Analysis of Presence of Heavy Metals in the Effluent of Sugar Mill Near National Capital Region, India: A Case Study

Manmohan Verma, Md. Merajul Islam* and Deepa Sharma
School of Basic Sciences & Technology
IIMT University, Meerut, Uttar Pradesh-250001, India
*E-mail: merajchem29@gmail.com
*Corresponding author.

Abstract

Heavy metal exposure has increased dramatically as a result of industrial and agricultural activities. The most frequent heavy metals that cause human poisoning through bio-magnification are Mercury (Hg), Cadmium (Cd), Zinc (Zn), Lead (Pb), Copper (Cu), Chromium (Cr), Arsenic (As), and Nickel (Ni). The National Capital Region (NCR) is one of India's most fertile agricultural lands, with many sugar mills and industries present. The effluents of sugar mills are used for agricultural purposes and they must be free from these heavy metals. We analyzed sugar mill effluent near National Capital Region (NCR) as a case study using APHA 23rd Edn., 2017, 1325 B methodology and found that As, Cu, Pb, and Zn are present in significant amounts while Cd, Cr, and Ni are under the permissible limit. Exposure to these increased levels of heavy metals can cause several fatal diseases, such as neurological disorders, prostate cancer, skin cancer, lung cancer, respiratory diseases, urinary diseases, cardiovascular diseases, etc. Being agricultural land, treatment of effluent before disposal and/or use of phytoremediation, a bio-remediation method, to control the increased level of these heavy metals in water and soil is necessary.

Key words: Heavy metals, Sugar mill effluent, Water & Soil Pollution, Phytoremediation, Bio-magnification.

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Introduction

Despite covering 71% of the earth's surface, just 3% is freshwater suitable for human consumption [1]. Human activities and technological advances threaten the aquatic environment [2, 3]. In underdeveloped nations, 90% of polluted water is untreated [4]. Untreated industrial wastewater contains foaming agents, surfactants, acids, dissolved salts, heavy metals, colors, etc. [5–7]. Heavy metal poisoning of water sources (water and sediment) has reached a potentially destructive level in some places [8–10]. Bioaccumulation in tissues amplifies metals' tropospheric effects [11].

"Heavy metal" refers to any metal or metalloid having a density more than 5 g cm^{-3}. It contains As, Cd, Cr, Cu, Hg, Pb, Ni, and Zn. Several activities [5, 12, 16] can produce metal pollution, say studies. Water contains metal pollution ions [17]. According to various studies [18–21], mining activities and metal plating and smelters, metal processing, preservation industries, refineries, etc. create considerable amounts of copper, mercury, manganese, and tin. Table 1 shows the heavy metal concentrations in India's rivers [22]. Due to industrialization and urbanization, the availability of heavy metals in the environment has grown considerably in recent decades [23, 24]. Heavy metals originate from water, oil, gas, fertilizers, sewage sludge, metal mining and smelting, pesticide application, electroplating, and fossil fuel combustion. Heavy metals aren't degradable by biological or physical processes and persist in soil or water for a long period [24]. They can enter the food chain through crops and bio-magnify in the body, providing a major health concern [33, 34]

Table 1. Heavy metal and metalloid concentrations (μgL^{-1}) in Indian rivers and tap water [22].

Metal	Effluent from pharmaceutical Industry	River Ganga	River Yamuna	River Brahmputra	River Narmada	River Godavari	Guideline for drinking Water standard (WHO)	Industrial effluent standard	Permissible limits in drinking water, ICMR
As	N. R.	……	……	……	……	..	$10^{b,}$*	100*	50*
Cd	N.R.	0.001–3.936	0.002–9.166	0.002 – 1.314	0.002–1.201	0.009–1.489	3*	100*	10*
Cr	64.7 – 1720*	0.080–205.82	0.010-36.370	0.040 – 53.100	0.080–26.66	0.010–21.510	$50^{b, c,}$*	500^{g}*	――
Cu	72 – 2300*	……	……	……	……	……	2000*	3000*	$1500^{e,}$*
Hg	N.R.	――	――	――	――	――	$6^{d,}$*	$5^{e,}$*	$1^{d,}$*
Ni	N.R.	――	……	……	……	……	70*	N. R.	N. R.
Pb	N.R.	0.020–36.91	0.010–22.67	0.020 – 21.480	0.080–21.930	0.020–22.870	10*	100*	$50^{e,}$*
Fe		――	1 – 613*	8 – 9872*	2 – 1312*	8 – 670*	10*	2000*	1000*
Zn	130000*	……	……		……		N. R.	5000*	100*

*** : converted from mg to microgram, ―: not informed, ... (dotted line): within acceptable limits, N.R.: not registered, b: provisional value, c: total concentrations, d: Inorganic form, e: action element, g: Cr(VI).**

Wastewater irrigation also accumulates heavy metals including cadmium, lead, nickel, and zinc. Zn, Cu, Ni, Cd, and Pb are present in untreated wastewater-irrigated soil. Long-term wastewater irrigation boosts soil heavy metal levels [35]. Unregulated municipal solid waste disposal increases soil contamination. These wastes include nutrients and harmful metals. Overuse of fertilizers, pesticides, and fungicides also contributes to metal contamination [36]. Transportation may contaminate metals. Road maintenance and deicing create groundwater and surface contaminants. Corrosion, tire wear, and brake abrasion all contribute to heavy metal production [37].

Heavy metals can cause cancer, cellular toxicity, and brain damage in people when exposed to them at high concentrations [38, 39]. Growth and development inhibition, gill necrosis, and other negative effects have been linked to heavy metal exposure in aquatic species [40–44]. Due to the potentially hazardous nature of heavy metals, organizations responsible for environmental monitoring have imposed permissible limitations on the quantities of those metals that can be found in water that is intended for human consumption [45–49].

Heavy metal ions can be removed from aqueous systems by membrane separation, solvent extraction, ion exchange, coagulation/flocculation, chemical precipitation, and biological approaches [50]. Most individuals prioritize environmental consequences, cost, efficiency, practicability, reliability, feasibility, and operational issues [51]. Traditional approaches have lost favor because to their high cost and difficulties in removing low heavy metal ion concentrations, as demonstrated in Figure 1 [50].

Phytoremediation is effective, visually attractive, cost-effective, and ecologically friendly. Phytoremediation plants absorb poisons through their roots and move them aboveground [52, 53]. Using metal accumulator plants for phytoremediation dates back to prehistoric times [54]. Agro-remediation, green remediation, vegetative remediation, green technology, and botano-remediation[55–57].

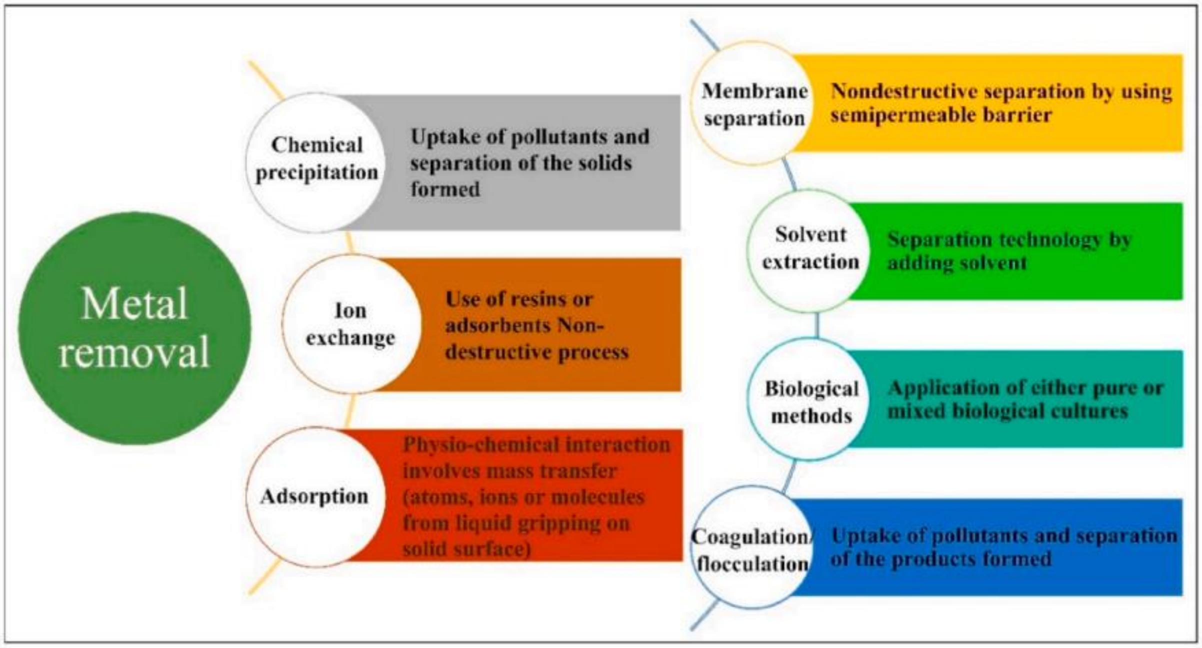

Figure 1: The current methods for removing heavy metals and their primary features [50].

Vegetative remediation uses plants, soil, micro-biota, and other agrochemical approaches to remove heavy metals [58, 59]. Both in-situ and ex-situ remediation are employed in phytoremediation. In-situ application reduces water and airborne pollutant multiplication, reducing environmental risk [60]. Phytoremediation may treat many contaminants on-site, reducing the need for a landfill. It inhibits soil erosion and leaching, slowing contamination [61]. Phytoremediation offers lower clean-up costs than previous methods [62]. Phytoremediation doesn't require specific equipment or expertise. This is effective and cost-efficient for large-scale area remediation [63].

Insecticides, chlorinated solvents, PAHs, PCBs, petroleum hydrocarbons, radionucleosides, surfactants, explosive components, and heavy metals are among toxins phytoremediation may remove [63, 64]. Several plant species collect heavy metals in leaves, stems, and roots without toxicity [65].

India's NCR is famed for its farmland and water. Due to urbanization and proximity to New Delhi, India's capital, several industries, including sugar mills, chemical synthesis, textiles, cosmetics, and sports goods, have emerged in the region. The region's sugar industry contributes to its economic growth, but its effluents pollute marine and terrestrial habitats. Sugar mills are a major source of wastewater pollution. The wastewater modifies the physicochemical and flora and fauna of receiving bodies. Spilled sugar industry effluent causes a serious health danger for rural and semi-urban NCR people who rely on stream and river water for agricultural and home usage. Untreated sugar plant wastewater generates a foul odor [66].

In the present paper, the type and quantity of heavy metals present in the effluent of sugar mill present in NCR, India as a case study is analyzed. Its impact on agricultural land and water contamination is also analyzed. The suitability of particularly phytoremediation process depending upon environmental conditions in and around NCR has also been recommended.

Materials and Methods

Study Area

There are many sugar industries situated near NCR, India. The climate of in and around NCR, India is categorized as warm and temperature. In this area, rainfall is in the summer while in winter it is very little. Summer is observed from March to October while winter is from November to February. Its latitude position is around 29° 5' 49.0416'' N while longitude is 77° 55' 13.7784'' E. The average annual temperature is 24.1 °C and rainfall is around 886 mm in NCR.

Collection of Effluent

The sugar mill effluent was collected from Sugar Mill which is situated near NCR. In a properly washed and cleaned plastic container, the required volume of effluent (2L) was collected from the discharge point of the Sugar Mill. Then the collected effluent sample was stored at room temperature and required testing of heavy metals present was conducted after sample correction from the source.

Methodology Used

The methodology adopted to detect the heavy metals in sugar wastewater sample is given elsewhere as per the APHA 23rd Edn.2017, 3125 B for standard methods for the examination of water and wastewater [67]. All the concern steps were adopted as per the APHA 23rd Edn.2017, 3125 B recommendations.

Results and Discussion

Table 2 shows the amount (in mg/L) of heavy metals such as As, Cd, Cr, Cu, Pb, Hg, Ni and Zn present in the Sugar Mill effluent at NCR. Its respective permissible limits and test methodology adopted are also mentioned. From Table 2, it is clear that the value of Arsenic (As) present in the effluent is 0.022 mg/L as per the APHA 23rdEdn. 2017, 1325 B methodology. Increased As (arsenic) (concentrations originating mostly from natural sources and from anthropogenic sources, such as the use of As in industry, mining and metal processing, and the use of As containing herbicides and fertilizers [68]. It was determined that long-term exposure to low As concentrations in drinking water did not eliminate the risk of skin, lung, and prostate cancer [68]. Furthermore, there are number of non-cancer consequences associated with low-dose of As intake, including cardiovascular disease, diabetes, and anemia as well as reproductive developmental, immunological, and neurological issues [68].

The concentrations of cadmium (Cd) and chromium (Cr) in the Sugar Mill effluent near NCR, India are 0.005 mg/L and 0.015 mg/L, respectively (Table 2.). These are one of the most dangerous pollutants because of their high-potential toxic effects, and due to a high primary consumption of water which causing negative health impacts in consumers such as renal illness and cancer. Through bioaccumulation in the human body, Cr can induce a range of illnesses. This includes anything from skin, kidney, neurological, and gastrointestinal disorders to the development of tumours in the lungs, throat, bladder, kidneys, testicles, bone, and thyroid [69]. The presence of Cd in contaminated water can disrupt the body's required functions, resulting in short- or long-term problems [70]. In the Sugar Mill effluent near NCR, India the Cd and Cr concentrations are within the allowed limits of the Indian standard (IS) (Table 2.) for effluent release. A similar result was reported earlier also [66].

Table 2. Heavy metals concentration in Sugar Mill effluent near NCR, India.

S. NO.	Test Parameters	Values (mg/L)	Test Method	Permissible Limits (IS)**
1	ARSENIC (As)	0.022	APHA 23rd Edn.2017, 3125 B	0.01*
2	CADMIUM (Cd)	0.005	APHA 23rd Edn.2017, 3125 B	0.01
3	CHROMIUM (Cr)	0.015	APHA 23rd Edn.2017, 3125 B	0.05
4	COPPER (Cu)	0.09	APHA 23rd Edn.2017, 3125 B	0.05
5	LEAD (Pb)	0.23	APHA 23rd Edn.2017, 3125 B	0.1
6	MERCURY (Hg)	0.005	APHA 23rd Edn.2017, 3125 B	0.01
7	NICKEL (Ni)	0.034	APHA 23rd Edn.2017, 3125 B	0.05
8	ZINC (Zn)	6.1	APHA 23rd Edn.2017, 3125 B	5

*Ref. [68]

** Ref. [71]

The copper (Cu) concentration in the Sugar Mill effluent near NCR, India is 0.09 mg/L (Table 2.) while the maximum permissible limit of Cu concentrations in sugar industry wastewater is 0.10 mg/L. It exceeded Indian norms'of maximum tolerance limit. Anthropogenic activities, agriculture, and industrial wastes poured into the neighboring agricultural regions could all be to blame. The presence of greater Cu concentrations in the water can also be due to natural weathering of soil and industrial discharges. [71-73], have been published similar findings.

The concentration of lead (Pb) in the Sugar Mill effluent near NCR, India is effluent is 0.23 mg/L (Table 2.). It is higher than the recommended amount (IS 1992) (Table 2). Despite the fact that Pb occurs naturally in the environment, anthropogenic factors such as the discharge of various industrial effluents and the discharge of public sewage play a significant influence in the increased Pb concentrations in the sugar industry surrounding areas. Venugopal et al. [74] reported similar findings. Lead is a hazardous environmental pollutant that is highly poisonous to a variety of body organs. Pb can be absorbed through the skin, although it is primarily absorbed through the respiratory and digestive systems. Due to immune modulation, oxidative, and inflammatory pathways, Pb exposure can cause neurological, respiratory, urinary, and cardiovascular diseases. It has the potential to disrupt the oxidant–antioxidant system's balance and trigger inflammatory reactions in numerous organs. Pb poisoning can affect the body's physiological systems and is linked to a variety of disorders [75].

The average nickel (Ni) concentration in the effluent is 0.034 mg/L (Table 2.). It is within the acceptable range. Ni is a nutritionally important trace metal for a variety of animal species, microbes, and plants. Signs of deficiency or toxicity can appear when too little or too much Ni is taken. Earlier research had come up with similar results [76].

The average mercury (Hg) concentration is 0.005 mg/L (Table 2). The in-organic, organic or elemental Hg is very dangerous to health. Its concentration in the effluent is under permissible limit. So, no harmful effects are expected. The zinc (Zn) concentration is 6.1 mg/L (Table 2), which is higher than the permissible limit of 5 mg/L. It is an important micronutrient with a long biological half-life that impacts various metabolic processes in plants. Zn toxicity reduces plant growth and development, metabolism, and induces oxidative damage in a variety of plant species, including tobacco [77].

Conclusions

It is concluded from the present case study that the effluent of Sugar Mill situated near NCR, India found to have As, Cu, Pb and Zn in significant amount as compared to the standard permissible limit (IS). Whereas other heavy metals included in the study for the analysis such as Cd, Cr and Ni found to be in under permissible limits. Hence, the long term disposal of effluents in the local area may affect the land and water resources in the surrounding area. Being the green belt; the agriculture production is also affected to a greater extent. In view, it is recommended to treat the effluents before the disposal and plant the vegetation that is using phytoremediation in the surrounding areas which are effective in absorbing these heavy metals.

Statements and Declaration

Authors declare that all the research carried out at R & D section of IIMT University, Meerut, Uttar Pradesh, India.

Conflict of Interest

Authors declare no conflict of interest.

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