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Eco-Toxicological Impact Of Effluent Waste Discharged From A Chlor-Alkali Industry On Estuarine Fish And Its Significance.

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Abstract
The Chlor-alkali industry discharges its effluent and solid waste containing mercury in to Rushikulya River contaminating the river water, estuary and Bay of Bengal. Estuarine fish was collected from the contaminated estuary and sold in the local market and at places nearby. The present piece of work was planned to study the impact of effluent waste discharged from a Chlor-alkali industry on the estuarine fish. Mercury contained effluent significantly affected the estuarine organisms like fishes, crab and prawn. Physico-chemical analysis of the water samples in 8 sites, one located in the effluent channel, and 7 other sites on the Rushikulya River, where the effluent joins the river and the estuary were carried out. Monthly variations of few parameters were studied in all the eight stations selected for the purpose. Two sites in the upstream of the river before the effluent joining point, second, the joining point of the effluent channel with the river. All the tested physico-chemical variables showed normal and natural seasonal variation based on selection of sites / stations in the contaminated area. The leached chemicals from the solid waste dump site had moderate impact on the physico-chemical variable at all stations prior to effluent joining point. The effluent significantly altered the phyco-chemical properties at the down stream / estuary. The effluent waste showed serious impact on estuarine fishes and because of the effluent waste discharge on this site, the breeding of marine fishes was serious affected. The impact became more serious because of mercury concentration in the environment. The other physico-chemical variable had no significant effect because of dilution factor. No significant relationship exists between residual mercury concentration in fish body with either body length or weight of the fish collected from the contaminated estuary. Residual mercury in fish body depends on the availability and retention time of the fishes at the contaminated site. Residual mercury availability was high during in estuarine fish body was high till 2015, low levels of residual mercury was found in the estuarine fishes. In contrast in 2015, low mercury residue was noted in few fishes and in many estuarine fishes residual mercury was not detected or recorded. Availability of residual mercury in brain, liver and muscle tissues of the contaminated estuarine fishes warrants attention.

Keywords: Chlor-alkali industry, effluent, Rushikulya River, Estuary, Estuarine fish.

Introduction

Chlor-alkali industries are the notable sources for environmental contamination. In the process of manufacture of chemicals, the factory discharges the effluent containing mercury into Rushikulya River and the river joins the estuary. The industry collects the solid waste (brine mud, enriched with mercury) deposits and dumps on the adjacent land areas. The effluent coming out from the washings of the electrolytic cells, cell house, hydration chamber and compression chamber contains spilled mercury and left out mercury along with mud, contained huge amount of mercury. This mud and sediments in the effluent canal and effluent treatment tank and settling tanks of the industry contains significant amount of mercury. Periodically, the sediment of the effluent canal and settling tanks were removed and dumped nearby, which contained huge amount of mercury. During electrolysis high temperature in cells, evaporates mercury and evaporated mercury escapes along with the air of the cell house through exhausts and spreads all over the area and mercury after getting cooled naturally settles on allover the places, settles on plants, settles on

aquatic bodies and terrestrial land mass. During rainy season, these settled mercury escapes into water bodies which ultimately reaches river Rushikulya through drainages. After electrolysis, the Sodium-mercury amalgam is transferred to hydration chamber, where water is added with force for mixing. Sodium reacts vigorously with water to form Sodium hydroxide and hydrogen gas is released. Hydrogen gas is transferred to the compression chamber for further reaction with chlorine gas to form HCl acid. After hydration process is complete, sodium hydroxide is removed and the sediment waste comes out during washing of the hydration chamber which contains huge amount of mercury. This effluent waste passes through the effluent canal and reaches the treatment tank and settling tank before the effluent is discharged outside. The sediment waste containing mercury is periodically removed and dumped outside nearer to the River Rushikulya bank. During electrolysis, the evaporated mercury also escapes along with chlorine gas and carried to the compression chamber, where chlorine gas reacts with hydrogen gas coming from hydration chamber under high pressure to form HCl acid and mercury settles in the compression chamber which escapes during washing from the compression chamber as waste. Mercury is thus, discharged into the environment through effluent and solid waste routes, contaminating the adjacent aquatic and terrestrial ecosystems, respectively. This addition of mercury into the environment by effluent discharge and solid waste dump outside the industry is the primary contamination. The effluent discharged into the river which ultimately joins Bay of Bengal through Rushikulya estuary. The present study was planned to study the impact of effluent waste on the estuarine fishes collected from the estuary.

Materials and methods:

Location of the industry, experimental and collectio0n sites: The Chlor-alkali industry M/S Jayashree Chemicals Pvt. Ltd., is situated on the side of National Highway-16 at Ganjam. The industry is located very close to Ganjam Township; district Ganjam, Odisha state, India. The industry is located on the Bank of River Rushikulya discharging its waste into the river directly (initially) and nearer to Rushikulya estuary and about 1.5 km away from the sea, Bay of Bengal on the East and 30 km North of Berhampur city on the south-eastern side of India at 84^0 53'E longitude and 19^0 16'N latitude.

(Photographs showing the location of Chlor-alkali industry, effluent canal, effluent canal joining the Rushikulya River at Ganjam, Odisha.)

(Analysis of samples and collection of estuarine fish for analysis)

The physico-chemical properties of the effluent were determined as per the standard procedures of APHA (1995). Effluent waste was collected in glass bottles from different selected sites and brought to the laboratory for analysis. Few parameters were carried out with the help of field analysis kit. The water, soil and fish brain, liver and muscle and whole fish samples were digested in a Bethge's apparatus (Wanntorp and Dyfverman, 1955). Care was taken to avoid loss of mercury vapor during digestion and estimated in a Mercury Analyser-MA5800, ECIL (1981). Fresh live fish samples were collected from the fisherman at the time of netting at the estuary and kept in estuarine water and immediately brought to the laboratory for respiratory and enzyme studies. The fish was dissected and different parts like brain, liver; muscle & gill were carefully removed and separated. The samples were kept in ice chamber till analysis. Care was taken

to avoid mixing of tissues at the time of autopsy. Residual mercury content was expressed in terms of µg / gm dry weight of the sample. The observed data was statistically analyzed.

Results

Physico-chemical properties of the effluent samples sampled from the effluent canal and other collection sites like mid point, storage tank and effluent meeting river point are as follows Temperature-29.2 ± 1.6°C, pH-9.4 ± 0.4, Alkalinity-241.8 ± 18.5 as $CaCO_3$ in mg l^{-1}, Hardness-392.2 ± 12.6as $CaCO_3$ in mg l^{-1}, Chlorinity-1018.6 ± 24.2mg l^{-1}, Dissolved Oxygen- 4.2 ± 0.4mg l^{-1}, BOD-39.6 ± 5.4mg l^{-1}, COD-288.5 ± 12.4mg l^{-1}, Suspended solids-102.5 ± 6.4 mg l^{-1}, Total Nitrogen-3.9 ± 1.2 mg l^{-1}, Total Phosphorus- 0.27 ± 0.09mg l^{-1}, and total mercury-0.38 ± 0.14mg l^{-1}. The effluent analysis indicated that effluent which was discharged into the environment is toxic and a significant amount of mercury was available in the effluent site, even after the change in technology.

Table-1: Physico-chemical properties of the effluent collected from four discharge points in the effluent flow channel. Data are the mean of samples ± standard deviation.

Sl No.	Parameter	Immediately leaving the industry	Mid Point	Storage tank	Effluent Meeting River point
1	Temperature (°C)	30.2±1.5	29.8±1.2	28.2±1.4	26.5±0.8
2	pH	9.8±0.5	9.8±0.4	9.1±0.2	8.9±0.3
3	Alkalinity (mg l^{-1})	258.2±12.4	254.2±6.8	246.4±12.2	224.2±9.6
4	Hardness	481.8±17.4	406.2±14.2	385.9±12.6	347.4±31.3
5	Chlorinity (mg l^{-1})	1127.6±48.4	1098.6±22.9	962.5±22.6	841.5±19.2
6	Diss. Oxygen (mg l^{-1})	3.1±0.6	3.3 ± 0.2	3.4±0.4	3.7±0.8
7	BOD (mg l^{-1})	31.3±1.8	31.8±1.6	39.1±3.9	45.1±2.2
8	COD (mg l^{-1})	321.4±9.2	301.4±12.8	352.8±18.6	364.2±11.4
9	Susp. solids (mg l^{-1})	146.3±34.5	106.5±24.3	86.3±5.2	124.5±9.8
10	Total Nitrogen (mg l^{-1})	5.4±0.7	3.4±0.4	1.2±0.3	3.5±1.6
11	Total Phospho(mg l^{-1})	0.23±0.08	0.21±0.11	0.18±0.08	2.85±0.7
12	Total Mercury (mg l^{-1})	3.12±0.13	2.68±0.25	2.04±0.11	1.68±0.26

The temperature of the effluent at the river meeting point was normal and ranged between 26.5±0.8^{0}C to 30.2±1.5^{0}C. The pH of the effluent was alkaline and the value recorded was 8.9 ± 0.3 at effluent meeting river point. Maximum pH was recorded at effluent discharge point. The alkalinity was 224.2±9.6 as $CaCO_3$ in mg 1^{-1}. The hardness of the effluent sample was 347.4±31.3mg 1^{-1}. The Chlorinity was 841.5± 19.2 mg 1^{-1}. The dissolved oxygen content was low and ranged within 3.7 ± 0.8mg 1^{-1}. The BOD and COD values were 45.1±2.2mg 1^{-1} and 364.2±11.4mg 1^{-1}, respectively in the effluent collected from the river meeting point (Table-1). The suspended solids were little high and significant and the value was 124.5± 9.8mg 1^{-1}. A small amount of 3.5 ± 1.6mg.1^{-1} total nitrogen was also noted to be present in the effluent meeting river point. An insignificant amount of phosphorus was recorded in the effluent. However, a significant amount of mercury was recorded in the effluent discharged from the industry. An amount of 3.12±0.13 mg of mercury 1^{-1} was noted in the effluent sample, 2.68±0.25 mg of mercury 1^{-1} at mid point, 2.04±0.11 mg of mercury 1^{-1} at storage tank and 1.68±0.26 mg of mercury 1^{-1} at river meeting point (Table-1). The temperature of the effluent at the storage tank was low when compared to delivery point and mid point and ranged between 28.2 ± 1.4^{0}C. The pH of the effluent was alkaline and the value recorded was 9.1±0.2 (Table-1). The alkalinity was 246.4 ± 12.2 as $CaCO_3$ in mg 1^{-1}. The hardness of the effluent sample was 385.9 ± 12.6mg1^{-1}. The Chlorinity was 962.5 ± 22.6mg 1^{-1}. The dissolved oxygen content was little high when compared to discharge point and ranged within 3.4 ± 0.4 mg 1^{-1}. The BOD and COD values were 39.1 ± 3.9mg 1^{-1} and 352.8±18.6mg 1^{-1}, respectively in the effluent collected from the mid point and no significant difference was marked with the distance. The suspended solids were low but significant and the value was 86.3±5.2mg 1^{-1}. A small amount of 1.2 ± 0.3 mg.1^{-1} total nitrogen was also noted to be present in the effluent sample collected from the effluent storage tank, which was less than earlier value. An insignificant amount of phosphorus was recorded in the effluent in the effluent storage tank. However, a significant decrease in the amount of mercury was recorded in the effluent storage tank when compared to the delivery point and mid point from the industry. An amount of 2.04±0.11mg of mercury l^{-1} was noted in the mid point effluent sample. The lechate chemicals leaching from the storage tank into Rushikulya River showed very high values (Table-1). This might be due to aerial drying and surface evaporation of water from the storage tank enriching the chemicals in the storage tanks. Low values recorded in the river meeting

point was due high dilution of the effluent by river water except suspended solids, where the value recorded in the river meeting point was high and significant.

Table: 2. Residual mercury concentration in contaminated fish brain, liver, muscle and whole fish collected from Rushikulya river estuary and control fish collected from uncontaminated area at Palur. Data are the mean of 5 estimations. ND= Not detectable.

Sl. No	Name of the fish	Status of the fish	Residual mercury in whole fish and fish parts. µg of mercury / g dry weight			
			Whole fish	Brain	Liver	Muscle
1	*Mugil macrolepis*	Exposed Control	1.06±0.08 ND	0.96±0.34 ND	0.28±0.04 ND	0.31±0.08 ND
2	*Lutianus johnil*	Exposed Control	0.96±0.18 ND	0.98±0.19 ND	1.11±0.11 ND	0.86±0.11 ND
3	*Silago sihama*	Exposed Control	1.08±0.14 ND	0.98±0.31 ND	1.16±0.26 ND	0.84±0.17 ND
4	*Mystus vittatus*	Exposed Control	1.18±0.11 ND	1.21±0.14 ND	1.26±0.07 ND	0.91±0.18 ND
5	*Pentaprion longimanus*	Exposed Control	1.14±0.09 ND	0.86±0.15 ND	0.96±0.14 ND	1.65±0.35 ND
6	*Trachinocephalus myops*	Exposed Control	1.22±0.18 ND	1.26±0.06 ND	0.99±0.16 ND	0.63±0.14 ND
7	*Therapon jarbua*	Exposed Control	1.14±0.23 ND	1.14±0.07 ND	0.95±0.15 ND	1.85±0.26 ND
8	*Scatophagus argus*	Exposed Control	0.68±0.06 ND	0.38±0.05 ND	0.72±0.08 ND	0.89±0.08 ND
9	*Equala lineolata*	Exposed Control	1.32±0.09 ND	1.26±0.24 ND	1.34±0.17 ND	1.16±0.31 ND
10	*Arius nenga*	Exposed Control	1.25±0.31 ND	0.84±0.21 ND	1.95±0.35 ND	1.18±0.29 ND

The mercury concentration in brain, liver and muscle of control fish were not detectable in all the eleven fishes studied. It can be presumed that the control fish were collected from non contaminated zone. However, the fish collected from the estuary showed significant level of residual mercury in brain, liver and muscle. When compared to previous data, it was not possible to indicate biological magnification. But in some fish species higher level of residual mercury was recorded. In majority of fish species, low level of residual mercury was recorded. This might be due to the age of the fish and also the period of exposure of fish in the contaminated area. In case of exposed *Mugil macrolpis*, the brain accumulated 0.96±0.34 µg of mercury g^{-1} fresh weight, liver accumulated 0.28±0.04µg of mercury g^{-1} fresh weight and muscle accumulated 0.31±0.08µg of mercury g^{-1} fresh weight. In case of all control fish varieties tested, no residual mercury was detected (Table-2). In case of exposed *Lutianus johnil*, the brain accumulated 0.98±0.19µg of mercury g^{-1} fresh weight, liver accumulated 1.11±0.11µg of mercury g^{-1} fresh weight, muscle accumulated 0.860.11µg of mercury g^{-1} fresh weight. In case of exposed *Silago sihama*, the brain accumulated 0.98±0.31µg of mercury g^{-1} fresh weight, liver accumulated 1.16±0.26µg of mercury g^{-1} fresh weight and muscle accumulated 0.84±0.17µg of mercury g^{-1} fresh weight (Table-2). In case of exposed *Mystus vittatus*, the brain accumulated 1.21±0.14µg of mercury g^{-1} fresh weight, liver accumulated 1.26±0.07µg of mercury g^{-1} fresh weight and muscle accumulated 0.910.18µg of mercury g^{-1} fresh weight. In case of exposed *Pentaprion longimanus*, the brain accumulated 0.86±0.15µg of mercury g^{-1} fresh weight, liver accumulated 0.96±0.14µg of mercury g^{-1} fresh weight and muscle accumulated 1.65±0.35µg of mercury g^{-1} fresh weight. In case of exposed *Trachinocephalus myops*, the brain accumulated 1.26±0.06µg of mercury g^{-1} fresh weight, liver accumulated 0.99±0.16µg of mercury g^{-1} fresh weight, and muscle accumulated 0.63±0.14µg of mercury g^{-1} fresh weight. In case of exposed *Therapon jarbua*, the brain accumulated 1.14±0.07µg of mercury g^{-1} fresh weight, the exposed liver accumulated 0.95±0.15µg of mercury g^{-1} fresh weight and muscle accumulated 1.85±0.26 µg of mercury g^{-1} fresh weight (Table-2). In case of exposed *Scatophagus argus*, the brain accumulated 0.38±0.05µg of mercury g^{-1} fresh weight, liver accumulated 0.72±0.08µg of mercury g^{-1} fresh weight muscle accumulated 0.89±0.08µg of mercury g^{-1} fresh weight. In case of exposed *Equala lineolata*, the brain accumulated 1.26±0.24µg of mercury g^{-1} fresh weight, liver accumulated 1.34±0.17µg of mercury g^{-1} fresh weight and muscle accumulated 1.16µg of mercury g^{-1} fresh weight. In

case of exposed *Arius nenga*, the brain accumulated 0.84±0.21µg of mercury g^{-1} fresh weight, liver accumulated 1.95±0.35µg of mercury g^{-1} fresh weight and accumulated 1.18±0.29µg of mercury g^{-1} fresh weight (Table-2). The tissues of respective control fishes collected from Gopalpur and Palur sea beach and back water did not show any residual mercury level. The distribution of mercury in different tissues of the fishes did not follow any significant trend. It was difficult to assess, whether the accumulation in brain was more or in liver or in muscle tissue. But in general, accumulation of mercury in different tissues of the fish drags the attention of ecologists and toxicologists and warrants attention. The level of accumulation and the extent of accumulation of mercury in fish caught from the estuary indicate the potential future danger in the Rushikulya River, Rushikulya estuary and near by places of Bay of Bengal.

Discussion

Environmental pollution by mercury is considered to be one of the most important problems faced by all plants, animal and mankind and studied extensively. Mercury as an element has multiple uses but when it is present in the environment in excess, it can be considered harmful and equally dangerous at higher level. Mercury finds its way in many different ways into the environment. The most important source of mercury in the environment was the burning of fossil fuel, Chlor-alkali industry waste and Aldehyde industry waste. Chlor-alkali industry is accepted as the bigger source of mercury pollution, where mercury is used as a cathode in the electrolytic process. This metallic mercury travels from electrolysis cell to hydration chamber, compression chamber and ultimately mercury is recycled back into the electrolytic cell. In the process of manufacture of caustic soda (NaOH) mercury evaporates in the cell house during electrolysis due to high heat generated during electrolysis process and moves along with chlorine gas released during electrolysis to compression chamber. Mercury reacts with sodium ion released during electrolysis to form sodium-mercury amalgam. The amalgam is transported to the hydration chamber by a pipe line. In the hydration chamber the amalgam is hydrated with water. In the process caustic soda is produced and metallic mercury is released free. The produced NaOH contains mercury as impurities. The metallic mercury so released is then transported back (recycled) to the cells of the cell house for future electrolysis. The hydrogen gas thus produced in the hydration chamber also contains mercury vapor which is canalized to compression chamber for further reaction with chlorine gas to produce HCl acid, which also contains residual mercury. During transport, spillage of mercury from pipe lines, during washing of the cells, cell house, hydration chamber and compression chamber, mercury escapes into the environment along with washings called effluent. This escaped mercury settles in the settling effluent tank and effluent canal along with sediment. This sediment is periodically removed and dumped outside as solid waste in the environment which contains mercury. The operation of industries dealing with mercury allows mercury availability in the environment. Mercury is discharged into the environment in elemental form, which under goes natural oxidation and reduction along with environmental chemicals under different climatic conditions and seasonal variations. Elemental mercury is converted to inorganic mercury and organic mercury mediated by microbes and other flora and fauna. Mercury is absorbed by plants and animals from the environment. The live biotic systems absorb, accumulate and mercury bioconcentrate and the same chemical gets biomagnified in the food chain and food web and this becomes a threat to human health and mankind (Wu and Wang, 2011). The same authors also pointed out that the toxic responses are specific to different types of metals and different types of species, but the sub-cellular basis underlying such inter-species and inter-metal differences was not very clear and needs a detailed study. We agree with the views of above authors. Chlor-alkali industries discharge mercury in elemental form in to the environment or more appropriately mercury escapes into the environment in elemental form along with effluent coming from four sources and the whole effluent accumulates in the effluent stocking pond for treatment, where the pH was adjusted and the effluent is discharged through the effluent canal into the environment. The mercury present in the effluent or in the sediments collected from the effluent canal and settling tank or treatment tank contained elemental mercury only. This elemental form of mercury which has escaped from the industry under goes transformation naturally and also by biotransformation, to form other forms of mercury either in the inorganic form or in the organic form, after absorption and conversion by biological agents (Raut, 2013, Mishra, 2013). Hence it was felt necessary to study and understand movement of mercury in the environment and absorption, mobilization of mercury and impact of mercury on animals particularly fish available in river and the estuary.

The physico-chemical analysis of the water samples were carried out in eight stations selected for the purpose. The parameters selected were based on relevance and necessity for studying the fishes collected by the fisherman. Fish was generally caught by fisherman at the estuarine zone. The temperature of the effluent channel was highest, when compared to all other stations in every month assessment. Highest temperature was recorded in July (late summer months, pre monsoon period) and the lowest was recorded in

January (winter). Station-IV was located nearer to the estuary and after station-III, where a mixture value of temperature was recorded. Temperature variation in stations VI - VIII situated at the estuary showed no significant variation due to regular in flux of tidal waves coming from sea. The stability of pH in stations-VI to VIII was mainly due to tidal influx coming from sea and the effluent water coming from the industry. Station-III showed higher pH values in all months studied, when compared to Station-I and Station-II. Station-V showed the highest pH 11.9 in July (late summer) and lowest pH in 9.1 in October (Rainy month). The pH in this station was highest in all months, when compared to the rest of 7 stations. During rainy season, the dissolved solids were less because of dilution by rain water and in summer months the dissolved solid load was highest in the effluent, because of high rate of evaporation. During rainy season, the suspended solid load was highest in the estuary due to flood water, effluent load and influx of tidal water from the sea and mixing in the estuarine zone. The station-I showed the lowest dissolved solids, when compared to other stations. The area becomes dangerous during rainy season, hence measurement was avoided. The dissolved oxygen varied with the change in water temperature. In cooler months the dissolved oxygen content was high and in temperate months the dissolved oxygen was low. Higher value of dissolved oxygen in stations VI to station VIII was due to tidal waves influx with the river water. It was highest in rainy season due to high inflow of flood water. Significant low dissolved oxygen at station-V was due to the effluent of the industry. This is one of the reasons why fishes, fingerlings, phytoplanktons were not seen at station-V. The salinity level of the effluent channel was not estimated. Quantitatively stations VI to VII showed the highest values for all the parameters followed by station III and then station I. It appears from the figure that station II was largely under the influence of the effluent water. Trend of increase in the quantitative values from station I to III to IV is well understood as we move towards the mouth the estuarine water becomes more and more oceanic and high salinity levels were observed. Salinity is widely used as an indicator of the estuarine conditions. Distribution of salinity varied from time to time depending upon the influence of fresh water influx and penetration of sea water into the estuary. In the present study values of salinity ranging from purely marine to the almost freshwater were recorded. Significant variations were marked in the salinity content of different stations in different months.

The effluent which was found to contain very high amount of mercury, when released from the factory finds its way finally into the Rushikulya river estuary. Out of twelve analyses carried out in twelve months, only once, in the month of March, a lower concentration of mercury (0.0268 mg 1^{-1}) was observed. Though the concentration in March was low, the value was in itself much higher than the permissible limit. Higher concentration of mercury, as recorded in the month of January, was to the tune of 1.549mg 1^{-1}. Concentration of mercury in the effluent was found to be fluctuating having a mean value of 0.4474 ± 0.4466 mg 1^{-1}. Elevated levels of alkalinity at station I and III might be because of the effluent discharge. In polluted system OH^- ions released from chemical factories play on important role in increasing measured is not the true alkalinity. Variance ratio test analysis revealed a significant difference in the alkalinity between seasons as well as between stations. It was observed that the residual mercury accumulations in fishes are mostly weight dependent and indirectly length dependent. The changes in body length and body weight were time dependent. It depends on the habitational time period of the fish in the estuary and the residual mercury increases with time. The size of the fish also depends on environmental parameters and totally genetic. Hence uniform biological rule of growth cannot be adopted as a standard protocol for estimations, measurements and interpretation to understand a biological mechanism might be related to environmental stress. The residual accumulation of mercury in fish is definitely time dependent. The figures however indicated that residual accumulation occurred in fish body and the correlation is positive for both the parameters but not significant. Fishes with higher weight accumulated less mercury and fishes with lower body weight accumulated more amount of mercury. Hence, the accumulation of mercury cannot be only either due to weight of the fish or length of the fish. It may be due to the metabolic activity and time of exposure of the fish to the toxicant. The fishes having higher weight and length might have reached to the contaminated site late when compared to other fishes where higher accumulation was marked. In field conditions when the area is open and free movement of fishes occur, it is really difficult to assess the residual accumulation and interpret with either weight or length of the fish. It may so happen during fish catch, large fishes might have reached the site from sea without getting contaminated and the fisherman catches those fishes for us for analysis. Residual accumulation in static ecosystems is easy to assess but in dynamic ecosystems, difficult to assess. Similar interpretations are also equally valid when we correlate fish length with residual accumulation.

In both the years under study in this project, fishes were collected from estuarine area, particularly from stations-nearer to Bay of Bengal and inside the estuarine belt. Out of total 17 different fish species collected, only 10 varieties were found common in the fish catches of both the years. Absence or presence

of fish in a particular year did not indicate any environmental variation. But in 2015, more varieties of fishes were available. The availability of good number of fishes might be due to the decrease in environmental mercury load. No residual mercury in the body of some fishes in 2015 may be either due to less availability of mercury in the environment or due to fresh fish coming from the sea. The estuary was contaminated as the effluent of the industry was discharged directly into the river Rushikulya and (LC) leached chemicals from the SW (solid waste) dump enter into Rushikulya River and consequently into the estuary leading to Bay of Bengal. Considering the rough size of the estuarine fish, similar type and size fishes were collected from Gopalpur on sea. The data showed clearly the size and weight of the estuarine fish was smaller in contrast to the control fish collected from Gopalpur and Palur. The difference in size may not be exactly due to the toxicant present in estuarine water. This difference was probably due to the type, size and the age of the fish collected from both the sites. In absence of clear knowledge on the age of the fish, it was really difficult to assess the potentiality of the toxicant on the fish size and fish weight. However, a general idea can induce us to conclude that the length and weight of the fishes decreased in the contaminated fish, in contrast to the control fish. The data collected from the local fisherman also indicated that bigger and larger fishes of these varieties were available beyond 5 km away from the estuary and many varieties were also available beyond 5kms from the estuary. In this Rushikulya estuary only few limited 17-20 varieties of fish were available that to in limited quantities. During rainy season / flood time, different types of fishes were available. The data collected from the local fisherman also revealed that many sea fishes were coming to the estuary for egg laying and breeding. But due to heavy contamination, since the last decade, no more fishes were coming during breeding season. If some species reach during breeding time, they were either caught by the fisherman or die due to polluted water of the estuary in 2013. Similar case was not found in 2015. Mercury is discharged into the environment through effluent and solid waste routes, contaminating the adjacent aquatic and terrestrial ecosystems, respectively. This addition of mercury is the primary contamination. The secondary contamination occurs through the chimney into the atmosphere and its fall out by the process of precipitation. All these discharges collectively seem to cause a major environmental threat. Long-term exposure of animals to toxicants might cause pathological changes in addition to physiological and biochemical changes. The rapid absorption of the toxicant (industrial effluent) through the gill, skin and gastro-intestinal tract of fish was well evident in the observed exposed fish. Similar findings and trends were also reported earlier in mercury intoxication (Panigrahi, 1980). The observed depletion in metabolic activity in exposed fish indicate probable damage caused to respiratory system, and inhibition of enzymes or an important system, was totally acceptable and agree with the findings of Panigrahi (1980). Mishra (2002) and Panda *et al*., (2017) reported the effect of red mud waste and red mud waste extract on fresh water fishes whole body oxygen uptake separately and also indicated that these wastes depress active metabolism and the exposed fish intake of oxygen decreases significantly. Considerable information are available pertaining to residual toxicity levels in fresh water, estuarine and marine fishes but relatively very little work has been done on the mechanism of toxic action of mercurial compounds especially on studies concerning active transport across cellular membranes. The residual mercury accumulation in fish tissues increased the body burden and impacted severely the respiratory metabolism which was reflected in depletion of whole body oxygen uptake and residual mercury accumulation in brain affected the nervous system leading to erratic swimming, nervous disorders and paralytic movements. In the present case the impact was very high and the behavioral changes were more acute and drastic confirming mercury poisoning in the affected areas at Ganjam, Odisha.

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Conflict of interest

The authors declare that they have no conflict of interest for this publication.

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