Research Article

Journal of
Environmental
Nanotechnology

A Systematic Review on Removal Efficiency of Heavy Metals from Yamuna Water

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Received: 20.03.2024 Accepted: 29.04.2024 Published: 30.06.2024
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ABSTRACT

Yamuna River fulfils the water needs of various regions of North India. With the increasing level of pollution, the Yamuna River is declared as one of the polluted rivers in India. Numerous researches have reported the heavy metal presence in Yamuna River. Hence, we have focused our review towards analysing the heavy metals present in Yamuna River Basin and their concentrationlevel during pre-pandemic and post-pandemic period. Delhi being the main polluter city causes the cloud formation (froth) and as a consequence a health risk among children and adults. Mathura and Agra are equally responsible in polluting the Yamuna River. Further, we have also included the role of microalgae as a promising solution for heavy metal removal. Altogether, this review will help the future researchers towards identifying potential approaches for water remediation.

Keywords: Heavy metals; Froth; Removal efficiency; Yamuna River.

1. INTRODUCTION

Rivers are at the heart of the society's progress. All the ancient civilizations developed around them. Rivers have cultural, religious and social importance (Anderson *et al.* 2019). Rivers are treated as Goddesses in Indian culture. River Ganga, Yamuna, Saraswati, Brahmaputra, Godavari, Narmada, Meghna, Mahanadi, Krishna, Kaveri, and Penna River are some important rivers of India. River Yamuna is called Yami and Kalindi. In India, River Yamuna isworshiped as the daughter of the Sun God and his wife Saranyu (Goddess of clouds). Water has a great importance in the lives of human beings. Water has provided the growth and development and progress of the communities. However, with the growth and development, there has been an increment in the pollution level on Earth. All living beings depend on water. Heavy metals come under the inorganic pollutants that are present in the Earth's crust and are found in pesticides, fertilizers and in residues from mining industries (Shanbehzadeh *et al.* 2014; Sun *et al*. 2018). Yamuna originates from the Yamunotri glacier in the Himalayas. It flows through many major cities like New Delhi, Noida, Mathura, Prayagraj and many more. Yamuna River is one of the most polluted rivers in India, especially in New Delhi. Various studies have done on the Yamuna River water and showed the presence of various heavy metals that affect the health of humans. Heavy metals can be defined as a group of metals and metalloids of relatively high density in comparison with water, which means the atomic density of heavy metals is greater than 4 g cm^{-3}. Health risk assessment showed that children are more affected than the adults due to the consumption of polluted water (Sharma and Gulati, 2014). The most polluted river that flows through the national capital territory does not fulfil the criteria of drinking water (Patel *et al*. 2020). Even though only 1 % of Yamuna flows through Delhi, the city is responsible for more than 55% of the contamination occurring in Yamuna. These contaminations are heavy metals, anions, pollutants, etc. It has been found that the concentration of some metals increased while others decrease during the COVID-19 pandemic. Their mean concentration order was Fe > Cu > Zn > Ni > Cr > Pb > Cd (Bhardwaj *et al.* 2017) and the order of contamination factors for metals was Zn > Cd > Cr—Ni > Pb—Cu (Parween *et al.* 2021). Karunanidhi *et al.* (2021) and Singh *et al.* (2022) showed that the quality of water improved during pandemic as the concentration of some heavy metals showed declination (Tables 1 and 2). The next major city after Delhi from where Yamuna flows is Mathura. This city is also responsible for the pollution and contamination of heavy metals and pollutants in Yamuna River because in Mathura, there are many factories. In addition, agricultural wastes and runoffs containing fertilizers are released directly into Yamuna. As a result, the groundwater in the area along the course of Yamuna gets salinated with increased amounts of heavy metals surpassing the limits prescribed by BIS 2012 and WHO 2017. Ahmed *et al.* (2022) created maps using the software Surfer-11 to highlight the areas of iron contamination. Untreated or partially treated waste inputs affect the water quality (Bhutiani *et al.* 2018).Yamuna water is used as a household supply in the areas like Delhi, Mathura, Agra, Allahabad etc. About 93% of Yamuna water is used for various purposes like drinking, irrigation, etc. The total capacity of the hydropower plant to generate the electricity in Yamuna basin is 1300 MW. Presently, the utilization is just one third of the total capacity i.e., around 440 MW. In India, various kinds of rituals are also performed near the banks of rivers. They are also used for cattle bathing process, which hampers the quality of Yamuna.

2. YAMUNA WATER CLOUDS (TOXIC FOAM)

Although Yamuna water is a lifeline for the people residing in Delhi region, it becomes perilous during winter season. During winter season, when the temperature is low and the flow of river is less, clouds (toxic foam) are formed. The primary reason for the froth formation is the presence of phosphate in high concentration, due to the detergents used in dying industries, dhobi ghats and households from Delhi, Haryana, UP region. Waste and sewage water flowing through unused drains also contains high concentration of phosphate. The phosphoric compound forms by turbulence when the water falls from a height at a barrage, leading to the formation of foam.

3. IMPROVEMENT DURING PANDEMIC

During lockdown period, water quality of Yamuna River showed an improvement of 37%. The values of BOD and COD showed a decline by 42.83% and 39.25%, respectively (Biswas and Vellanki, 2021). Another study showed that values of BOD declined by 30.32% during lockdown and increased by 39.5% post-lockdown (Khan, 2020). Singh *et al.* (2022) found an average BOD of 39.62, 30.33 and 40.50 mg/L , and average COD of 116.52, 136.07 and 148.69 mg/L in pre-lockdown, during lockdown and post-lockdown periods, respectively. In just three weeks, the average value of BOD and COD level decreased to 62% and 60%, respectively (Chaudhary *et al.* 2022). Improvements were recorded in terms of BOD and DO at Palla, Nizamuddin bridge and Okhla. The concentration of heavy metals in the pre-lock down samples was in the order: Cd>Pb>Ni>Cu> Mn>Zn>Cr>Fe, and during lockdown period, it was Cd>Ni>Cu>Pb>Mn>Zn>Cr>Fe (Table 1).

Table 1. Concentration of Heavy metals in the rivers (Karunanidhi *et al.* 2021)

Metal	Pre-lockdown (mgL^{-1})	During lockdown (mgL^{-1})
Fe	0.048–1.33	0.039–0.161
Mn	0.039–0.121	0.03–0.089
Zn	0.039–0.161	0.018–0.11
Cd	0.001–0.004	0.0009–0.0032
Cu	0.01–0.128	0.007–0.08
Ni	0.002–0.029	0.001–0.018
Pb	0.001 & 0.014	0.007 & 0.08
Cr	0.327	0.108

Formation of toxic foam is the sign of deeply polluted river. Out of 1370 km, only 20 km flows through Delhi in which New Delhicreates 720 million gallons of waste per day and is responsible for 70% of the pollution of theriver.

Table 2: Concentration range of heavy metals in mg/L in the Yamuna River

Metal	Pre-lockdown		During Lockdown	
	(Bhattacharya and Dey, 2015)	(Yadav and Khandegar, 2019)	(Lal *et al.* 2022)	(Asim, 2021)
Cr	0.00 - 0.42	0.0352	<0.005	0.02667
Mg	ND	-	0.027-2.017	-
Fe	ND	6.4672	0.343-2.403	0.12667
Ni	0.01 - 0.13	0.0254	<0.005	0.164
Cu	0.02 - 0.64	0.0813	<0.005	0.075
Zn	0.13 - 2.22	1.3651	<0.01	1.516
Ar	ND	-	<0.005	-
Cd	0.00 - 0.07	0.0374	<0.001	-
Pb	0.03 - 0.27	0.0212	<0.005	0.01533

ND: Not determined

There is a significant improvement in all 13 parameters during lockdown as there were minimal industrial activities (Sharma and Gupta, 2022). According to the CPCB data released during April 2020, water quality of Yamuna River showed a significant improvement in the pH and conductivity. The pH decreased from 7.6 during pre-lockdown period to 7.3 during lockdown period. Similarly, conductivity was found to decrease (pre-lockdown period: 688 to 2485 µS/cm; during lockdown period: 273-1657 µS/cm) (Arif *et al.* 2020). In the river Ganga, heavy metals showed some fluctuations during lockdown. The average concentration of metals in 2020 was in the order Fe > Zn> Cu> Cr> Mn> Pb> Co> Ni> Cd> Al> As, whereas in 2021, it was Fe> Pb> Zn> Cr> Cu> Mn> Co> Ni> Al> Cd> As (Subuddhi et al., 2023).

Table 3. Water quality variables in Yamuna River (Singh *et al.* 2022)

	Pre-lockdown			During Lockdown			Post-Lockdown		
	Average	max	min	Average	max	min	Average	max	min
pH	7.53	7.77	7.27	7.26	7.80	6.59	7.64	7.80	6.59
TSS	57.2	178.00	6.00	30.33	160	5.00	60.40	256	8.00
BOD	39.62	100.00	8.00	31.32	250	1.30	40.50	180	2.80
COD	116.52	322.00	6.80	136.07	784	6.40	148.69	724	8.80
Conductivity	1743.01	3310	8.1	1500.24	3020	7.10	1467.39	3290	7.20

Table 4. Removal of heavy metals by *A. plantensis*

Metal	Removal Efficiency	Removal Amount
Cu	74%	54 mg/g
Cd	77%	58 mg/g
Ni	50.5%	39 mg/g
Cr	76%	62.8 mg/g
Pb	76.5%	58.9 mg/g
Co	63.5%	45.3 mg/g

4. MICROALGAE FOR THE REMOVAL OF HEAVY METALS

Microalgae could be an effectual solution for the removal of heavy metals. Chalima *et al.* (2019) showed that A. platensis proved to be an appropriate choice for the isolation of heavy metals and production of valuable pigments. Its removal efficiency is shown in Table 4 and in Fig.1. Illumination with optimum wavelength triggers the metabolic activities of A. platensis and enhances the removal efficiency (Mehan *et al.* 2018). The bacterial strain CR2 of genus Jeotgalicoccus showed a great removal efficiency for the heavy metals mentioned in Table 5 and Fig. 2 (Shivani *et al.* 2022). During lockdown, when people were confined to their homes and all industrial activities were shut, waste disposal was minimal so that the rivers got a healing time for rejuvenation (Sehgal *et al.* 2020).

During pandemic, heavy metals were found below the maximum permitted limits in Yamuna River. Singh *et al.* (2022) showed that concentration of heavy metals decreased during pandemic in Yamuna water at Mathura district of UP. The quality of Yamuna water showed a significant improvement during lockdown period in Mathura. Removal efficiency of heavy metals by Jeotgalicoccus is shown in Table 5 and Fig.2. The Energy Research Institute (TERI) conducted water monitoring of the Yamuna River during COVID-19 lockdown (Table 6).

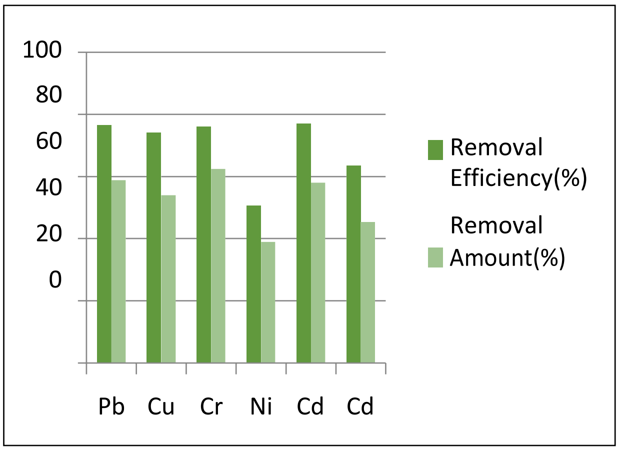

Fig. 1 Illustration of efficient removal of heavy metals by *A. plantensis*

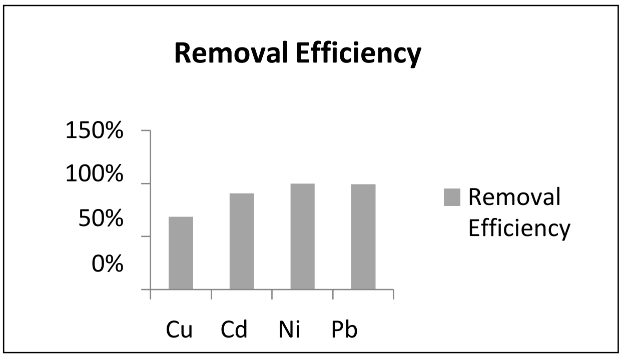

Fig. 2: Aplamtensis with optimun wavelength

Table 5. A plantensis

Metal	Removal Efficiency
Cu	*68.57%*
Cd	90.8%
Ni	100%
Pb	99.2%

Table 6. Survey conducted by The Energy Research Institute (TERI), 2020

S. No.	Heavy metal tested	Present study results (mg/L)*	Earlier studies		Acceptable limit	Permissible Limit (as perIS:10500)
			Sehgal *et al.* (2012)	Bhardwaj *et al.* (2017)*		
1	Chromium	<0.005	0.976±0.622	0.363±0.674	0.05	No Relaxation
2	Nickel	<0.005	0.064±0.034	0.851±955	0.02	No Relaxation
3	Copper	<0.005	0.091±0.157	4.791±4.776	0.05	1.5 Max.
4	Zinc	<0.01	0.191±0.21	3.518±7.257	5	15 Max.
5	Arsenic	<0.005	0.012±0.012	Not reported	0.01	0.05 Max.
6	Cadmium	<0.001	BDL (<0.005)	0.110±0.146	0.003	No Relaxation
7	Lead	<0.005	0.202±0.225	0.255±0.363	0.01	No Relaxation
8	Mercury	<0.0001	0.207	Not reported	0.001	No Relaxation

5. HEAVY METAL REMOVAL EFFICIENCY OF BIO-SORBENTS FROM CONTAMINATED WATER

One of the most favoured and widely used techniques for the wastewater treatment is adsorption. It is a cost effective process with high efficiency (El-Baz *et al.* 2020). Rice husk consists of cellulose (32.24%), lignin (21.44%), hemicellulose (21.34%), and mineral ash (15.05%) (Chuah *et al.* 2005). Krishnani *et al.* (2008) examined an alkali-treated and autoclaved rice husk on eight different metals, which showed a highest adsorption of Pb metal as shown in the trend: Pb> Hg > Cd > Cu > Co > Mn > Zn > Ni. Rice husk ash also showed higher Pb adsorption when compared to Hg (Feng et al. 2004). Avocado fruit waste seeds showed an adsorption capacity of 93.75 mg/g for arsenic. Raw avocado seeds could remove more than 50% arsenic from water without any modification (Mqehe *et al.* 2018). Surfactant-modified waste can improve the adsorption capacity to a great extent. The surfactant cetyltrimethyl ammonium bromide has been used to modify the husk and carbon powder derived from Moringa oleifera, which improved heavy metal removal efficiency. Isothermal modelling of fish scale biomass has shown a great potential to adsorb Cd and Pb ions that could be a promising solution (Jyoti *et al.* 2020).

Table 7. Removal of heavy metal percentage by rice husk (Shamsollahi and Partovinia, 2019)

Metal	Removal (%)
Cd	18-99
Cr	98.86
Pb	95
Zn	35.3
Ni	27.8
Cu	50

Table 8. Efficiency of different algae in heavy metal removal

Metal	Algae	Removal efficiency	Reference
Cu	*Hizikia fusiformis*	31.6%	Pham *et al.* (2021)
	Cladophora	14.71%	Lee and Chang (2011)
	Chlorella pyrenoidosa	84%	Zhou *et al.* (2012)
	Desmodesmus sp. MAS1	27%	Prudkin *et al.* (2021)
	*Heterochlorella sp.*MAS3	43%	Abinandan *et al.* (2019)
Cd	*Hizikia fusiformis*	14.9%	Pham *et al.* (2021)
Ni	*Hizikia fusiformis*	10.9%	Pham *et al.* (2021)
Pb	*Cladophora*	46.51%	Lee and Chang (2011)
Pb	*Hizikia fusiformis*	10.9%	Pham *et al.* (2021)
Cr	*Gracilaria sp.*	52.5%	Kang and Sui (2010)
Zn	*Gracilaria sp.*	36.5%	Kang and Sui (2010)
	Chlorella pyrenoidosa	83%	Zhou *et al.* (2012)
Fe	*A. maxima*	97.9%	Blanco *et al.* (2022)

6. HEAVY METAL REMOVAL EFFICIENCY OF BACTERIA

Heavy metal tolerant bacterial strains can be used to treat the industrial waste water before releasing it into water bodies. Bacterial strain similar (99%) to Pantoea agglomerans JCM1 and Enterobacter asburiae JCM 6051 extracted from contaminatedwater showed a great tolerance to Cd (3000 µg/L) and Ni (2000 µg/L) (Neeta *et al*. 2016). Jeotgalicoccus sp. CR2 showed a great removal efficiency towards Cu metal (Kumari *et al*. 2022)

Table 9. Removal % of *Jeotgalicoccus sp* CR2

Metal	Removal %
Cu	96.65
Zn	94.4
Pb	69.4
Ni	65

7. EFFECTS OF HEAVY METAL ON HUMAN HEALTH (GIVE THIS INFORMATION IN THE FORM A TABLE IN THE INTRODUCTION SECTION)

Pb - severe Pb presence in body can cause the dysfunction in the kidney, reproductive system, liver, brain.

Cd - Cd having a precise gravity 8.65 times greater than water can be lethal for liver, placenta,kidney, lungs, bones.

Ni - Foodstuff intake, gastric emptying and peristalysis of the intestine are of substantial impactfor the bioavailability of nickel (Parihar *et al*. 2019)

Ar - can cause immunotoxicity (Mudhoo *et al*. 2011)

Cu - causes anaemia, stomach pain, infection in liver kidney, nausea in children.

Ni - allergy, cardiovascular and kidney disease, lung and nasal cancer (Genchi *et al*. 2020)

Cr - hexavalent chromium could lead to damage in lipids, protein and DNA (Achmad *et al.* 2017).

Zn - excess presence of zinc causes respiratory disorder, metal fume fever, nausea, vomiting,diarrhoea, risk of prostate cancer (Plum et al. 2010)

8. CONCLUSION

Yamuna River plays an important role in various processes, but with the increasing pollution ithas become unusable for human consumption and for domestic purposes. Although during pandemic there was an improvement in the Yamuna water pollution, as human activities continued, the pollution level got worse gradually. Various experiments and appropriate approaches are required to combat this pollution problem. Microalgae and bacteria played a significant role for the removal of heavy metals. However, more experiments are required to find the different species of microalgae and strains of bacteria for the efficient heavy metal removal. Biosorbents can provide a promising cost-effective solution for the removal of heavy metals.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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