Trends and Health Risks of Heavy metal present in Sewage Sludge: A Situational Analysis in Indian Context

Vedpriya Arya [1]

[1]Affiliation not available

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Acharya Balkrishna[1,2], Sourav Ghosh[1], Srimoyee Banerjee[1], Sumit kumar Singh[1], Vedpriya Arya[1, 2]*

[1]Patanjali Herbal Research Division, Patanjali Research Institute, Haridwar, Uttarakhand-249404

[2]Department of Applied and Allied Sciences, University of Patanjali, Haridwar, Uttarakhand.

***Coressponding Author**

Patanjali Herbal Research Division, Patanjali Research Institute, Haridwar, Uttarakhand-249404; vedpriya.arya@prft.in

Abstract

Soils altered with sewage sludge typically have higher amounts of a variety of heavy metals, making them of importance in terms of their possible influence on human health. In this review, we attempt to explore how sewage sludge is created, as well as its features in the presence of heavy metals. Sewage sludge is commonly utilized in agricultural airs or landfills. Soil, plants, and humans are all linked in some way in both circumstances. Heavy metals including Zn, Pb, Fe, and Cu are prevalent in the environment and play an important role in the sustainability and balance of ecosystem processes. However, because of their bioaccumulation, non-degradability, and abundance, these metals pollute the food chain and constitute a source of toxicity to humans and the overall ecological function, which is a major problem in the study of environmental science and geochemistry. The current study intends to consolidate all of the previously mentioned features of heavy metal distribution in nature and their implications. This study would be designed to persuade policymakers to intervene with a viable and rapid solution to the nuisance.

Keywords: Heavy metals, Sewage Sludge, Industry, Agriculture, Human health

Introduction

"Too many cars, too many factories, too much detergent, too many pesticides, multiplying contrails, inadequate sewage treatment plants, too little water, too much carbon dioxide - all can be traced easily to too many people." The famous quote by Paul R. Ehrlich (Ehrlich 1969) could highlight the contextual viewpoint of the population inflation related to the management of sewage. Sludge generation and its management are the prime headaches for both developed and developing countries. To move forward with this discussion, we need to first realize what is Sewage Sludge (SS)? Sewage is described as a residual, semi-solid material created as a byproduct of industrial or municipal wastewater treatment (Kumar and Chopra, 2016a). Precisely, sewage sludge is created as a byproduct of the various treatment stages of residential home wastewater, and it may also comprise industrial and commercial effluents. (Williams, 2005).

Sewage sludge can be utilized to generate energy (through anaerobic digestion or thermal treatment), processed and applied to land as a fertilizer and soil conditioner, or even used to extract valuable chemicals (phosphorous recovery). A considerable number of wastewater treatment plants (WWTPs) compost dewatered sewage sludge with green wastes or other bulking agents under aerobic conditions, or dry it in heat drying facilities to 95 percent dry mass for use as fertilizer or fuel. Most industrialized countries place a premium on effective sewage sludge treatment to enhance the quality and safety of land usage. Biosolids are defined by the United States Environmental Protection Agency (US-EPA) as treated sewage sludge that fulfills the appropriate levels of pollutants or pathogens and is utilized as fertilizer for landscape application (USEPA, 2009). Wastewater sludge is a complex heterogeneous mixture of microorganisms, undigested organics such as cellulose, plant residues, oils, or fecal material, inorganic material, sand is a resource of organic matter, nitrogen, phosphorous, micronutrients, and even heavy metals, bio-fuel, hydrogen, syngas, bio-oil, bio-diesel, bio-plastics, bio-pesticides, proteins and enzymes (Tyagi and Lo, 2013). The exploration of the best recycling solutions for such precious chemicals is now one of the primary trends in the creation of sustainable human societies (LeBlanc et al., 2009).

However, when it comes to waste that is reintroduced into natural systems, cautious measures must be taken, especially when it comes to the limit values (quality criteria) for probable toxins and pollutants that are hazardous to human health and the environment.

The Sewage Sludge Regulation (86/278/EEC) (SSD), Europe's oldest mandatory directive, was established to stimulate the use of sewage sludge in agriculture and to control its usage to minimize detrimental effects on the environment by restricting the probable transmission of heavy metals and infections. In general, the Directive had a favorable impact on enhancing source control methods to ensure high sludge quality, albeit it is today regarded out-of-date and has been flagged by the Commission as a candidate for change for roughly ten years (Environment, 2014). According to a European Commission report released in 2010, only 39% of sewage sludge in the EU gets recycled into agriculture owing to increased leaching of pollutants into water and soil, smells, and greenhouse gas emissions (CH_4 and CO_2). Sludge usage on land varies greatly across the EU, ranging from none (Nederland, Switzerland) to more than 50% (Norway, Great Britain, France). In November 2013, the German federal government reached an agreement that said, "We would oppose the direct use of sewage sludge as a fertilizer on land and support the recycling of phosphorus and other nutrients" (Bergs, 2015). In other high-income nations, such as the United States, Canada, Australia, and New Zealand, treated biosolids are commonly applied to soils; however, incineration has been proposed as a possible option for ultimate sewage sludge disposal. Nonetheless, land application of treated sewage sludge is becoming a feasible alternative to landfilling in underdeveloped countries.

From the above facts, the obvious question would come to mind where the sludge is coming from? and what are its general characteristics? In the next section, we would focus our discussion on the same.

Source and Characteristics of Sewage Sludge (SS)

Primary, secondary, and chemical treatment procedures all produce sewage sludge. Primary sludge is the settleable material that accumulates at the bottom of the clarifier. Because it has not been decomposed, primary sludge is also known as raw sludge. Raw primary sludge from a normal household facility is unpleasant and has a high amount of water, both of which make handling problematic. The secondary treatment is intended to convert colloidal materials into settleable solids that may be removed. These solids are removed in the secondary clarifier once they have settled. Domestic sewage, industrial sewage, and storm sewage are the three forms of sewage. Domestic sewage transports wastewater from homes and flats; it is also known as sanitary sewage. Water from manufacturing or chemical operations is utilized in industrial sewage. Storm sewage, often known as stormwater, is drainage from precipitation gathered in a network of pipelines or open channels. Domestic sewage contains slightly more than 99.9% water by weight. The remainder, less than 0.1 percent, is made up of a wide range of dissolved and suspended contaminants. Depending on the nature of the industrial process, industrial effluent often comprises particular and easily recognizable chemical components. Storm sewage contains organic compounds, suspended and dissolved particles, and other things that it picks up as it passes through the ground. The features of sewage sludge or biosolids vary and comprise organic and inorganic compounds, harmful metals, and microorganisms. Because of its broad use in soil amendment, energy generation, nutrient delivery, and other applications, it is frequently regarded as a resource. The sewage sludge, which contains around 1% wastewater when it enters the sewage treatment plant for treatment, is digested anaerobically, resulting in the removal of the wastewater from the sludge. After mechanical drying, sludge has almost 80% moisture and 20% dry matter at the production vent. (Kumar et al., 2017). The details of the Physicochemical and biological constituents of sludge have been discussed below (Table 1).

Table 1: Physiochemical and Biological properties of sewage sludge

Properties	**Observed values in Raw sewage**
pH	5.0-8.0
Total solids	0.83-12.0
Volatile solids (% of TS)	30.0-88.0
Moisture	Not more than 95%
Proteins (% of TS)	15.0-41.0
Phosphorus (% of TS)	0.8-11.0
Potassium (% of TS)	0.4-3.0
Sillica (% of TS)	10.0-20.0
Organic acids (mg L^1 HAc)	200.0–2000.0
Total coliforms (CFU/g dry wt)	10^4-10^8
Fecal coliforms (CFU/g dry wt)	10^7-10^9
Fecal Streptococci (CFU/g dry wt)	10^3 -10^5
Salmonella sp. (CFU/g dry wt)	10^{2-} 10^3
Enteric virus (PFU/g dry wt)	10^2-10^4

Source: Pedersen, 1981; Rulkens, 2003. Khalil, 2011; Lopez et al., 2020; Prado et al., 2014

Sources and Characteristics of Heavy metals in SS

Heavy metals are metallic elements with a comparatively high density in comparison to water. Heavy metals such as chromium (Cr), cadmium (Cd), mercury (Hg), lead (Pb), nickel (Ni), and thallium (Tl) can be harmful in mixed or elemental form. Because heavy metal contamination is colorless and odorless, it is difficult to detect. It does not directly harm the environment in a short time. However, when it surpasses the environmental tolerance or when environmental conditions change, heavy metals in the soil may be activated, causing major ecological harm (Emenike et al., 2018).

With the rise of the global economy in recent years, both the type and concentration of heavy metals in soil produced by human activities have continuously grown, resulting in environmental degradation. (Zojaji et al., 2014). Heavy metals are extremely dangerous to both the environment and organisms. To understand the current situation and the impact of heavy metal contamination in the world, in the present study we would first understand the characteristics of heavy metals and then analyze the sources of heavy metals. If the air and water are contaminated, the pollution problem can most likely be remedied by dilution and self-purification when the pollution sources are turned off. However, using dilution or self-purification procedures to reduce heavy metal pollution and improve soils is challenging. Some heavy metal-contaminated soils are estimated to take one or two hundred years to repair (Emenike et al., 2018). Previously, soil contamination was mostly caused by a single heavy metal. However, in recent years, a greater number of instances have been discovered to be caused by a range of heavy metals (Sarkar et al., 2021). The heavy metal burden is significant in every sector in India. According to two ICMR investigations conducted in 1993 and 1996, canned food goods contain metals such as lead, aluminium, tin, and zinc. After a year of storage, the tin content of canned food goods maintained at room temperature increased from 27 mg/kg to 542 mg/kg - from 7 to 15 times higher than when these products were canned. According to a study, vegetables grown in Dhapa-Bamtala, Calcutta, contain hazardous metals. This region produces one-fourth of the veggies sold in the city's markets. Every kilogramme of Dhapa-grown cauliflower has 44.1mg of lead and 3.3mg of cadmium (Patra et al., 2001). These heavy metals are mostly found in industrial sewage. Heavy metals are vital to Indian manufacturing. Soon after independence, India entered the second part of the twentieth century with a surge in the creation of heavy industries, which required a huge number of heavy metals. Mining began on a vast scale, and mine wastes, sewers, and spewing chimneys poured large amounts of metals into river channels and the environment. Heavy metals are required in the production process as catalysts or as additives. The Indian subcontinent is rich in minerals, and practically every state has its own coal or metal reserves with substantial mining. India is the world's fifth largest coal producer. Mining releases harmful heavy metals such as chromium, cadmium, lead, and mercury. Some of the "hot sites" of metal contamination are Raniganj in West Bengal, Jharia in Bihar, and Singrauli in Madhya Pradesh. Lead, zinc, nickel, chromium, copper, iron, manganese, and tin are among the various metals extracted in India. Cadmium, a strong carcinogen, accounts for approximately 20% of the cadmium released from zinc mining and smelting processes (Anuj & Banerjee 2012). Thermal power stations are another cause of heavy metal contamination. India currently has 80 of these. A 2,000 megawatt (mw) thermal power plant consumes eight million tonnes of coal each year and produces 1,600 tonnes of lead, 800 tonnes of zinc, 80 tonnes of cadmium, and 40 tonnes of uranium (Anbazhagan, 2018). Chlorine is used for a variety of reasons in the Indian chemical sector, which primarily produces fertilizers and pesticides. Gujarat and Maharashtra feature some of the most densely packed chemical industry clusters in the country (Mahanta, & Bhattacharyya 2011). Tanneries also emit significant amounts of chromium into the environment. In India, there are around 2,500 tanneries. According to, total wastewater discharge ranged from 80,000 to 1,00,000 cubic metres per day (Dotaniya 2017). 70% of the entire amount of lead generated in the world is utilized in the production of lead batteries. In storage batteries, cadmium and nickel are also employed. Currently, a significant amount of discarded batteries are purchased in India by tiny operators who are ill-equipped to handle these pollutants (Ayyanar, & Thatikonda, 2020). The Indian information and technology and computer hardware industries are growing at a rate of 40% per year. Even after subtracting the heavy metal composition of batteries, many other heavy metals, such as lead, tin, copper, cadmium, and nickel, are employed in the IT industry (Chabukdhara, & Nema, 2013). All of this lead will eventually end up in the environment. It is not simply the environment that suffers. Every day, its workers are exposed to hundreds of toxins, putting them prone to diseases caused by long-term toxin exposure. Several studies have found that the rate of miscarriage among female laborer working with toxic materials in the United States, for example, is much higher than normal rates (Rim, 2017).

Apart from the above sources, heavy metals occur naturally in the soil environment as a result of pedogenetic processes of weathering parent materials at trace (1000mg/kg) and hazardous levels. The potential paths or sources of heavy metals are depicted below (Figure 1).

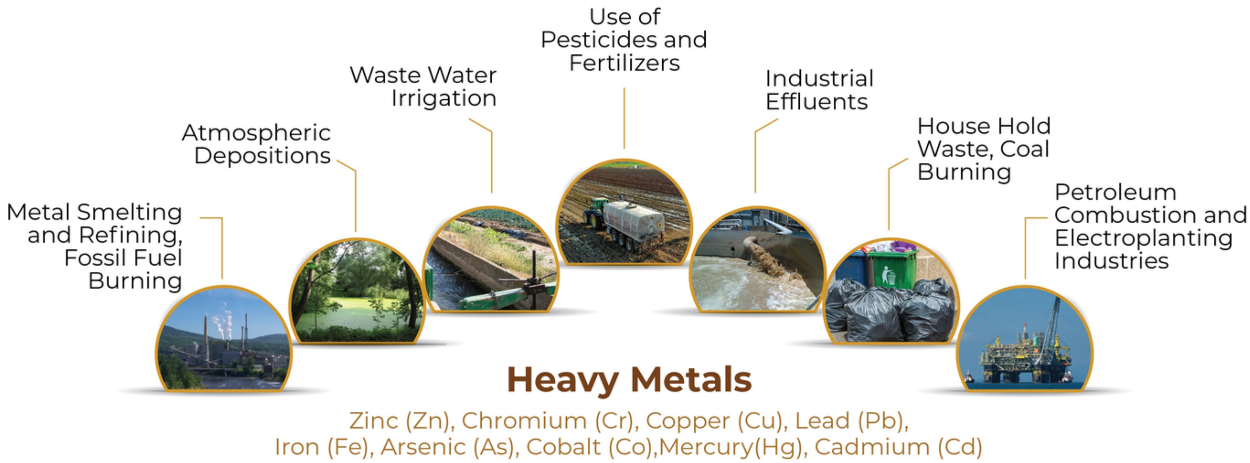

Figure 1: Possible sources of heavy metal in sewage sludge

Use of SS in Agriculture practices and its associated threats

Impact of SS on soil fertility

Because sewage sludge has a high organic matter, content, its addition to soil has a considerable influence on soil's physical qualities and has a beneficial soil conditioning effect. Because of the stability of organic components in biosolids, the application of sewage sludge enhances soil's physical qualities such as aggregate formation and stability, bulk density, porosity, and water holding capacity (Angin and Yaganoglu, 2011, Usman et al., 2012). Wortmann (2005) found that increasing SSA dosages for growing wheat reduced bulk density while improving overall porosity. Several additional investigations have found that when sludge application rates increase, so do the bulk density and penetration resistance. (Garcia-Orenes et al., 2005; Cogger, 2005). The increase in aggregate stability and total porosity is thought to be a contributing factor to the decrease in bulk density. (Lindsay and Logan, 1998). The favorable effect of sludge application on soil physical qualities is also dependent on soil type, with Improved soil physical qualities as a consequence of SSA resulting in a higher soil filtration rate, decreased surface runoff, and therefore reduced water erosion. (Chambers et al., 2003). Epstein (1975) researched to investigate the effect of 0.5 percent SS on soil water retention, hydraulic conductivity, and aggregate stability and found that both raw and digested sludge enhanced overall soil water retention capacity, with raw sludge supplemented soil having the largest gain. Sludge addition resulted in a considerable increase in soil hydraulic conductivity after 27 days of incubation. But the pH has severy decrease in the same case (Epstein, 1975).

Because of its high organic matter, content, sewage sludge, soil application aids in the creation of homes compounds and a variety of other organic acids, which play an important role in the conditioning of soil qualities. Tsadilas et al. (1995) discovered an increase in soil pH when municipal sewage sludge was applied to soils. Epstein et al. (1976), on the other hand, contradict the above result. Changes in soil pH have been linked to sludge calcium carbonate concentration and acid generation during the sludge breakdown (Sommers, 1977). In a study on calcareous soil, Jamil et al. (2006) found that increasing dosages of sewage sludge (up to 100 t ha–1) lowered soil pH from 8.2 to 8.0. In principle, applying SS to agricultural soils raises heavy metal concentrations in both soils and plants (Saha et al., 2015). A composted sewage sludge (total carbon 28.6 percent, organic carbon 12.8 percent, N 1.5 percent, pH 6.65, EC 7.1 ds/m, P 0.12 percent) was amended into the top 100 mm of each column at rates of 357, 223 and 22 t/ha dry wt (Gasco et al., 2005). The soil was irrigated with 5000 ml of water to each column, and 6-pore volume water was leached from each column. Finally, soil samples were taken and examined for Cd, Cr, Cu, Pb, Ni, and Zn at depths of 0–100 mm, 100–300 mm, 300–500 mm, and 500–840 mm. Analyzing the leachates revealed the metal mass balance. The average proportion of metals leached was determined to be in the following order: Cd (0.04%) > Cu (0.02%) = Ni (0.02%) = Zn (0.02%) > Pb (0.01%) = Cr (0.01 percent). The mean metal concentrations and maximum metal concentrations in leachates were found to be lower than the limit values for irrigation water established by Branson et al. (1975) for most metals, with the exception of Pb and Ni, which were higher than the drinking water limits (WHO, 1996). Many studies have found that applying sewage sludge increases microbial biomass-C, basal respiration, N-mineralization, and some soil enzyme activities, all of which promote nutrient recycling for crops (Göcmez and Okur, 2010; Angin and Yaganoglu, 2011). The increased organic matter content of the sewage sludge is linked to the favorable effect of the treatments on microbial biomass and enzyme activity of the soils. Although sludge application reduced the diversity of the microbial population, the overall size of the soil microbial biomass and its nutrient mineralization potential, as well as the potential activities of soil enzymes were either unchanged or increased, according to Banerjee et al. (2021). Studies could prove the increment of yeast, pathogenic bacteria, fungus and viral population after application of sewage sludge in landfilling (Singh, & Agrawal,2008, Ramulu, 2002). The similar finding shows metal concentrations that are even below the European Community's maximum permitted concentration limits for metals in sludge-treated soils have harmed microbial activity, populations of cyanobacteria, Rhizobium leguminosarum bv. trifolii, mycorrhizae, and total microbial biomass. For example, with soil metal concentrations of (mg/kg): 127 Zn, 37 Cu, 21 Ni, 3.4 Cd, 52 Cr, and 71 Pb, N2fixation was hindered by free-living heterotrophic bacteria. N2 fixation by free-living cyanobacteria was inhibited by 50% at metal concentrations of (mg/kg): 114 Zn, 33 Cu, 17 Ni, 2.9 Cd, 80 Cr, and 40 Pb. At soil metal concentrations of (mg/kg): 130-200 Zn, 2748 Cu, 11-I5 Ni, 0.8 to 1.0 Cd and 130-200 Zn, Rhizobium leguminosarum by. trifolii populations reduced by several orders of magnitude (McGrath et al. 1995). Sludge application to soil resulted in reduction of diversity of the microbes (Banerjee et al., 1997). The accumulation of harmful organisms in sewage sludge is the most serious impediment to its use in agriculture. Pathogenic microorganisms like viruses and protozoa can be found in sewage sludge and have the ability to cause diseases in humans, animals and plants (Usman et al., 2012).

Impact of SS on the plant

The bulk of a study conducted in India and elsewhere revealed that sewage sludge land application increased crop yield; nevertheless, toxic metals such as Cadmium, Ni, Pb, and Zn may accumulate in plant tissues and pollute the food chain. (Singh and Agrawal, 2010a, 2010b). Crops grown in soil treated with sewage sludge produce yields that are often equal to or higher than those produced in soil treated with recommended fertilizer applications (Epstein, 2003) unless the sludge has a high C to N ratio, excess heavy metals, high soluble salts, or is applied at extremely high rates (Warman and Termeer, 2005; Angin et al., 2012). Although the SS over 4.5 kg m^{-2} boosted rice output, it also raised the danger of food chain contamination since Ni and Cd concentrations in rice grains were found to be beyond the Indian acceptable limits of human consumption above 4.5 kg m^{-2} SS and Pb concentrations above 6.0 kg m^{-2} SS. (Singh and Agrawal, 2010a). However, in the case of mungbean, Pb and Ni concentrations in the grains were greater than the Indian permitted limits at and above 9.0 kg m^2 sludge application rates, while Cd concentrations were higher than the Indian permissible limits at and above 12.0 kg m^2 sludge application rates. (Singh and Agrawal, 2010b). The increased availability of various important nutrients to the plants may be one of the causes of the improvement in yield and productivity of various crops as a result of sludge application. Because sludge is a key source of nitrogen, phosphate, micronutrients, and Organic Content, its application improved soil, Organic content and enhanced the availability of plant critical nutrients in the soil, notably nitrogen, increasing plant biomass output. This increase was sometimes observed to be greater than those produced on prescribed NPK treated soils. However, a significant rise in heavy metal concentrations in the edible section of the plant was discovered, which should be considered before proposing sludge application. As a result, before adding sewage sludge to the soil, the dose should be calibrated based on heavy metal and other pollutant concentrations for a certain crop. The use of untreated sewage water in agricultural soils can cause metals to build up to harmful levels in the topsoil and, as a result, in the crops grown on it. Saha et al. (2015) examined several crops growing on long-term sewage-irrigated sites in Kolkata, India, for heavy metal accumulations and found that Colocasia and Amaranthus acquire the most metal-based on total metal uptake. The comparison of mean heavy metal concentrations (Zn, Cu, Pb, Cd, and Ni) in different crops with the permissible limit of the Prevention of Food Adulteration (PFA) Act 1954 SEPA (2005) revealed that heavy metal concentrations such as Pb, Cd, and Ni were above the permissible limit in all of the examined crops generally grown in these areas (Table 2). Previous research has found elevated amounts of heavy metals in edible food crops cultivated in sewage-irrigated soils (Kharche et al., 2011). In continuation, a comparative study has been also documented to showcase the existed reports on heavy metals found from sewage sludge in different crops in different countries (Table 2)

Table 2: Metal accumulation in different crops upon long term treatment of sewage sludge

Plants
Brassica sp., Chenopodium sp., leafy and root vegetables, grains
Grain, maize (Zea mays), green cabbage, Brassica juncea L, radish (Raphanus sativus L), turnip, Brassica napus, spinach, c
Brassica sp., food grains, and leafy vegetables
Spinach
Amaranthus
Sesame, Chilli, Okra, Jute, Brinjal, Poi, Amaranthus, Colocasia Cowpea, Cauliflower

According to the data shown above, heavy metal pollution is more prevalent in Asian countries. Rapid population increase and industrialization have resulted in land-use changes across the Asian subcontinent, necessitating persistent efforts to improve agricultural productivity in restricted geographical regions to provide appropriate quantities of food. Unfortunately, to achieve that goal, wastewater, treated effluent, and sludge loaded with heavy metals have frequently been utilized as low-cost irrigation supplies in portions of Asia and Africa, causing food quality and hence health to suffer. The buildup of dangerous heavy metals in plants may easily be transmitted to the human system, resulting in heavy metal bioaccumulation in human tissues. The outcomes of such might have serious ramifications in the future.

Impact of SS on the Human system

According to existing studies, heavy metals in urban soils can enter the human body through skin absorption and dust inhalation, among other routes, and so directly affect, particularly children's health. The toxicity levels of several chosen metals in humans are as follows: Co Al, Cr Pb, Ni Zn, Cu Cd Hg (Mansourri & Madani 2016). The toxicity of heavy metals in humans is determined by their dose, rate of emission, and duration of exposure. Hg, Cd, and Pb are three heavy metals that have attracted more attention in recent decades (Valavanidis, & Vlachogianni, 2010). In humans, the negative health consequences of Hg and mercuric compounds include potential carcinogens, brain, lung, and kidney damage, fetal harm, high blood pressure or heart rate, vomiting and diarrhea, skin rashes, and eye irritation (Martin, & Griswold, 2009). The US EPA has set a regulatory limit of 2 parts per billion (ppb) for Hg in drinking water (Martin, & Griswold, 2009).

Chronic Cadmium toxicity in children includes lung, kidney, skeletal, and cardiovascular system damage, as well as the development of malignancies of the lungs, kidneys, prostate, and stomach (US-EPA 2010; WHO 2011). People are exposed to Cadmium via consuming contaminated food, smoking cigarettes, and working in cadmium-laden environments and primary metal industries (Paschal 2000).

Lead exposure can occur through the inhalation of contaminated dust particles and aerosols, as well as through the consumption of contaminated food and drink. Lead poisoning affects the kidneys, liver, heart, brain, bones, and neurological system in humans. Headache, dullness, memory loss, and irritability are some of the initial signs of lead poisoning (Flora et al., 2006).

Hexavalent Chromium compounds, which include Ca, Zn, Sr, and Pb chromates, are extremely soluble in water, poisonous, and carcinogenic. Furthermore, Chromium compounds have been linked to delaying the healing of ulcers. Chromate chemicals have also been discovered to be capable of destroying the DNA in cells (Matsumoto, 2006).

Thallium is a soft, tasteless, odorless whitish-blue metal that, when exposed to oxygen, oxidizes to thallium oxide. Thallium can be found in electronics, optical glasses, semi-conductors, and mercury lamps, among other places. Thallium enters the body by eating, inhalation, and cutaneous contact. Thallium is very poisonous, with a fatal dosage ranging from 6 to 40 mg/kg. Thallium poisoning causes anorexia, vomiting, gastrointestinal bleeding, abdominal discomfort, polyneuropathy, alopecia, renal failure, skin erythema, seizures, mood disturbances, autonomic dysfunction, cardiotoxicity, and coma, among other symptoms (WHO 2011).

Humans are exposed to Ni through food, air, and water. Previous research has shown that ingestion of nickel-contaminated dust was the primary exposure pathway for local populations, as opposed to inhalation and cutaneous exposure (Sobhanardakani 2019). Other heavy metals, such as Arsenic (As), have been linked to dermatitis, bronchitis, and poisoning. A high Zn content might induce skin rashes and damage to nerve membranes. Cu may cause intestinal discomfort as well as liver and renal damage (Singh et al., 2011). The permissible limits of the heavy metal in the human body & drinking water have been documented below (Table 3)

Table 3: Permissible limit of the heavy metals in the Human body and Drinking water according to the different regulatory bodies (Source Singh et al., 2011; Paul 2017)

Heavy metals	Drinking water (mg/L)	Drinking water (mg/L)	Drinking water (mg/L)	Drinking water (mg/L)
	WHO	CPCB	ICMR	BIS 10500- 2012
As	0.05	NR	0.05	0.01
Cd	0.005	NR	0.01	0.003
Pb	0.05	NR	0.05	0.01
Ni	Data Not available	Data Not available	Data Not available	0.02
Hg	0.001	NR	0.001	0.001
Zn	5.0	15.0	0.1	5
Cr	0.1	NR	-	0.05
Cu	1.0	1.5	1.5	0.05

WHO: World Health Organization; CPCB: Central Pollution Control Board, India; ICMR: Indian Council of Medical Research, India; BIS: Bureau of Indian Standard

Impact of SS on river bodies

The environmental impact of raw sewage disposal in river water bodies is vast, and it represents one of the most serious challenges we face in our ecology as a result of human activities such as waste from houses, industry, and agriculture, which causes pollution. Residues formed in WTPs are often the result of filter washing water and decanter discharges, which comprise particles from the raw water as well as chemicals employed in the treatment process. Sludge is a quantitative and qualitative issue that needs proper categorization, treatment, and disposal solutions (Sharma et al., 2022). Because of the contaminating potential, direct discharge into water bodies should be avoided. There have been studies that have revealed the harmful effects of sludge as well as the potential threats that incorrect disposal might provide to soil and aquatic organisms. The majority of the environmental issues linked with WTP sludge are due to chemicals employed in raw water treatment, including various heavy metals, which are one of the key components of sludge.

Contaminants such as pathogenic microorganisms, polyaromatic hydrocarbons, organo-chlorine, and other heavy metals are frequently found in raw sewage or partially treated sewage sludge. All of these might significantly contribute to the negative impacts on the plant and human systems. The dumping of raw sewage into several rivers in India has become a major issue. If we particularly focus on states of the southern and western regions of India, where industrialization predominates, the dumping of raw sewage into different rivers is practiced regularly (Figure 2).

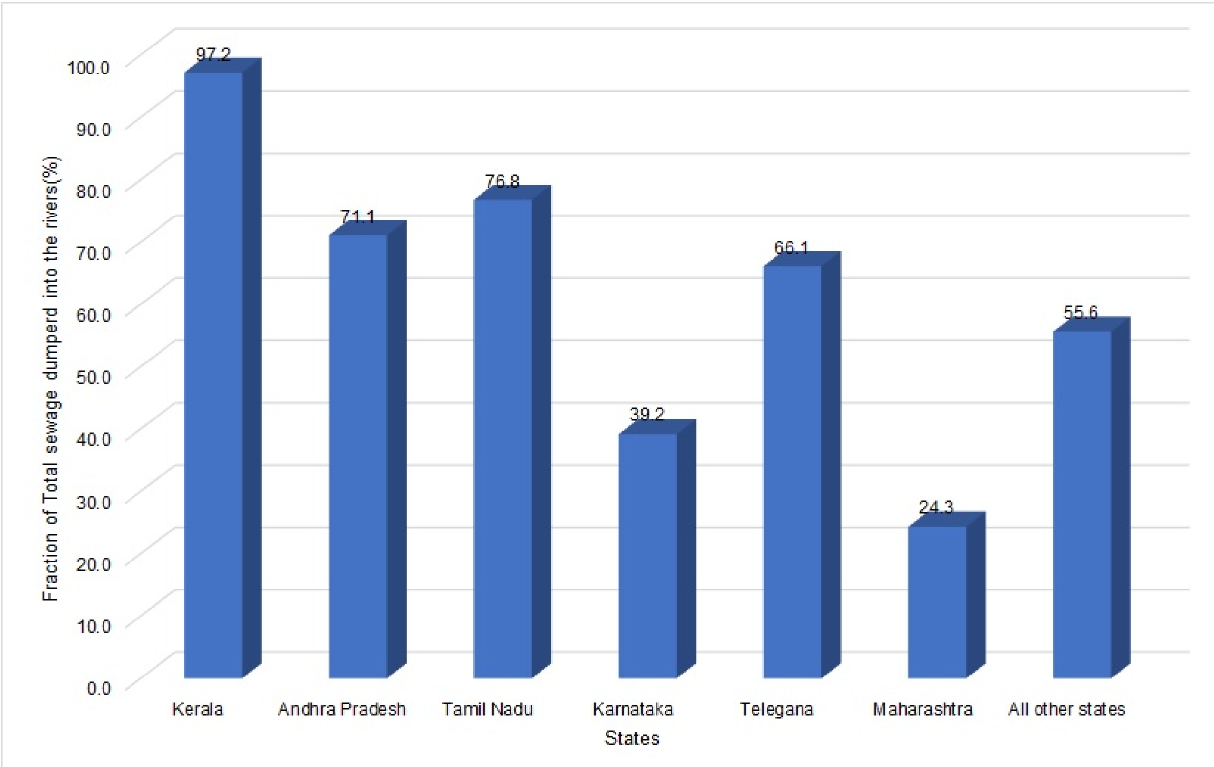

Figure 2 : Proportion of sewage disposal directly to the rivers in different states of India (Source: Kumar, 2021)

From the data obtained from the Central Pollution Control Board, India, it can be concluded that there is still lacking in the implementation of the laws or regulations in the Indian context. The disposition of sewage is associated with heavy metal contamination as we have apprehended from the above sections. Thus, in the next part, we will mostly cover the effects of heavy metals found in sewage and the pollution caused by them. Heavy metal pollution has been a serious environmental concern in river basins for the last 40 years, and extensive research has been conducted to demonstrate the sources, diffusion, and destiny of the pollutants, as well as the accompanying interactions with civilization. The worldwide number of heavy metals discharged into the environment in the final half of the twentieth century was 22,000 tonnes of Cd, 939,000 tonnes of Cu, 783,000 tonnes of Pb, and 1,350,000 tonnes of Zn (Sharma 2011). Heavy metals, due to their solubility, may be spread by water and, as a result, harm aquatic habitats. (Masindi & Muedi 2018). In 2006, the dissolved metal content in the Buriganga River (Bangladesh) was 126 ppm of Cd, 805 ppm of Pb, 5,274 ppm of Cr, and 595 ppm of As (Bhuiyan et al. 2015). Such high amounts of heavy metals in surface water are a direct hazard to human health and necessitate immediate action as well as more investigation (Siddiqui & Pandey, 2019). In the case of Indian rivers, the Ganga river contains the majority of heavy metal pollution. The next part will go through the present state of the situation.

Effect of Heavy metal pollution on river Ganga water and sediments

The Ganga is India's most significant river system. The abundant supply of water throughout the year has played a significant role in the development of Indian civilization and economics. It accounts for 25% of India's total water resources. The Ganga is the world's thirty-first-longest river, with a basin size of 861,404 $km^{2.}$ (Siddiqui & Pandey, 2019). In India, the Ganga River flows through 29 class I cities, 23 class II cities, and around 50 towns, resulting in the discharge of various sorts of contaminants such as industrial, sewage, and so on into this enormous river eco-system. Most heavy metals enter rivers from a variety of sources, which can be both natural (due to erosion and weathering) and human (due to pollution). Natural sources of heavy metals from leaching and weathering of rocks in the environment are normally of minor consequence in light of the strong human activity. The precipitation of heavy metal carbonates, hydroxides, and sulfides, which settle and become part of the sediment, causes the presence of heavy metals in sediments. The most prominent anthropogenic sources of heavy metals are various industries and household sewage. The practice of dumping waste from industry and untreated household sewage into the aquatic ecosystem is still in place, leading to an increase in heavy metal concentrations in river water. In recent years, much study has been undertaken on Ganga contamination caused by heavy metal pollution. An overview of several noteworthy research for the previous 37 years has been published below (Table 4), which demonstrated the damage to Ganga River quality and its related flora and fauna from the last decade to the present.

Table 4: Summary of the research findings on heavy metal pollution in Ganga

Sl. No.	**Places**	**Heavy metals found(PPM)**	**Heavy metals found(PPM)**	**Remarks**	**References**
	Uttar Pradesh	Cd:0.01-0.09; Co: 1.3-10.6; Cr:5.2-2100; Cu:5.9-39.2; Fe: 463-1873; Mg:441-1880; Ni:5.6-23.3; Pb:3.4-13.7; Zn:17.8-232.5.	Cd:0.01-0.09; Co: 1.3-10.6; Cr:5.2-2100; Cu:5.9-39.2; Fe: 463-1873; Mg:441-1880; Ni:5.6-23.3; Pb:3.4-13.7; Zn:17.8-232.5.	The study finds various quantities of heavy metals in fish (Heteropnuestes Fossilis	Ajmal et al. 1984
	Ganga and Bramhaputra river	Fe: 8040-2220; Mn: 183-523; Cr: 16-134; Ni: 7-49 Zn: 22-101; Cu: 2-62	Fe: 8040-2220; Mn: 183-523; Cr: 16-134; Ni: 7-49 Zn: 22-101; Cu: 2-62	The temporal and regional fluctuations in the distributions of heavy metals observed in Ganga sediment	Subramanian et al. 1987
	Mirzapur	Cd: 13.37–32.73 Co: 10.50–26.77. Cu: 38.0–157.80 Fe: 19.75–72.77 Mn: 34.25–105.55 Ni: 67.25–176.13 Pb: 34.25–185.75 µg/L and Zn: 94.25–423.75 µg/L.	Cd: 13.37–32.73 Co: 10.50–26.77. Cu: 38.0–157.80 Fe: 19.75–72.77 Mn: 34.25–105.55 Ni: 67.25–176.13 Pb: 34.25–185.75 µg/L and Zn: 94.25–423.75 µg/L.	The study pointed out, heavy metal deposition in Ganga sediments and sewer-river confluence locations	Sharma et al. 1992
	Kanpur	Cr: 0.15-0.75	Cr: 0.15-0.75	Heavy metal pollution of the Ganga River from tannery industry sludges	Khwaja et al. 2001

Sl. No.	Places	Heavy metals found(PPM)	Heavy metals found(PPM)	Remarks	References
	Lucknow, Kanpur, Delhi, and Agra	Cr: 115–817; Mn: 440–1 750; Fe: 28700–61100, Co: 11.7–29.0, Ni: 35–538, Cu: 33–1 204, Zn: 90–1974, Pb: 14–856 Cd: 0.14–114.8	Cr: 115–817; Mn: 440–1 750; Fe: 28700–61100, Co: 11.7–29.0, Ni: 35–538, Cu: 33–1 204, Zn: 90–1974, Pb: 14–856 Cd: 0.14–114.8	The study discovered heavy metals in freshly deposited stream sediments of rivers related to Ganga Plain urbanization.	Singh et al. 2002
	Haridwar to Farraka	Cr 121 – 200 ; Mn 1150 – 3070; Fe 34,100 – 46,200 ; Co 14.7 – 25.3 ; Ni 35 – 63 ;Cu 44 – 69; Zn 87 – 181 ; Cd 0.41 – 1.31 ; Pb 18 – 35	Cr 121 – 200 ; Mn 1150 – 3070; Fe 34,100 – 46,200 ; Co 14.7 – 25.3 ; Ni 35 – 63 ;Cu 44 – 69; Zn 87 – 181 ; Cd 0.41 – 1.31 ; Pb 18 – 35	The geogenic distribution and baseline concentrations of heavy metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb) were discovered in Ganga River sediments.	Singh et al. 2003
	West Bengal	Pb: 30.7-35.77	Pb: 30.7-35.77	The study discovered the negative consequences of lead levels in Ganga water and sedimets	Dutta et al., 2005
	Varanasi	Cu: 1.7-2.0; Cr: 0.16- 0.2; Ni: 0.1-0.9 Fe: 1.0-1.5 Zn: 0.50 -0.6 ; Cd: 0.1-0.16	Cu: 1.7-2.0; Cr: 0.16- 0.2; Ni: 0.1-0.9 Fe: 1.0-1.5 Zn: 0.50 -0.6 ; Cd: 0.1-0.16	According to their research, this location was contaminated, and the water is unfit for residential use, irrigation, or other reasons.	Chaturvedi and Pandey, 2006
	Babughat, Diamond Harbour and Gangasagar, West Bengal	Hg: 0.16-0.95 Pb: 0.017-0.076	Hg: 0.16-0.95 Pb: 0.017-0.076	The study looked at the high levels of dissolved heavy metals including Fe, Zn, Mn, Cu, Pb, and Hg in three biologically diverse zones along the Ganga's course.	Sarkar et al., 2007

Sl. No.	**Places**	**Heavy metals found(PPM)**	**Heavy metals found(PPM)**	**Remarks**	**References**
	Varanasi	Hg: 0-0.00191	Hg: 0-0.00191	The report studied Hg pollution in biotic and abiotic components of the Ganga River	Sinha et al. 2007
	Kanpur city	Upstream	Downstream	According to the study, tannery waste is dumped into the Ganga River, and the concentration of Cr in downstream sediment was 30-fold greater than in upstream sediment, and it was above the likely impact limit.	Beg and Ali, 2008
		As:0.25-0.25 Cd: 2.5-6 Cr: 0-5 Cu: 7-10 Mn: 85-125 Pb: 2.5-25 Ni: 5-7.5 Zn: 23-44.5	As: 0.25-0.25 Cd: 2.5-2.5 Cr: 105-250 Cu: 15-17 Mn: 160-254 Pb: 2.5-25 Ni: 8.5-13 Zn: 55-70		
	Rishra-Konnaga, West Bengal	Zn: 5.229-12.292 Cu:0.949-7.598 Cr: 2.212-3.432 Pb:0.014-0.017 Cd: 0.719-1.454	Zn: 5.229-12.292 Cu:0.949-7.598 Cr: 2.212-3.432 Pb:0.014-0.017 Cd: 0.719-1.454	The study looked at the buildup of heavy metals in water, sediment, and tissues of several edible fishes. The metal accumulation in fishes were in below order Zn>Cu>Cr>Cd>Pb	Bhattacharya et al. 2008

Sl. No.	Places	Heavy metals found(PPM)	Heavy metals found(PPM)	Remarks	References
	West Bengal	Fe: 0.025-5.49, Mn: 0.025-2.72, Zn: 0.012-0.370, Ni:0.012-0.375, Cr: 0.001-0.044 ; Pb: 0.001- 0.250; Cd:0.001-0.003 Cu: 0.003-0.032	Fe: 0.025-5.49, Mn: 0.025-2.72, Zn: 0.012-0.370, Ni:0.012-0.375, Cr: 0.001-0.044 ; Pb: 0.001- 0.250; Cd:0.001-0.003 Cu: 0.003-0.032	The presence of several heavy metals investigated in the surface water of the Ganga River was reported in the following order: Fe > Mn > Ni > Cr > Pb > Zn > Cu > Cd. 92% of the analyzed samples found the presence of the heavy metals	Kar et al. 2008
	Allahabad	Cu:0.054-0.452 Cr:0.056-0.068 Cd: 0.032-0.044 Pb: 2.32-2.35 Zn:8.7-10.62	Cu:0.054-0.452 Cr:0.056-0.068 Cd: 0.032-0.044 Pb: 2.32-2.35 Zn:8.7-10.62	The study looked at the presence and bioaccumulation of numerous heavy metals (Cu, Cr, Cd, Pb, Zn) in the muscles of two catfish species caught in the Ganga.	Gupta et al. 2009
	Rishikesh to Allahabad	Cd: 0.6-13 Cu: 10-36 Pb: 2.4-26 Zn: 12-106	Cd: 0.6-13 Cu: 10-36 Pb: 2.4-26 Zn: 12-106	The authors investigated the distribution of non-radioactive heavy metals (Zn, Cd, Cu, and Pb) in Ganga River water and discovered that concentrations of detecting heavy metals exceeded the regulatory limits in selected regions.	Sharma et al. 2012

Sl. No.	**Places**	**Heavy metals found(PPM)**	**Heavy metals found(PPM)**	**Remarks**	**References**
	Varanasi.	Cr: 126.84–196.11 Ni: 14.63–82.5 Co: 29.98–102.24 Fe: 7175.5–9385 Zn: 137.25–201.2 Cu: 12.67–84 Cd: 9.52–79 Pb: 148.83–211.36	Cr: 126.84–196.11 Ni: 14.63–82.5 Co: 29.98–102.24 Fe: 7175.5–9385 Zn: 137.25–201.2 Cu: 12.67–84 Cd: 9.52–79 Pb: 148.83–211.36	The investigation discovered that Pb, Cd, Cu, and Ni were present in considerable amounts in the accessible fraction.	Pandey et al. 2015
	Kaushambi	Cu: ND-1000; Fe: ND-600; Pb:ND-9;Zn: ND-980	Cu: ND-1000; Fe: ND-600; Pb:ND-9;Zn: ND-980		Chaudhury et al., 2017
	Ganga Basin	Cr:7.12-155.0 Cd:0.21-3.6 Pb:2.1-36.5;Ni:3.54-53.1;Cu:2.1-73.98; Zn:6.3-104.3; Fe: 17389-49568 Mn:139-2167	Cr:7.12-155.0 Cd:0.21-3.6 Pb:2.1-36.5;Ni:3.54-53.1;Cu:2.1-73.98; Zn:6.3-104.3; Fe: 17389-49568 Mn:139-2167	The study found that the amounts of Cr and Cd in water, as well as Mn in sediment, were greater in the Ganga River than in many other rivers throughout the world.	Siddiqui & Pandey, 2019
	Rishikesh to Roorkee	Zn:32.84; Pb:3.73 Mn:3.52; Fe:5696.92 Cu:52.4; Si:1.54 Ni:2.91; Cd: 2.81; Co:2.9	Zn:32.84; Pb:3.73 Mn:3.52; Fe:5696.92 Cu:52.4; Si:1.54 Ni:2.91; Cd: 2.81; Co:2.9	The current study's Heavy Metal Pollution Index (HPI) findings suggest that the water samples from the Ganga River were severely contaminated with heavy metals. The HPI observation was above the high class (HPI>30).	Matta et al., 2018
	Gomti-Ganga River basin	As: 6.1; Fe: 152.3; Cd: 19.5; Pb: 83.9; Mn: 52.4; Cr: 7.6	As: 6.1; Fe: 152.3; Cd: 19.5; Pb: 83.9; Mn: 52.4; Cr: 7.6	COVID-19 lockout improved the Ganga River's dissolved heavy metal burden.	Khan et al., 2021

The Ganga River is regarded as sacred by the people of India since it provides life, nourishment to the ecosystem and ecology. Anthropogenic activities have resulted in significant changes in aquatic habitats during the last several decades. The advancement of human civilization has raised severe concerns about the safety of using river water for drinking and other purposes. River water contamination caused by heavy metals is a serious problem in most developing-country urban areas. Toxic heavy metals released into the environment may cause bioaccumulation and biomagnification. These heavy metals are not easily degradable and accumulate to dangerous levels in both animal and human systems, causing unpleasant consequences over a certain threshold.

Conclusion and way forward

Sewage sludge is a byproduct of sewage treatment procedures that contains organic compounds, macro and micronutrients, trace elements including hazardous metals, bacteria, and micropollutants. The use of sewage sludge results in more robust plants with faster development and higher biomass production, although the shorter cultivation period may be a matter for worry. Crops cultivated on excessively high doses of sludge amendment into soils have dangerous quantities of heavy metals when compared to crops grown on a lesser dose of sludge amendment, as well as unamended ones. The eating of such plants could endanger human health. Along with this, sludge disposal is related with heavy metal pollution in the environment. To tackle such conditions, a variety of treatments could be implemented. To mitigate the negative effects of the heavy metal environment, sewage treatment plants, sewage networks, and effective industrial policies could be established. Raw sewage sludge management is very critical in current scenario. Overall, raw sewage sludge is not advised for agricultural applications or even land filling. Interventions like as heavy metal dilution via fortification methods and pathogenic organism reduction via sterilizing procedures could be advantageous in this case. Heavy metals below a specific concentration are not dangerous to humans or the environment. To minimize such annoyance, strict regulations on sewage remediation practices should be implemented with immediate action.

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Conflict of Interest

No

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