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A Multi-Index Analysis Approach to Heavy Metal Pollution Assessment in Budhasagar pond of Rajnandgaon town, Chhattisgarh, India

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The industrial revolution which took place in the 18th and 19th centuries changed the scenario of the world with greater and efficient industrial production with the help of machines. The revolution was powered by fossil fuels, which has turned out to be the biggest menace for the planet in modern times.

Water pollution is regarded as a major type of pollution. We are living in an environment contaminated with different pollutants. Pollutants are entering different biogeochemical cycles and ecosystems and making them unsuitable for life. Surface water is more vulnerable to pollution than underground water. Agriculture and industrial waste such as pesticides, fertilizers, toxic chemicals, and heavy metals are often discharged into rivers untreated, thereby contaminating these freshwater sources.

A pollutant is defined as a substance that is present in the environment that may harm flora and fauna or environmental quality standards (Kumar, 1995).

Water pollution is a hot topic of international and national debate and a vast domain related to many types of pollutants entering the hydrological cycle account as water pollutants. River water, lakes, ponds, underground water, as well as seawater contamination are all subjects under the broader subject of water pollution. The current research deals with the contamination of freshwater by heavy metals.

The term "heavy metals" denotes elements with an atomic density of more than 4 g./c.m.^{3}. Some metals and metalloids come under this category (Nriagu, 1988). The term is generally used to refer to metals like mercury (Hg), Cadmium (Cd), Silver (Ag), Iron (Fe), Chromium (Cr), Lead (Pb), and Copper (Cu).
Heavy metals can be categorized into two main groups – essential and non-essential heavy metals. Some heavy metals like iron, zinc, chromium, copper, and manganese play a vital role in the proper functioning of body organs because of their role in metabolism. If their concentration exceeds an optimum level, they pose health risks to the body (Unger, 2002).

Materials and Methods

Collection of Samples

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Water and fish samples were collected from the selected site during different seasons between 2015-2017. During the entire study period, samples were collected three times a year: during winter (January/February), summer (May/June), and post-monsoon (September/October). In each sample, three replicates were collected every time. The sampling was done between 9.30 A.M. to 11.00 AM. Sampling was done as follows:

2. Fish Sample:

Fish samples were collected from each selected site in the morning (9.30 - 11.00 AM) by taking the help of local fishermen. Three replicates were collected for the fish sample. The size varied from 15-17 cm and 100 gm in weight. Collected fishes were transported to the laboratory in the ice-box on the same day.

2. Heavy metal analysis

Heavy metals analysis of fish samples was done by Inductively coupled plasma - optical emission spectrometry (ICP-OES). Heavy metals such as lead, cadmium, chromium, iron, and mercury were selected for the study. Samples were digested and analyzed using inductively ICP-OES (Perkin Elmer, Optima 4100DV) according to the method described in the American Public Health Association (2005) and the United States Department of Agriculture (2008). Before the digestion of samples, glassware used for the experiment was rinsed with 10% (v/v) nitric acid and deionized water. Fish samples were thawed and tissues of fish removed with sterilized surgical blades and scissors. Fish tissues were oven-dried at 80°C in acid-washed Petri dishes up to a constant weight. Fish samples were kept in desiccators for cooling. Fish tissues were homogenized with mortar and pestle and ground to a fine powder and weighed. 0.5g of finely powdered tissue sample processed in duplicate and then digested using closed-vessel microwave digestion (Milestone model Start D, Italy). Fish tissues were digested in Nitric acid and subjected to follow four steps of the microwave digestion program. After digestion, 2 ml of 30% hydrogen peroxide is added to digests because it reduces vapors of nitric acid and accelerates the organic substance digestion by increasing the temperature (Dig-Acids, 2001). Blanks are used for the authentic determination of analysis. For analytical quality, fish samples were analyzed in triplicates. The digested fish samples were diluted with 50 ml ion-free water in acid-washed standard flasks and each fish sample was filtered through 0.45 µm Whatman filter paper. After filtration, digested samples were analyzed using ICP-OES. Operational parameter settings of ICP-OES (Perkin Elmer, Optima, 4100DV) are shown in Table B. Multi-elemental standard solutions (Merck) were used for the standardization and prepared by diluting stock solutions of 1000 mg/L (Mohammed 2013). The levels of heavy metals in fish were expressed as mg/kg dry weight. All experiments were done in triplicates. The detection level was set as 0.01 mg/kg or ppm (parts per million), below this level result indicated BDL (Below detection limit).

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Metal Pollution Index (MPI):

Metal Pollution Index (MPI) MPI shows the cumulative effect of all the Heavy metals investigated (Usero et al., 1996).

$MPI = (Cf_1 x Cf_2 ... Cf_n)^{1/n}$

where Cf_n = concentration of the metal n in the sample.

Geometric average, as stressed by Ott (1978), has advantages when compared with other aggregations methods, since it highlights concentration differences.

Hazard Index (HI):

To assess the overall potential for non-carcinogenic effects posed by more than one Heavy metal, a Hazard Index (HI) approach has been developed based on the EPA's Guidelines for Health Risk Assessment of Chemical Mixtures (USEPA, 1986). This Hazard Index is given by the sum of the Target Hazard Quotients, as described in the below equation. When the Hazard Index exceeds one, there may be a concern for potential health effects (USEPA, 1989; EC, 2002).

$$HI = \sum_i \text{THQi}$$

The pollution load index (PLI):

Wilson and Jeffrey (1987) proposed PLI to ascertain ecological risk due to heavy metals.

$$PLI = (PLI_1, PLI_2, . . . ;PLI_n)^{1/n}$$

It varies from 10 (unpolluted) to 0 (highly polluted).

$$PLI = \text{antilog}_{10}\, 1 - \frac{C-B}{T-B}$$

B is the baseline value—not contaminated; T is the threshold, minimum concentrations associated with degradation or changes in the quality. Wilson and Jeffrey (1987) define B and T for the different contaminants, C the concentration of the pollutant. For each place, the PLI calculation takes into account all the n contaminants (Wilson and Jeffrey, 1987).

Pollution Load Index Guidelines (mg/kg	Heavy metals	Baseline	Threshold
	Cd	0.5	1.5
	Pb	10	100

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b.w.)	Cr	5	50
	Hg	0.05	1.5

Observations and results

Hazard index (HI):

Hazard index indicates the total value of heavy target hazard quotient (THQ)

For the Year 2015-16

Adults:

In gill, during summer season it was 0.072, in post-monsoon 0.096 and nil in the winter season, in the liver, it was 0.059, in post-monsoon 0.074 and nil in the winter season. In muscle, during the summer season, it was 0.030, in post-monsoon 0.075, and nil in the winter season

Table 62: Hazard Index (HI) Year 2015-16 for adults

Index	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint .	Sum.	Post Mon.	Wint .
HI	0.072	0.096	0	0.059	0.074	0	0.030	0.075	0

Children:

In gill, during summer season it was 0.199, in post-monsoon 0.265 and nil in the winter season, in the liver, it was 0.163, in post-monsoon 0.206 and nil in the winter season. In muscle, during the summer season, it was 0.084, in post-monsoon 0.020, and nil in the winter season.

Table 63: Hazard Index (HI) Year 2015-16 for children

Index	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint .	Sum.	Post Mon.	Wint .
HI	0.199	0.265	0	0.163	0.206	0	0.084	0.020	0

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For the year 2016-17

Adults:

In gill during the summer season, it was 0.166, in post-monsoon 0.132, and 0.197 in the winter season, in the liver, during summer. it was 0.265, in post-monsoon 0.194 and 0.196 in the winter season. In muscle, during the summer season, it was 0.083, in post-monsoon 0.083 and 0.100 in the winter season.

Table 64: Hazard index Year 2016-17 for adults

Metal	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.
HI	0.166	0.132	0.197	0.265	0.194	0.196	0.083	0.083	0.100

Children:

In gill during the summer season, it was 0.462, in post-monsoon 0.365 and 0.546 in the winter season, in the liver during summer season it was 0.732, in post-monsoon 0.535 and 0.540 in the winter season. In muscle, during the summer season, it was 0.231, in post-monsoon 0.231 and 0.280 in the winter season.

Hazard index Year 2016-17 for children

Metal	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.
HI	0.462	0.365	0.546	0.732	0.535	0.540	0.231	0.231	0.280

<u>Metal pollution index (MPI):</u>

The year 2015-16

In gill, during summer season it was 3.97, in post-monsoon 2.52 and 3.24 in the winter season. In the liver, during the summer season, it was 4.29, in post-monsoon 3.16 and 2.20 in the winter

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season. In muscle, during the summer season, it was 2.30, in post-monsoon 3.23 and 2.21 in the winter season.

Metal pollution index (MPI) for the year 2015-16

Index	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.
MPI	3.97	2.52	3.24	4.29	3.16	2.20	2.30	3.23	2.21

The year 2016-17

In gill, during summer season it was 3.87, in post-monsoon 4.77 and 1.79 in the winter season. In the liver, during the summer season, it was 5.96, in post-monsoon 8.56 and 2.56 in the winter season. In muscle, during the summer season, it was 2.73, in post-monsoon 3.06 and 1.61 in the winter season.

Metal pollution index (MPI) for the year 2016-17

Index	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.
MPI	3.87	4.77	1.79	5.96	8.56	2.56	2.73	3.06	1.61

<u>The pollution load index (PLI):</u>

The year 2015-16

In gill, during summer season it was 9.69, in post-monsoon 9.42 and 10 in the winter season. In the liver, during the summer season, it was 9.63, in post-monsoon 9.44 and 10 in the winter season. In muscle, during the summer season, it was 9.51, in post-monsoon 9.70 and 10 in the winter season .

Pollution load index year 2015-16

Metal	Gill			Liver			Muscle		
	Sum.	Post	Wint.	Sum.	Post	Wint	Sum.	Post	Wint

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		Mon.			Mon.	.		Mon.	.
Hg	10	8.89	10	10	10	10	10	10	10
Pb	10	10	10	10	10	10	10	10	10
Cd	10	10	10	10	9.16	10	10	10	10
Cr	8.83	8.87	10	8.62	8.70	10	8.18	8.87	10
PLI	**9.69**	**9.42**	**10**	**9.63**	**9.44**	**10**	**9.51**	**9.70**	**10**

The year 2016-17

In gill, during summer season it was 7.31, in post-monsoon 9.24 and 9.00 in the winter season. In the liver, during the summer season, it was 9.50, in post-monsoon 6.69, and 9.01 in the winter season. In muscle, during the summer season, it was 9.06, in post-monsoon 9.10 and 7.57 in the winter season.

Pollution load index year 2016-17

Metal	Gill			Liver			Muscle		
	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.	Sum.	Post Mon.	Wint.
Hg	10	10	8.55	10	10	8.59	10	10	5.57
Pb	8.57	8.35	8.33	8.66	8.45	8.33	8.33	7.92	7.79
Cd	4.08	10	9.84	9.88	2.80	9.84	10	10	9.44
Cr	8.18	8.74	9.37	9.52	8.47	9.37	8.09	8.68	8.05
PLI	**7.31**	**9.24**	**9.00**	**9.50**	**6.69**	**9.01**	**9.06**	**9.10**	**7.57**

Discussion

Metal pollution index (MPI)

The metal pollution index shows the cumulative effect of all the Heavy metals investigated in a particular tissue or particular location. In 1st year of study liver tissue shows the highest MPI in

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the summer season and the lowest in the liver of the winter season, similarly in 2nd year of study in the post-monsoon season liver shows the highest MPI and in the winter season muscle shows least MPI. MPI during the whole study period was in the following order Liver > Gill > Muscle, hence liver emerges as an organ of highest accumulation.

Andy et al. (2007) investigated cephalopods, bivalve, crustaceans, and fish and reported high MPI in octopuses (9.55). Omaret al.(2015)investigated the river Nile, Egypt, Using Nile Tilapia, *Oreochromis niloticus,* as Bioindicator and recorded MPI

in different organs in the following order kidney > liver > gill > muscle. MPI was 31.49 for the kidney, 22.25 for the liver, 8.47 for the gill, and 2.24 for muscle.

Adeniyi et al.(2011) recorded MPI between 1.72 and 5.39 in Ebute Ogbo river catchments, Ojo, Lagos, Nigeria. Stankovic et al. 2014 calculated the metal pollution index of Seagrass *P. oceanica* and found it in a range of 11.1to 17.3.

Nemr et al. (2012) investigated eight Heavy metals in bivalve from the Egyptian Mediterranean coast and reported a metal pollution index between 1.87 to 6.57

Javed M. and Usmani N (2013) assessed Heavy metals pollution in effluent-dominated rivulet water and calculated metal pollution index and found maximum MPI in the liver (298.68) and lowest in muscle (44.64).

Abdel-Khalek et al. (2016) studied *Oreochromis niloticus* found in the river Nile and concluded that highest MPI in the liver (27.62) and lowest in muscle (0.81).

Ramteke et al. (2016) studied Heavy metal contamination in vegetables consumed in Raipur city of Chhattisgarh state and calculated metal pollution index between and 3.1 to 16.2 for different vegetables.

Luczynska et al. (2018) investigated Heavy metal content in gills, liver, gonads, and muscles of perch, *Percafluviatilis* and roach*, Rutilus rutilus* from Lake Pluszne Poland and calculated metal pollution index in different tissues it was highest in gill (7.68) and lowest in muscle (3.13) of roach and highest in the gonad (5.84)and lowest in gill (3.25)of perch.

The pollution load index (PLI)

This empirical index provides a simple, comparative means for assessing the level of Heavy metals pollution. It is a scale between 0 (Highly polluted) to 10 (unpolluted). We assessed it in different tissues and different seasons taking into consideration of four Heavy metals namely mercury, lead, cadmium, and chromium. Our results range from10 (unpolluted) in the year 2015-16 in winter samples of all three tissues and 6.69 in the year 2016-17 summer season, liver tissue. The highest contamination is found in liver tissues. In both years contamination of tissue follows the same pattern, higher contamination in the liver, medium in the gill, and lowest in muscle.

PLI - Liver > Gill > Muscle.

Utete et al. (2018) studied gills, liver, stomach, and muscle tissues of *Oreochromis niloticus* and *Clarias gariepinus* in peri-urban lakes Chivero and Manyame, Zimbabwe, and reported no metal contamination by calculating the pollution load index.

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