fish and water quality sampling was carried out in 2017–2018

2.4 Statical analysis

To understand the factors that describe contrast in contaminants were determined and was calculated as contamination factor $CF = \text{metal concentration in specimen} / \text{background values of the metal}$ [12]. WHO permissible values were used to compare results obtained in this study (WHO, 1989). A pollution load index (PLI) for each site was estimated using the method described by Tomlinson et al. [13] as $PLI = (CF_1 \times CF_2 \times \dots \times CF_n)^{1/n}$, where n is the number of metals and CF is the contamination factor. A PLI value of > 1 indicates that area is polluted and PLI values < 1 indicates the area is not polluted [14, 15]. Principle component analysis (PCA) and a hierarchal cluster analysis were performed to determine environmental and monthly habitat characteristics. Euclidean distances were used in respective sampling months. Data analysis was done using Past3 and SPSS 16.0 ver software.

3 Results

3.1 Morphological measurement

Summary of the basic parameters such as total fish weight, sex, habitat, feeding habits and economical or ecological

importance were selected to test concentration of heavy metals. Details of fish habitat, commercial value, gender, feeding habits and economic and ecological value are given (Table 1).

3.2 Water quality variables

In situ water variables temperature, conductivity, oxygen, pH and total dissolved substances (TDS) were recorded during each sampling site (Table 2).

3.3 Heavy metal determination in fish flesh

Concentrations of heavy metals were beyond the limitation set by World Health Organization (WHO) and other health associated international organisations (EU [16, 17]; [18, 19]. However, of these four heavy metals arsenic was significantly high than rest of the metals found in fish flesh whereas mercury was lowest and below detection level September (Fig. 2). Dictation of metals beyond limits consequence abnormality in fishes of high ecological and economic species. High detection of arsenic in most of the months reflect that Indus River Estuary (IRE) is highly contaminated with arsenic sourced by industrial dilution from major cities of Punjab province in upper areas of

Table 1 Summary of the ecologically and economically important fish species with basic biological data studied in this study

Months	Species	Total length	Weight (g)	Sex	Habitat	Feeding habits	Fisheries importance
September	<i>Sillago sihama</i>	18	28.52	F	Pelagic	omnivores	High
October	<i>Mugil cephalus</i>	14	23.23	F	Pelagic	carnivores	High
November	<i>Megalapsis cordyla</i>	14	19.48	F	Pelagic	carnivores	Low
December	<i>Anadonta chacunda</i>	11.5	18.26	M	Pelagic	omnivores	High
January	<i>Sillago sihama</i>	14.5	52.75	M	Demersal	omnivores	Low
February	<i>Liza subviridis</i>	18.5	73.33	F	Pelagic	omnivores	Low
March	<i>Hilsa kelee</i>	18	34.53	F	Neritic	carnivores	Low
April	<i>Nematalosa arabica</i>	14.8	84.76	M	Benthopelagic	omnivores	High
May	<i>Cynoglossus arel</i>	23.2					

Table 2 In situ water quality variables recorded in different months from sampling location and in respective months

Month	Temp (°C)	Sp Cond (mS/cm)	Salinity	TDS (g/L)	DO	pH
Sep	28	48.05	0.02	30.85	4.90	7.00
Oct	29	47.67	31.03	30.51	5.1	7.20
Nov	23	41.02	26.22	26.25	6.27	7.10
Dec	17	44.66	28.98	28.63	6.87	7.11
Jan	20	33.37	20.95	21.34	6.88	7.13
Feb	23	49.16	32.09	31.47	5.99	7.20
Mar	28	53.27	35.13	34.12	5.08	7.00
Apr	31	51.82	34.55	33.17	4.53	7.11
May	30	54.8	29.55	34.86	4.73	7.00

Fig. 2 Range description of heavy metal concentrations and intensity are highlighted with distinct colour patterns

the country, whereas Pb contamination is outcome of domestic waster being released in to the waster significantly in September (flood season) with noticeable fluctuation throughout sampling period. However, CF value

Table 3 Description of allowable level of heavy metals in food items can be consumed by human proposed by renowned international organizations

	WHO mg/Kg	EU mg/Kg	CFA ppm	JECFA ppm
Cadmium	0.3	0.05		0.5
Lead	0.5		0.5	0.3
Mercury		0.5	0.5	0.5
Arsenic			3.5	0.5

of Cd, Pb, Hg and As are also active partners of meatal contamination in IRE (Table 3).

3.4 Canonical correspondence analysis (CCA)

We found that the first component of the CCA and the second component described 46.92% and 30.96% of the variability (Fig. 3). The CCA was established using four environmental variables (temperature, salinity, oxygen and conductivity) in relation to the heavy metal cadmium, chromium, lead and mercury. The eigenvalue of 0.093 and 0.0073 was estimated for CCA coordinate

Fig. 3 Bi-chart CCA was established using four environmental parameters and four heavy metals observed in fish flesh of highly commercial species in Indus River Estuary. Six clad of Euclidean distance was noticed (Fig. 5) from a cluster established for different months / heavy metal concentration

Fig. 4 Pollution load index (PLI) variations in different months in the Indus River Estuary. Dotted red colour line added to highlight baseline values

Fig. 5 Hierarchical cluster based on Euclidean distance established for different months in this study

I (91.76%) and CCA II (7.16%) respectively. From the bi-plot heavy metal is inclusion riverine flow (group I) when there is rainy season and water from upper areas reaches to the estuary is brining contamination whereas if there is no flow no dilution of contamination noted. Group II from December to February indicates

high salinity and oxygen but meagre presence of heavy metal confirms that these can only transported from upper areas when flow of river takes water to estuarine area where they stay for longer time due to slow fresh and marine water mixing process and eventually transmit through the food chain into fish and then ultimately reached to the human.

3.5 Pollution load index (PLI)

Overall mixed trends of PLI revealed that Apr, Sep and Dec were loaded with high intensity of pollutants that has soared PLI beyond safe line indicates that IRE getting high contamination in the months when river flows during flood season. A monthly PLI demonstrates APR > SEP > MAR > OCT > NOV > MAY > JAN (Fig. 4).

3.6 Cluster analysis

Heavy metal concentrations in nine month were used to establish Euclidean distance using cluster analysis. We identified six sub-groups using cluster analysis (Fig. 5). Further first clad encompasses month 1–4 and another month 5–9. However, minimum distance among various months can be described on the basis six sub-groups. Cluster grouped together shows similarities among months.

3.7 Seasonal oscillation and species patterns influenced by the environmental parameters

Northern Arabian Sea area is influenced by four monsoonal patterns; autumn inter monsoon (AIM), Northeast monsoon (NEM), south inter monsoon (SIM), and southwest monsoon (SWM). Monsoonal oscillations are the key triggers can influence on the coastal, oceanic and estuarine ecosystems. Besides low precipitation can also have immense influence on the distribution, spawning and reproductive potential of various species inhabiting in shallow water regimes. The bi-plot (Fig. 6) indicates that in AIM five fish species are influenced by the salinity during meagre precipitation (group I), ten species (pelagic

or demersal) are distributed during winter season when water currents become passive and low (group II), temperature doubtlessly have influence on the distribution of five species (group III) massive intervention of conductivity in Indus estuarine can be noted from the distribution of large number (ten) of fish species (group IV).

4 Discussion

The coastal belt of Sindh provincial territorial waters is contains a number of creeks, semi-arid mangroves ecosystem, and the Indus River Estuary (IRE), an area noted for its fish production. Unfortunately, rampant use of estuarine set bag net (ESBN) in the narrow creeks and IRE has impacted fishery resources. Lack of proper treatment plants for industrial waste continues to be a chronic problem in the IRE. Steel manufacturing industries and ancillary industrial activity contributes lead and arsenic to the agriculture waste. In this study we provide evaluate contamination in fishes, which has direct consequences to human health. Or primary findings are that contaminants are high during flood season when river flow is greatest. During this time, contamination reaches the lower IRE. During the residual period, contaminants enter the food chain.

The information obtained from this study is useful for environmental agencies to monitor the aquatic system and safe use of sea food could be made by management of human health practice. The bioaccumulation of metals depends on the total metal content of the exposure, the chemical composition, and several environmental and biological conditions. Metal speciation is expected to influence metal bioavailability and therefore metal content in

Fig. 6 Bi-plot established to understand influence of environmental parameters on the distribution of fish species based on seasonal changes. To increase readability it is further divided in four respective groups

biota [20]. On the other hand, the biological characteristics of metals, such as bioactivity, play an important role in homeostatic regulation. Food chain in aquatic ecosystem is the main constituent of accumulation of heavy metal hence feeding content was analysed. Most of the samples were not within the permissible limit. Trace metals such as cadmium, lead, Mercury and Arsenic Concentrations were analysed with in commercial important fish species indicated sea food consumption risk therefore stringent actions to minimize direct release of industrial discharge in the river.

Generally, habitat characteristics and environmental conditions in tropical and sub-tropical regions result in sudden change of water quality of the rivers, estuaries, and coastal areas. We show that fish species are distributed or influenced by the environmental parameters and we delineate environmental impacts (i.e. concentration of heavy metals) using a multivariate approach. Our analysis indicates that four heavy metals while component II explains 7.16% of the variance mainly represents the no pollution during inflow of Indus river up-to estuarine area. These pollutants indicated that pollution is solely source from sewage smelting and industrial race on upper areas. However, Cd is considered as an identification element of agriculture activities. Further pollution load index (PLI) validates parallel notion extracted from the CCA analysis. Generally, factors such as the season, length and weight, the physical and chemical state of the water [21] can play a role in the accumulation of metals in water sediment and tissues. Metal concentrations based on seasonal variation in fish can result from intrinsic factors such as the growth cycle and the reproductive cycle and changes in water temperature (Dural [22]). Heavy metals are known to accumulate in the tissues of aquatic animals and therefore heavy metals measured in the tissues of aquatic animals may reflect past exposure (Canli [23]). In addition, global Climate Risk Index assessment has recently ranked Pakistan on fifth number on the global climate risk and forewarned more than expected losses due to inconsistent weather changes. This catastrophe would not only damage national economy but also immensely destroy terrestrial and aquatic ecosystems [2].

Analysis shows that metal accumulation through food chain can causes spinal deformities in fish species of the high commercial value. Members of the family Mugilidae and Synodontidae are essential part of coastal food web structures and a consumable stuff. Our result pointed out that accumulation of heavy metal beyond normal level detected from *Mugil cephalus* and *Liza subviridis* fish species can cause lordosis disorders as noticed by other researchers [24] in *Mugil* species, [25] in *Zosterisessor ophiocephalus* fish species. Moreover, skeletal abnormality can cause vertebral deformity and finally reach to

human. However, recent studies on the subject indicates that heavy metal can affects the quality of fish [26–28]. Concentration over the optimum range of heavy metals induces significant physiologic and biochemical damage to the fish and higher consumers (human) [29, 30]. Nevertheless, heavy metal pollution enhances the toxic effects by interfering with fish-protection mechanisms, inducing negative affect on the physiological homeostasis of fish and invertebrates [11, 31].

5 Conclusion

We examined heavy metals in commercial and ecological valuable fishes inhabiting in the Indus River Estuary (IRE) for the first time. Fish muscle tissues contains high concentration of arsenic whereas metal concentration was categorized as in descending order $Hg > Cd > Pb > As$. As was highest in the month of April when concentration of such metals stable during winter (inflow) of river and lowest in the month of January due to meagre riverine flow. In addition, frequent appearance of abnormalities in fishes as a result of contamination in the IRE. To provide solid and sound deportment we provided multivariate approaches to determine the efficacy of environmental parameters to predict heavy metal concentration. This study can be an in put to set research priorities to improve water quality monitoring and mitigation are recognized. Moreover, the information obtained from this study could be useful for environmental agencies to monitor the aquatic system and safe use of sea food could be made by management of human health practice. The bioaccumulation of metals depends on the total metal content of the exposure, the chemical composition, and several environmental and biological conditions in the marine environment.

Declaration

Conflict of interest Authors declare no conflict of interest.

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