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Assessment of Heavy Metal Pollution in Water Resources and their Impacts: A Review

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Abstract—*Heavy metals in water are extremely essential to living organism but concentration beyond the limit recommended by various national and international organization may cause physiological disorders. Excess of these in water environment occurs, via a wide range of process and pathways, by natural and anthropogenic sources. Accumulation of these metals in living organism can be toxic and carcinogenic due to its non-biodegradable nature. For this purpose water, quality management and assessment in light of heavy metal is of prime importance. The overall water quality status and identification of source of origin of heavy metals are required for water quality management. Heavy metal pollution index (HPI) and Factor analysis (FA) are most convenient and effective approaches to assess the status of water quality and identifies the source of pollutants. This paper reviews the source, impact on human health and assessment technique of heavy metal contamination in aquatic environment.*

Keywords: *Heavy Metals; Environment; Heavy metal pollution index (HPI); Factor Analysis (FA).*

1. INTRODUCTION

The term 'heavy metals' refers to any metallic element that has a relatively high density mainly greater than 4 g/cm^3 [1-3]. Few metals in minute amount are necessary for metabolic activity in human system while others causes acute and chronic diseases [4].

Heavy metals enters into aquatic system by natural and anthropogenic sources. During the last two centuries, heavy metals released by anthropogenic influence have superimposed its contribution by natural source [5]. Water pollution because of these elements is the major environmental as well as socio economic problem [6]. Various water quality management strategies has been implemented to safeguard water from pollution.

Heavy metals reviewd in this paper include some significant metals of biological and environmental toxicity, such as iron (Fe) , lead (Pb), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), chromium (Cr), arsenic (As), nickel (Ni) and manganese (Mn). To understand the impact of heavy metal contamination of water, the manuscript will explore its sources, impact and assessment techniques.

2. SOURCES OF HEAVY METALS

Excess heavy metals in water environment occur via a wide range of process and pathways by natural and anthropogenic sources. The natural source includes wet and dry deposition of atmospheric salts, water-soil and water-rock interaction. Anthropogenic sources comprises rapid urbanization and industrialization.

2.1. Natural Source

Occurrence of heavy metal in water by natural sources depends on the local geology, hydrogeology and geochemical characteristics of the aquifer [7]. The basic source of elements polluting the water body is by weathering of sedimentary rock like limestone, dolomite, shale, sandstone. Interaction of water with igneous rock such as granite, gabbro, nepheline syenite, basalt, andesite, ultramafic also contributes some major elements. The specific minerals or ores that on dissolution increase the level of elements are magnetite, hematite, goethite, siderite (Fe); calcite, cuprite, malachite, azuite (Cu); chromite (Cr); kaolinite, montmorillonite, arsenic trioxide, orpiment, arsenopyrite (As); calamine, smithsonite (Zn); pyrolusite, rhodochriste (Mn) [8- 13]. As is also found concentrated in sulfide-bearing mineral deposits, especially those associated with gold mineralization; and hydrous iron oxides ores [14]. Few minor elements like Cd, Co, Mn occurs in earth crust along with other minerals [15]. Apart from this Ni, Pb and Hg get deposited into aquatic system from dry or wet fall out of atmospheric aerosols formed from wind-blown dust, volcanic emissions, forest fires and vegetation [16 – 19].

2.2. Anthropogenic Source

The rapid race of industrialization and urbanization decreases the carrying capacity of water sharply. The concentration level of Hg in water increases mostly due to agricultural activities, human activities such as tillage and logging, domestic sewage discharge, atmospheric deposition from solid waste incineration, coal and oil combustion, pyrometallurgical processes (Fe, Pb and Zn) and mining activities. Surface runoff from rain or snow brings Hg contaminated soil to adjacent water systems [20, 21]. Industrial processes which are responsible for polluting water with Hg includes chlor-alkali, batteries, fluorescent lamps, thermometers, and electronic switches production. Chemical industry has been among the largest intentional polluting source of mercury in the world [22].

The anthropogenic source of Ni is from the corroded metal pipes and containers [16]. Lead in aquatic environment comes from compounds like paints and petrol additives and precipitation of aerosols formed from high temperature industrial process such as coal combustion, smelting and cement production [19].

Cd enters into water system through industrial discharge and galvanized pipe breakdown [23]. Cadmium is also present in phosphate fertilizers act as one of the source of polluting agent in water body [15].

Cu normally occurs in drinking water from copper pipes, industrial waste, as well as from additives designed to control algal growth [24].

Fe and Mn in water comes from industrial effluent, acid-mine drainage, sewage and landfill leachate [25].

Anthropogenic source of Cr includes discharge of industrial wastewater from various industries such as metallurgical (steel, ferro- and nonferrous alloys), refractories (chrome and chrome-magnesite) and chemical (pigments, electroplating, tanning and other) [25].

Sources of As in aquatic ecosystem includes nonferrous mining, mineral extraction, combustion of fossil fuels and wastes, poultry and swine feed additives, pesticides [14, 27-28]. Other sources also include incineration of municipal and industrial wastes [29 – 30], wood preservatives and through the roasting of arsenious gold ores [7].

The load of Zn in water system is closed or ongoing ore-mining activities [13].

Most of the heavy metals in aquatic ecosystem is contributed to elevated level through acid mine drainage (AMD), one of the most serious environmental hazards from the mining industry. The AMD is generated by the oxidation of sulfide-bearing minerals exposed to weathering conditions resulting in low quality effluents characterized by acidic pH and a high level of dissolved metals (e.g., As, Cd, Cu, Zn) and anions (e.g., sulphates and carbonates) [31].

3. IMPACTS OF HEAVY METALS CONTAMINATION

Heavy metals enter into human body through drinking water obtained from a various sources like wells, rivers, lakes, reservoirs, ponds etc. The occurrence of metals in the drinking water beyond the recommended limit prescribed by various national and international organization (Table 1) can cause health hazard.

Table 1: Drinking Water Standards

Heavy Metals	**USEPA,2008 (µg/l)**	**WHO,2008 (µg/l)**	**EU,1998 (µg/l)**	**BIS** (ISO: 10500,2012) **(µg/l)**
Fe	300	NGL*	200	300
Pb	15	10	10	10
Zn	5000	NGL**	NM	5000
Cd	5	3	5	3
Cu	1300	2000	2000	50
Hg	2	6	1	1
Cr	100	50	50	50
As	10	10	10	10
Ni	100	70	20	20
Mn	50	400	50	100

NM- Not Mentioned; NGL* No Guideline, because it is not of health concern at concentrations normally observed in drinking water, but may affect the acceptability of water at concentration above 300 µg/L ; NGL** No Guideline, because it occurs in drinking-water at concentrations well below those at which toxic effects may occur; USEPA- United States Environment Protection Agency; WHO- World Health Organisation; EU- Europen Standards; BIS- Bureau of Indian Standards.

Ni and Hg are carcinogenic and cause damage to DNA (Deoxy ribo-nuclicacid).Ni also causes systemic toxicity, allergy, hair loss and anemia [32, 34].

Pb, one of common heavy metal in general beyond desirable limit is metabolic poison and enzyme inhibitor [34]. It can also damage nervous connections and cause blood and brain disorders. Other than this the biochemical effects of lead is its interference with haemo synthesis, which leads to haematological damage [24].

Fe and Mn at low concentration is needed for enzyme activity [32] but at high concentration, it accumulates in muscle, liver and affects brain and central nervous system [33].

Cr known as carcinogenic and toxicological agent can cause dermatitis and ulceration of the skin. Long-term exposure can cause kidney, liver damage, circulatory and nerve tissue damage [32]. As at higher concentration can cause lesions on skin, hyperpigmentation, respiratory complications, hormonal change, chronal renal failure [33].

Zn as needed in lower concentration for acting as catalyst in enzyme activity of living system but it accumulates in muscle and liver [33]. The chronic health effects of Zn include cancer, birth defects, organ damage, disorders of the nervous system and damage to the immune system [24, 32, 35].

Cd, classified as toxic trace element appears to accumulate with age, especially in the kidney and it is considered as an agent to cause cancer and cardiovascular diseases. Industrial contaminated drinking water causes bone and renal disease. With long-term exposure it can replace calcium in bones [36] and damage kidney [37]. Cd may interfere with the metallothionein's (a protein that binds to excess essential metals to render them unavailable) ability to regulate Zn and

Cu concentrations in the body which causes elevation in zinc in urine [32, 38].

Cu exposed for long term or high concentration can cause chronic diseases like nervous system disorder, liver and kidney failure. Elevated level of Cu in drinking water can also cause vomiting, abdominal pain, nausea, diarrhea and anemia [24, 32, 39, 40].

4. ASSESSMENT OF WATER QUALITY

Researchers and various organization in present time focus on assessment of water quality to reduce the impact of pollutant on human health and environment. The hydrological study timeline illustrate the development of numerous approaches to identify the source of origin and overall access the quality of water. Extensive literature survey evidences that statistical technique (Factor analysis) and heavy metal pollution index are most convenient and effective approaches for water quality assessment.

4.1. Heavy Metal Pollution Index

Heavy Metal Pollution Index (HPI) represents the overall quality of water. The following equation model (equation 1 and II) calculates the index as:

$$Q_i = \sum_{i=1}^{n} \frac{[Mi\ (-)\ Ii]}{Si-Ii} \times 100 \ \ldots\ldots\ldots\ldots (1)$$

Mi: Measured value for the ith parameter.

Ii: Ideal value or highest desirable value for ith parameter.

Si: Standard or permissible value allowed for ith parameter.

The (-) sign denotes numerical difference of the two values ignoring the algebraic sign [41- 43].

$$HPI = \frac{\sum_{i=1}^{N} W_i\, Q_i}{\sum_{i=1}^{n} W_i} \ \ldots\ldots\ldots\ldots\ldots (II)$$

Qi: Sub index calculated for the ith parameter,

Wi: Weight assigned to the ith parameter.

Weight of the samples are based according to the importance of the parameters that is assigned between zero to one. It can also be considered as inversely proportional to the standard value for each element [41 – 48]. Water quality based on heavy metal pollution index is categorized as: low heavy metal pollution (HPI <100), heavy metal pollution on the threshold risk (HPI = 100) and high heavy metal pollution (HPI > 100) [41].

4.2. Statistical Approach

Factor Analysis (FA) is a multivariate statistical technique, which reduces and classifies a large number of metals and in turn analyses the source of origin of these heavy metals in aquatic environment. The main steps involved in factor analysis are extraction of factors from a large data set and selection of rotational methods. The aim of extraction is to reduce a large number of metals into factors. The most common method to extract factors is principal component analysis (PCA) [49]. Principal component method involves generation of eigen values and eigen vectors (loading or weightings) from the square matrix (either covariance or correlational) formed from the data set [50]. Eigen vector with the highest eigen value is termed as principal component (PC) or factor. Statistically, PCs are the uncorrelated (orthogonal) metals obtained by multiplying original correlated heavy metals with eigen vectors (loading or weightings) [51 – 52]. The following equation shows PCs generated through PCA:

$$y_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots\ldots\ldots + a_{im}x_{mj}$$

Where y = score of heavy metal, a = loading/eigen vector, x= measured value of the heavy metal, i= number of heavy metal, j= sample number and m =total number of heavy metals.

The first principal component (PC1) accounts for the maximum possible proportion of the total variance in the data set and the second component (PC2) accounts for the maximum of the remaining variance and so on. Only few numbers of PCs with eigen value greater than 1 (known as Kaiser criteria) are retained in principal component analysis [53]. The number of principal components are less than or equal to the number of original variables (metals in the study) [54 – 55]. Rotational method is applied to easily interpret the source of origin of related metals [56]. Most of the literature has cited orthogonal varimax rotation for data analysis because of the fact that uncorrelated factors are more easily interpretable [57 – 59]. This approach is most widely accepted in the field of hydrology to identify the source of origin of the heavy metals. The result of FA easily identify the correlated metals, which has same source of origin in the study area. Loading plot generated in this process helps in visualization of the software-generated results. Researcher having the background knowledge of study area will easily interpret the natural or anthropogenic activities, which are responsible for heavy metal pollution in water.

5. CONCLUSION

The source of heavy metal in aquatic environment is natural and anthropogenic. Natural sources include weathering of mineral enriched rocks, precipitation of atmospheric salts generated from natural processes such as volcanic eruptions, forest fire, etc. The major anthropogenic source includes the discharge of wastewater, sludge from industrial activities. Agronomic and household activities also elevate the level of heavy metals in the adjoining water system. Combustion of fossil fuels, incineration of municipal as well as industrial waste, vehicular and industrial emissions generate aerosols, which fall out as dry and wet precipitation also contaminate the aquifers. The concentration of heavy metals in drinking water beyond the recommended limit prescribed by various national and international organization causes acute and choric diseases. These can be nonfatal such as such as muscle and physical weakness to an extent of fatal for example brain, nervous system disorder and even cancer. For the safeguard of human health and environment throughout investigation of water quality is required. The first step is to access the overall quality of water and then identify the source of pollutants to diminish the level of pollution. Heavy metal pollution index is well-documented method to check the status of water with respect to heavy metals. Factor analysis proved an effective method to identify the source of origin of heavy metal polluting the water body. Application of both approaches subsequently represent the actual status and understanding of water body and further helps in preparing a management plan to reduce the pollution level.

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