Degree of partitioning of heavy metals in different environmental segments of a sewage-fed fishery pond at East Kolkata Wetland, India – A case study.

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Abstract

Anthropogenic activities like industrialization, unplanned urbanization, deforestation and profit oriented capitalism have resulted introduction of many undesirable substances into our immediate environment creating environmental degradation to a great extent. Normally, nature takes the responsibility of reducing the adverse effect of these substances through the operation of many physical, chemical and biological processes such that these substances can be partitioned in various biotic and a-biotic components of an environmental ecosystem. Present study is an attempt to highlight the extent of partitioning of some heavy metals in the compartments of water, sediments, macrophyte and fishes of a sewage-fed fishery pond in East Kolkata Wetland (EKW). Study distinctly revealed that all heavy metals show a common preference to be deposited on the sediments with higher values (28.5 to 56.5%) followed by macrophytes (20.3 to 35.4%), fishes (15.7 to 43.2%) and water (less than 1.0%). Similar types of partitioning might be observed in each higher plants and animals. As an example, in fishes, higher accumulation of heavy metals were in viscera (27.5 to 69.2%) followed by bone (4.6 to 47.7%), gill (8.1 to 30.6%) and least in flesh (< 1.0 to 19.0%). Again, in cases of toxic metals, it has been observed that flesh contains less than 1% and while the essential group of metals (Zn and Cr) showed comparatively higher degree of accumulation (11.3 to 19.5 %). Thus, the study evidently forecasted that re-distribution of heavy metals in large number of inter and intra compartments of natural biotic and abiotic agents, could be considered as the most effective mechanism for reducing the undesirable consequences of heavy metals or any toxic waste along with passage of time.

Keywords: Biotic and abiotic components; Heavy metal partitioning; Fishery pond; East Kolkata Wetlands; Natural rectification.

Introduction

The East Kolkata Wetlands (EKW), situated at the eastern fringe of Kolkata city is a good example of an area where anthropogenic pressure and natural rectification processes compete with each other[1-4]. The entire city waste water amounting to about 50,000 m^3 day^{-1} including domesticorigin and effluents of large number of industries like tannery, rubber, electroplating, pigments, potteries and batteries flows down in some canals through the EKW in a zigzag way towards Kultigang, about 40 km away from Kolkata[5,6]. Along with this, about 3,500 metric tons of solidsaved the city from constructing waste treatment plant; provide employment for large number of local residents and serve the society by producing huge amount of edible components like fishes,mussels, vegetables and paddy cultivation as resources for the humans[7,8]. For these, the EKW has been listed as a Ramsar site, wetlands of international importance. About 364 number of fishery ponds are distributed on both sides of sewage flowing canals. Previous studies have revealed the presence of normal level of heavy metals in sewage[8,15] but comparatively higher level in pond sediments , specially, the ponds near to the canals [5]. Besides, some aquatic macrophytes showed higher degree of accumulation acting as an efficient process of rectification of heavy metals from the aquatic system [9, 10].

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Heavy metals are termed as metals having density of about 5 g/cc or more such as Zn, Cr, Cd, Pb and others. The metals like Pb, Cd etc are toxic having no biochemical role in biotic life[11] while Zn, Cr etc act as micro nutrients but show toxic at higher concentration than the amount for normal growth[12]. These are not, in general easily available for biotic life in nature, but are injected into the ambient environment through various anthropogenic activities and ultimately become a source of pollution with an adverse consequences in natural system, to human or to the living organisms by way of accumulation in soil/sediments,water and biota[13]. The food containing enriched amount of heavy metals might cause serious harmful effect on human health through the way of bio-magnification[8]. But in a true sense, the distribution of heavy metals in different segments like, hydrosphere, lithosphere, biosphere and atmosphere should be considered as the natural phenomenon, the main objective of which is to decrease the level of accumulation of metallic load such that no untoward effect on biotic life could be observed in any segments. Large numbers of this time dependent physical, chemical and biological processes are involved which if and when allowed, insignificant adverse effect could be witnessed. This is an efficient method and may be called as natural rectification process or self-organization of an ecosystem.

In the light of the above facts, present study is an attempt to represent the degree of partitioning of some heavy metals like Zn, Cr, Cd and Pb in various biotic and abiotic components in a metal contaminated sewage-fed fishery pond of the EKW.

Materials and Methods:

Water samples were collected from different sites of a fishery pond of the EKW by water sampler from 0.5m depth (Fig. 1) and these were mixed together for making composite sample. Similarly, surface sediments were also collected[21, 22] from a number of sites by grabs throughout the pond randomly. Any lithogenic and foreign materials present in sediments were removed by hand picking and composite sample is done by mixing by homogenizer. Most abundant floating macrophyte (Water hyacinth) was also collected as described earlier[9, 10] from sides of the pond by hand net and washed with distilled water for several times. Along with this, full grown fishes (*Oreochromisniloticus*) of almost equal sizes were purchased from fishermen during fishing of this pond[13]. All these collected samples were kept in ice-box and transported to the laboratory in cold condition. In all cases, attempts were usually taken to follow the standard collection procedure as described.

Water samples were filtered through GF/C (0.45 micron) filter paper, the filtrate was evaporated to dryness and digested with the mixture of HNO_3 and $HClO_4$. The volume of solution was made up to the mark and kept for metal analysis. Fish was dissected into bone, gill, viscera and flesh by using proper methods and different organs of fishes were kept in pre-cleaned plastic jar separately. All these processed samples were dried in air oven at 105^0C, ground to fineness, sieved with a 2mm grade sieve and were digested according to the USEPA method [14].

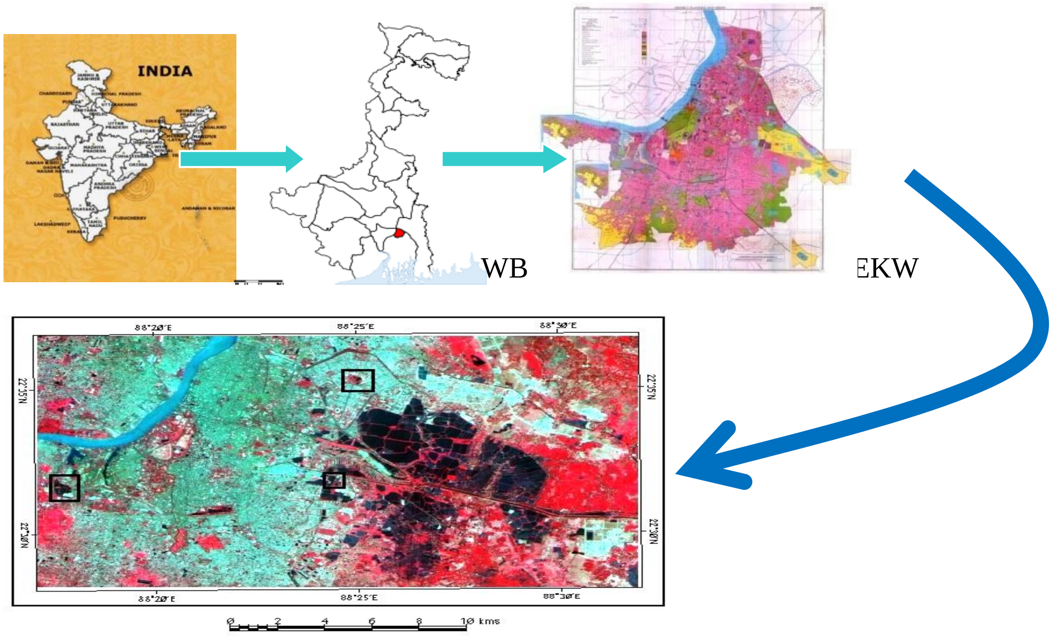

Figure1: Location Map of the sewage-fed fishery pond at the EKW

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The metal analysis was carried out by using AAS (Model: Varian spectra AA55) with graphite furnace atomizer. Sample blank was also prepared in all cases following the same sequence of treatment of sample and metals are analyzed against the blank. A standard curve was run with each analysis and the results were expressed as ppm or mg/kg of dry weight. Double distilled water was used throughout the analysis. All chemicals and standard solutions used in the study were obtained from Merck and were of analytic grade. Accuracy and precision of the results were carried out by analysis of standard samples. The recovery and mean relative standard deviations were within 97% and 10%, respectively. The detection limits of Pb, Cd, Cr and Zn are 0.05, 0.002, 0.02 and 0.005 mg/L. Heavy metals in all segments (water, sediments, macrophyte and fishes) are summed up and considered as 100% level. On this basis, other calculations are done. Similarly, total amount of metals in fish organs are also taken as 100% and the percentage level in other organs are calculated accordingly.

Results and discussion

The distribution of heavy metals in various environmental segments and in different parts of fish organs have been represented in Fig-2 and Fig-3 respectively. From the results, some important discussions have been presented as follows.

Heavy metals in water

Investigations of general characteristics of waste water flowing through the EKW were extensively done previously in details [15-20]. In this study, it is evident that aquatic medium in the pond contained lowest level (<1%) of heavy metals in comparison to other environmental compartments. Similar levels of dissolved metals in aquatic medium were observed during earlier studies in this ecosystem[15]which were however, higher in levels than the Hooghly river water[23].The sources of Cr in EKW are mainly originated from large number of tannery units which use Cr salts for tanning the raw skins. The presence of Cd could be due to use in pesticides for garbage farming, pigment industries and road dust originated during abrasion of vehicular tyres. On the other hand, major sources of Pb and Zn may be due to mixing of waste water coming from pigments, potteries and electroplating industries situated besides the sewage flowing canals. The water shows pH value towards slightly alkaline range and this value almost remains constant due to buffering action of CO_3-HCO_3 system[24] together with exchange of various ions through organic matter and minerals in sediments. At this, most of the dissolved metals remain in hydroxide form with low solubility product. As a result, the concentration of dissolved heavy metals in water might not increase to a large extent at normal condition excepting in acidic condition. All the same, water does play a great role in retaining huge amount of heavy metals due to its large abundance (75%) not only in earth, but also in any biological life. Besides, water has potential role in distribution of various chemicals in different environmental components through dissolution due to high solubilising ability, hydration and solvation energy. Thus, water can act as universal solvent and can accommodate large amount of dissolved metals without increasing the concentration level appreciably. In addition, the movement of water in streams and rivers also can increase the dilution of heavy metals to a large extent during distribution in different environmental segments in course of moving from one place to another.

Heavy metals in soil/sediment

Soil/sediments is a part of lithosphere, which has been originated in upper surface of earth crust by weathering processes of bed rocks. Sediments act as a store house of all solid heavy metals and have great affinity to deposit the moving metals into the sediment/soil by way of adsorption, coagulation, sedimentation and precipitation. These characteristics might be responsible for higher degree of metal accumulation in sediments/soil. Present study also corroborated this fact that showed the presence of large percentage of heavy metals ranging from 28.5 to 56.5% (Fig. 2) in sediments. Among the metals, Pb and Cr have higher affinity to be absorbed into sediments (50.0and 55.5% respectively) in compared to other metals like Cd and Zn (27.8 and 36.6% respectively) possibly due to higher mobility of these divalent ions towards reactivity. Surface sediments in the pond are of in general, contain finer particulate form having large surface area which has the capability to adsorb significant amount of metals in association with organic matter present [5, 21, 22]. The level of occurrence of metals in the present study was also similar to previous study in this area and is true in sediments/soils of other areas also [26, 27]. Besides, chemically Cd is very similar to Zn and makes a competition to replace Zn from some enzymes by altering stereo- structure and impairing the catalytic activity. These metals, in general remain in different forms, may be further available or may not be and may become a part of soil mineral inside the crystal lattice. The pathways of transport of metals in soil/sediments are aerial fallout, fluvial runoff and amendment (spreading, injection etc.). Hence, sediments/soil does play a vital role in dilution through considerable accumulation of heavy metals and largely may be with time sequestered[28]in the dip of the lithosphere or may again available to the biotaby the activities of microbes[29]and may enter into the food chain following

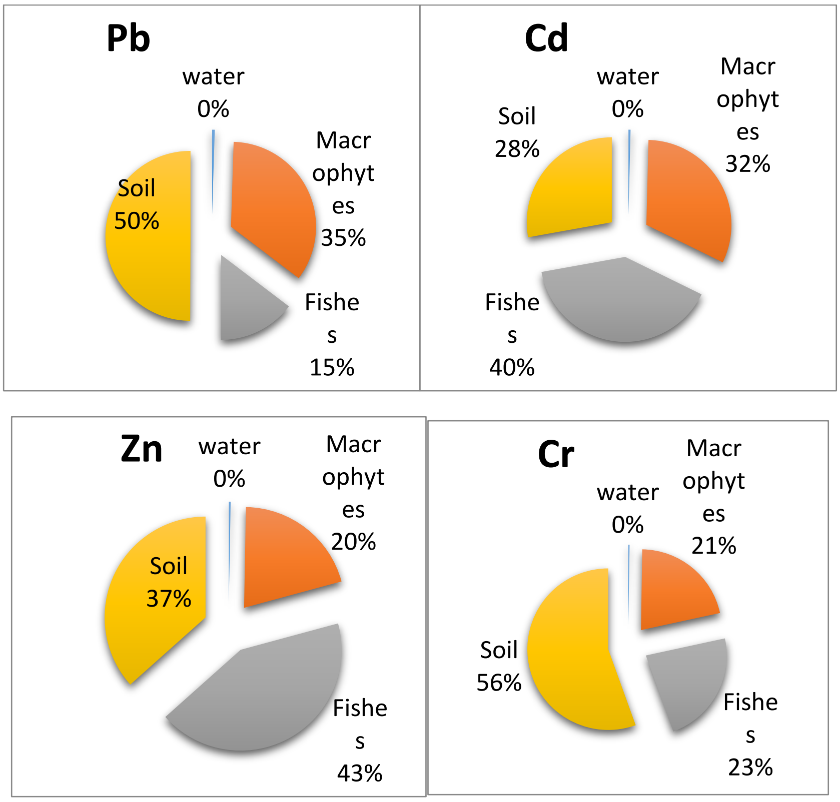

Figure 2. Distribution of heavy metals in different environmental segments. (0% indicates the presence of metal below 1% level).the same cycle in nature repeatedly until and unless, the availability is exhausted or diminishedwith passage of time.

Heavy metals in macrophyte

Large numbers of studies[9,10,27,30-32], in literature distinctly highlight the ability of aquatic macrophyte to accumulate heavy metals. Present study also recorded the high level of heavy metals with the range 21.35 to 34.9%, slightly less than sediments/soil (Fig. 2). The degree of accumulation of Pb, Cd, Cr, and Zn were 34.9, 31.82, 21.35 and 20.50 % respectively. Thus, the study clearly inferred that the metals, Pb and Cd could accumulate comparatively in higher level than Zn and Cr. The bio-concentration factor(BCF) which is the ratio of heavy metals in water hyacinth to the metal concentration in water have been found to vary from minimum value of 70 to the maximum of 170 indicating the extent of accumulation of metals by this particular macrophytes. However, comparatively higher values of this factor were recorded in earlier studies[9,10] from the ponds located in isolated areas with managed wetlands and less anthropogenic stress. Again in cases of higher plants, accumulation of heavy metals could be found in different parts like root, stem and leaves. It had been recorded from previous studies[32] in sewage irrigated agriculture farm producing vegetables that leaves showed large accumulation of heavy metals in comparison to other parts, especially, those metals which have similar ionic size and valency. But toxic group of metals find difficulty to accommodate in flower and fruitin higher extentdue to intensive cell filtration which protect the future generation from the effect of heavy metal contamination. So, plant communities also have some important role for accommodating significant amount of toxic heavy metals, thereby, acting as an efficient agent of making dilution in the metal level.

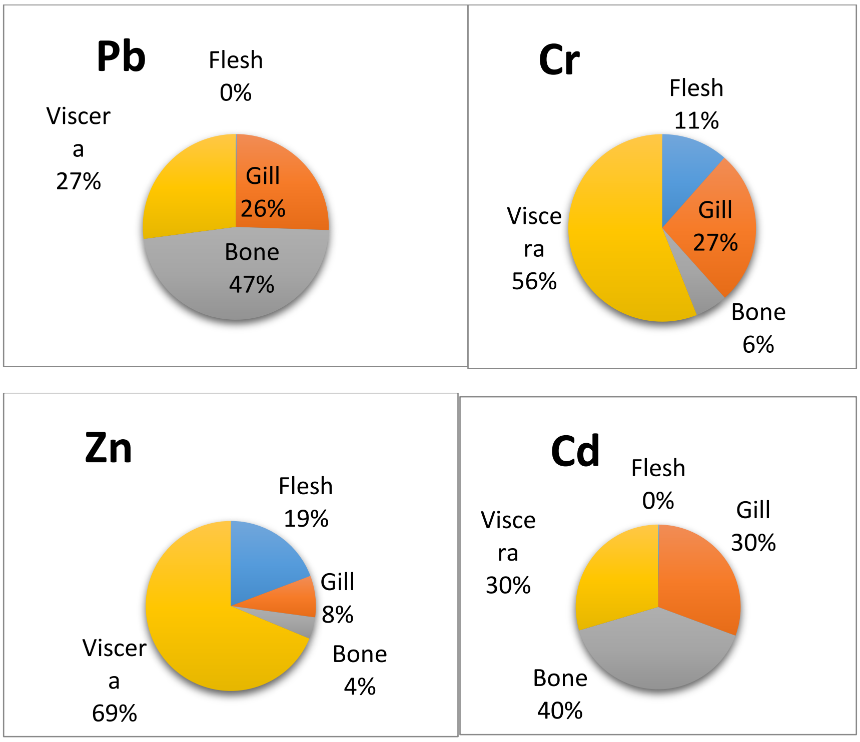

Figure 3. Distribution of heavy metals in different organs of fish (nylotica). (0% indicates the presence of metal below 1% level*Heavy metals in fish*

Similar to aquatic plants and sediments, the next agent is the group of animals present in the aquatic system. As for example, fish also accumulate heavy metals in the range of 14.73 to 39.85% (Fig. 2). The order of accumulation levels were Zn > Cd > Cr > Pb. The metal Pb is poisonous and has no well known biochemical role and hence unlike Cd it is not taken up actively by any biotic life. The accumulation of lowest level of Pb in the present study also substantiates this fact[11]. On the contrary, the metal Zn being an essential metal present in various enzymes is urgently needed by the biotic community resulting in relatively higher level as observed. Thus fish can be recognized as the important biotic agent of nature for sharing the load of heavy metals from the environment. Higher group of plants[32] and animals again can re-distribute the toxic metal burden through spreading in different organs. In the present study, the pattern of re-distribution of heavy metal in fish have been presented in Fig. 3. It has again been observed that among the organs; flesh, gill, bone and viscera, toxic metals of Pb and Cd, higher in bone(40.0 to 47.3%), followed by gill (25.3 to 30.6%), viscera (27.08 to 29.85) and least (<1%) was in the flesh. But essential heavy metal distribution was recorded higher in viscera (55.9 to 76.9%), followed by flesh (11.1 to 19.2%), gill (8.8 to 26.8%) and bone (4.62 to 5.59%). The similar chemical properties Pb and Cd might be responsible for the higher accumulation of metals in bone and gill. Hence these are rejected for their entrance by in-numerable cell membrane filtration which may ultimately result in lower content of toxic heavy metals (Pb and Cd) in flesh organs of the fish and make it safe to human consumption, however, the continuous exposure of these chemicals may cause higher degree of accumulation and becomes a potential source of human risk on consumption as observed in a recent study[33].

Conclusions

Dumping of toxic substances into any compartments of the environment is a burning consequence for environmental degradation. But nature by its own way, implement the most effective mechanism to combat the extent of harmful effect through the distribution of these undesirable substances in various biotic and abiotic components by way of transfer, transport, transformation, entrance, accumulation and excretion. Present study is an example of the extent of distribution of some heavy metals in a sewage- fed fishery pond ecosystem of the EKW, 'a Ramsar site' in India. Study forecasted that the sediment/soil can serve as a most effective depository system followed by accumulation in plants and animals. Again in biological system re-location of heavy metals was found in various organs taking an example of fish. These distribution patterns are seemed to be the inherent natural characteristics of the environment that could be designated as the self-rectification or self-organization capacity of the environment. In the present case, however not all compartments in the environment as well as various operating processes could be taken into account. If all processes would have been considered then not only the degree of dilution of heavy metals would have been more but also the untoward effect would have been diminished towards a safe and tolerable limit. Still, the present study is an endeavor to highlight the concept of degree of partitioning of some heavy metals in some components within an ecosystem. The study also establish the fact that all the constituents in an ecosystem are intimately interrelated to each other with some unseen forces and sharing in between and among them is a most effective method to mitigate environmental problems.

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