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Heavy Metal Contamination in Selected Perennial Ponds of Kanniyakumari District and Their Removal Using Natural Adsorbents

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Abstract

Water samples were collected from five perennial Ponds (I to V) in Kanyakumari district and analyzed for heavy metal contamination like Fe, Pb, Cd, Cu and Zn during pre-monsoon, monsoon and post-monsoon seasons. The results demonstrated that Cd and Pb concentrations exceeded the BIS standard limit in all ponds across all seasons, while Fe concentration exceeded the limits in Pond I and II during the post-monsoon season. In contrast, Cu and Zn concentrations remained within safe limits. The contaminated water was analyzed to remove these heavy metals via three natural absorbents (powered peels of orange, banana & lemon) at varying concentrations. Orange peel showed significant efficacy in removing Pb, while banana peel showed notable removal efficiency of Cd and Fe, rendering the water safe for consumption. This study highlights the potential of natural absorbents as eco-friendly solutions for effectively removing heavy metals, particularly in cases of low contamination, from water sources.

***Key words*:** Heavy metals, Ponds, Water contamination, Natural adsorbent, Heavy metal removal

Water contamination by heavy metals is a critical environmental issue, particularly in aquatic ecosystems such as ponds, ditches, and rivers that support local communities [1]. These water bodies are often dependent on domestic needs, agriculture, aquaculture, and other essential activities. However, the presence of toxic metals in these ecosystems can pose serious health and environmental risks. Heavy metals, including lead, cadmium, mercury, and arsenic, can enter aquatic environments through both natural processes, such as weathering of rocks and soil erosion, and anthropogenic activities, including industrial discharges, domestic effluents, urban stormwater runoff, agricultural practices, and landfill leachate [2]. Once introduced in water bodies, these heavy metals accumulate in sediments and persist for long periods, gradually contaminating the aquatic plants, animals, and the food web. The consumption of aquatic organisms contaminated with heavy metals can lead to food chain magnification, causing serious health hazards such as neurological disorders, organ damage, and chronic diseases in humans [3]. Additionally, the toxic effects of heavy metals can disrupt the ecological balance, harming aquatic biodiversity and affecting the overall health of these ecosystems.

Resolving heavy metal pollution in ponds and other freshwater habitats is essential for maintaining the sustainability of these natural resources and safeguarding human health [4]. Conventional heavy metal removal approaches, like chemical treatments and sophisticated filtration systems, can produce secondary contaminants and are often expensive. Using natural, low-cost, and eco-friendly adsorbents has emerged as a promising alternative in this context [5-6]. This study explores the potential of commonly available fruit waste materials such as orange peel, banana peel, and lemon peel as natural adsorbents for removing heavy metals from contaminated pond water. These fruit peels, rich in functional groups like hydroxyl, carboxyl, and phenolic compounds, have shown significant potential for binding and removing toxic metals through adsorption processes. The study intends to offer an economical and sustainable solution by examining the effectiveness of these natural adsorbents in reducing heavy metal pollution in ponds and other freshwater ecosystems.

MATERIALS AND METHODS

Sample collection and heavy metal analysis

The water samples were collected from five perennial ponds in pre-cleaned acid-washed plastic containers located in the Kanyakumari district: Pond I (Peria Kulam, Manavalakurichi), Pond II (Kothan Kulam, Monday Market), Pond III (Kalpadi Kulam, Vellimalai), Pond IV (Nilavadi Kulam, Velli Chanthai), and Pond V (Anathan Kulam, Aasaripallam). Sampling was conducted over one year, from June 2022 to May 2023. The pH of the sample was kept at 4 by adding the appropriate quality of acid. The samples were filtered with 0.45µm filter paper. The materials were further concentrated using the APDC-MIBK extraction process. The obtained samples were analyzed for heavy metals such as iron,

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manganese, zinc, copper, lead, and cadmium using an Atomic Abortion Spectrophotometer, AAS Perkin Elmer (Analyst 400). All chemicals and reagents used in the tests were of analytical quality.

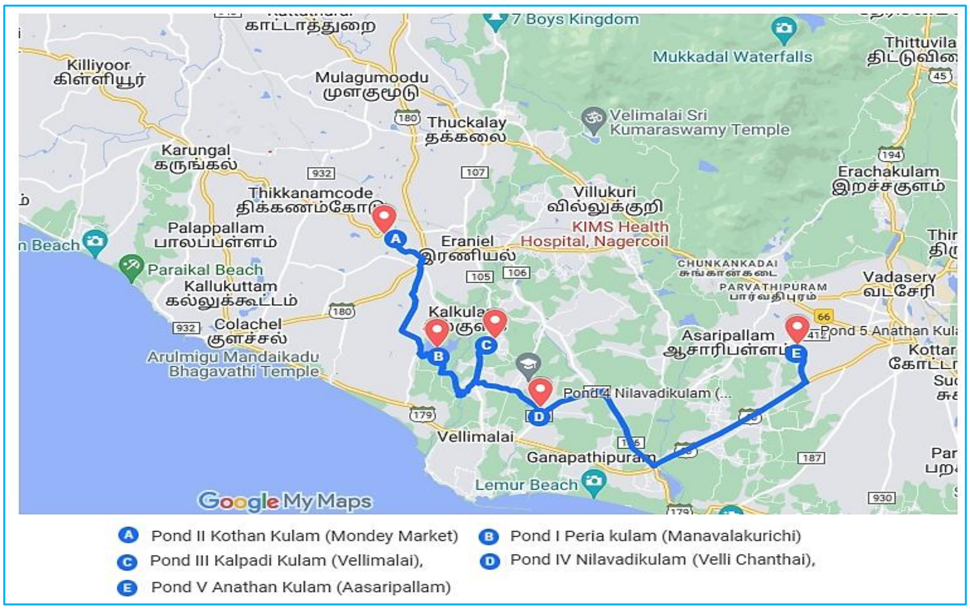

Fig 1 Location map of the study area showing sampling ponds

Natural absorbent preparation and heavy metal removal procedure

The adsorbents (orange peel, banana peel, and lemon peel) were first washed thoroughly with distilled water to remove any dirt and contaminants and then dried in sunlight for varying durations: orange peels for 3 days, banana peels for 7 days, and lemon peels for 2 days. Once dried, the peels were crushed into a fine powder and sieved for uniformity.

The powdered adsorbent (1g, 1.5g and 2g) were added to acidified water samples for the adsorption process. The solutions were treated differently based on the type of peel: for orange peel, the solution was boiled for 15 minutes, allowed to cool for 5 hours, and then filtered using Whatman filter paper No. 42. For banana peel, the mixture was shaken at 250 rpm using an orbital shaker, followed by filtration. The solution was boiled for 20 minutes for lemon peel, cooled for 5-6 hours, and then filtered. The filtrates were analyzed for heavy metals (Fe, Pb, and Cd) using an Atomic Absorption Spectrometer (AAS) to determine the concentration of metals after the adsorption process.

RESULTS AND DISCUSSION

Heavy metals analysis in pond water

The samples collected from five different ponds were analyzed for heavy metals. The mean concentration of heavy metals like Fe, Pb, Cd, Cu and Zn across pre-monsoon, monsoon and post-monsoon seasons are tabulated in (Table 1).

Lead (Pb) is one of the most poisonous heavy metals found in pond water [7-8]. During the pre-monsoon season, Pb levels range from 0.062 to 0.205 mg/L, with Pond I showing the highest concentration. Pb levels increased significantly in the monsoon season, ranging from 0.15 to 0.27 mg/L, with Pond IV having the highest concentration. In the post-monsoon season, Pb levels decreased slightly, ranging from 0.1 to 0.17 mg/L, with Pond II showing the highest concentration. According to BIS guidelines, the permissible limit for Pb in drinking water is 0.01 mg/L [9-10] but all the ponds consistently exceeded this limit across all seasons. The elevated concentration of Pb in drinking water poses serious health risks that adversely affect the brain, blood, kidneys, and cardiovascular system [11]. Pb contamination in pond water includes lead-acid batteries, treated wood, paints, fertilizers, old water supply infrastructure, and vehicle emissions [12].

Cadmium (Cd) is the next most toxic heavy metal detected in the pond water. In pre-monsoon season, Cd levels ranged from 0.015 to 0.02 mg/L, with Pond V showing the highest concentration. In the monsoon season, the concentration increased, ranging from 0.009 to 0.025 mg/L, with Pond IV and V exhibiting the highest values. In post-monsoon season, Cd levels ranged from 0.014 to 0.13 mg/L, with Pond I showing maximum concentration. According to BIS guidelines, the permissible limit of Cd concentration in drinking water is 0.003 mg/L. All five ponds exceeded this limit across all three seasons. Cd poses serious health risks, including cancer, "itai-itai" disease, severe rheumatoid arthritis, cardiovascular disorders, dyspepsia, and high blood pressure, even at low concentrations [13-14]. Cd contamination in water includes agricultural runoff, industrial discharges, battery waste disposals and mining activities [15].

The next heavy metal detected is Fe. Its levels ranged from 0.207 to 0.32 mg/L during the pre-monsoon season. In the monsoon season, Fe levels decreased, ranging from 0.15 to 0.26 mg/L. However, in the post-monsoon season, Fe concentration significantly increased, ranging from 0.21 to 0.50 mg/L. As per BIS guidelines, the permissible limit for Fe in drinking water is 0.3 mg/L [9-10]. All the ponds across three seasons remained within the permissible limit, except for Pond I (0.47 mg/L) and Pond III (0.32 mg/L), which exceeded the limits in the post-monsoon season. Fe can enter aquatic systems, such as ponds, through natural deposits, industrial waste, iron ore refinements, and the corrosion of Fe-containing materials.

As per BIS guidelines, the permissible limit for Cu in drinking water is 0.05 mg/L. The data shows Cu concentrations in all ponds across three seasons (0.003 to 0.017 mg/L) remain within the limit. Similarly, Zn concentrations in all ponds across three seasons are well below the permissible limit of 5 mg/L, ranging from 0.002 to 0.037 mg/L. these findings indicate no concern regarding Cu and Zn contamination in the water [10-11].

Based on their concentrations, the order of heavy metals detected in the ponds followed the order Pb>Cd>Fe>Cu>Zn

Table 1 Mean concentration of heavy metals (mg/L) in pond water I to V

Seasons	Mean concentration of heavy metals (mg/L)					
	Ponds	Pb	Fe	Cd	Zn	Cu
Pre-monsoon	I	0.205	0.23	0.015	0.002	0.011
	II	0.062	0.32	0.018	0.005	0.011
	III	0.08	0.21	0.018	0.002	0.017
	IV	0.09	0.21	0.019	0.005	0.014
	V	0.11	0.207	0.02	0.004	0.015
Monsoon	I	0.17	0.24	0.009	0.01	0.007
	II	0.15	0.24	0.011	0.012	0.01
	III	0.25	0.15	0.018	0.01	0.006
	IV	0.27	0.26	0.025	0.009	0.01
	V	0.24	0.21	0.025	0.008	0.003
Post-monsoon	I	0.11	0.47	0.013	0.009	0.009
	II	0.17	0.5	0.015	0.037	0.01
	III	0.1	0.32	0.016	0.006	0.01
	IV	0.11	0.26	0.014	0.01	0.016
	V	0.16	0.21	0.014	0.008	0.014
BIS standard		0.01	0.3	0.003	5	0.05

Heavy metals removal

The mean concentrations of heavy metal ions in the analyzed pond water (Table 1) indicate that Fe, Pb, and Cd levels exceed the standard limits. Consequently, the removal of these heavy metals is critically important. Ponds II, IV, and V, which exhibit higher concentrations of Fe, Pb, and Cd, respectively, were selected for treatment using natural absorbents, including powdered orange peel, banana peel, and lemon peel, at concentrations of 1 g, 1.5 g, and 2 g. The results reveal that increasing the concentration of the absorbents enhances the removal efficiency of heavy metals (Table 2-3, Fig 2). At a concentration of 2g, orange peel demonstrates the highest efficacy in removing Pb, achieving a removal rate of 94.19% (0.018 mg/L), followed by banana peel at 87.41% (0.039 mg/L), and lemon peel at 69.03% (0.096 mg/L). Notably, orange peel reduces the Pb concentration to a level close to the standard limit (0.01 mg/L).

Banana peel effectively removes Cd at a concentration of 2 g, achieving a removal efficiency of 93.39% (0.0035 mg/L). This is followed by lemon peel with an 89.62% removal rate (0.0055 mg/L) and orange peel with 81% removal (0.01 mg/L). Notably, orange peel reduces the Cd concentration close to the standard limit of 0.003 mg/L [16]. Banana peel proved to be the most effective biosorbent for Cd removal, achieving a 93.39% efficiency at 2 g, followed by lemon peel (89.62%) and orange peel (81%). While orange peel brings Cd concentration closer to the standard limit of 0.003 mg/L, banana peel demonstrates the highest potential for effective Cd remediation.

Fe is effectively removed using banana peel, achieving a 62.19% reduction (0.31 mg/L) at a lower concentration of 1g, which meets the standard limit of 0.3 mg/L. At a higher concentration of 2 g, banana peel further reduces Fe levels to 0.15 mg/L, with an efficiency of 81.70%. In comparison, orange peel and lemon peel at a concentration of 2 g reduce Fe levels to the standard limit, achieving concentrations of 0.33 mg/L and 0.27 mg/L, with removal efficiencies of 59.76% and 67.1%, respectively [17]. This highlights banana peel's superior potential for Fe remediation.

Table 2 Heavy metal removal efficiency of natural absorbents (mg/L)

Heavy metals	Initial concentration (mg/L)	BIS standard (mg/L)	Final concentration of metal ion (mg/L)								
			Orange peel			Banana peel			Lemon peel		
			1g	1.5g	2g	1g	1.5g	2g	1g	1.5g	2g
Pb	0.31	0.01	0.10	0.056	**0.018**	0.12	0.073	0.039	0.18	0.13	0.096
Fe	0.82	0.3	0.47	0.40	**0.33**	**0.31**	**0.21**	**0.15**	0.42	0.37	**0.27**
Cd	0.053	0.003	0.031	0.018	0.01	0.021	0.0073	**0.0035**	0.025	0.011	0.0055

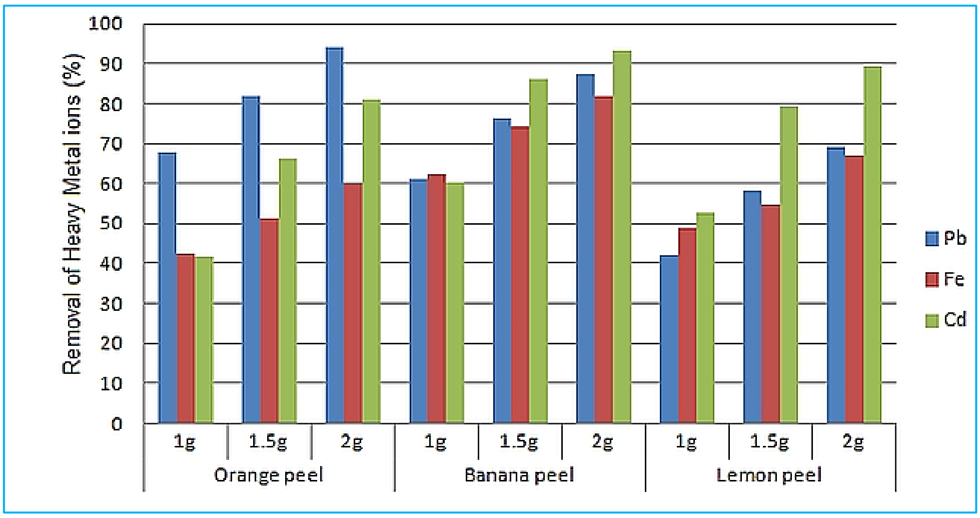

Fig 2 Heavy metal removal using natural absorbent

Table 3 Heavy metal removal efficiency of natural absorbents (%)

Heavy metals	Initial concentration (mg/l)	Removal of metal ion %								
		Orange peel			Banana peel			Lemon peel		
		1g	1.5g	2g	1g	1.5g	2g	1g	1.5g	2g
Pb	0.31	67.74	81.93	94.19	61.29	76.45	87.41	41.93	58.06	69.03
Fe	0.82	42.68	51.22	59.76	62.19	74.39	81.70	48.78	54.87	67.1
Cd	0.053	41.50	66.04	81.13	60.37	86.22	93.39	52.83	79.24	89.62

CONCLUSION

This study explored the contamination levels of heavy metals in five perennial Ponds (I to V) in Kanniyakumari district. Pb and Cd consistently exceeded the BIS standard limits in all ponds across all seasons. In contrast, Fe concentration exceeded Pond I and II limits during the post-monsoon season. These findings underscored the need for effective removal of these contaminants. Using an eco-friendly approach, the Pond II, IV and V with elevated Pb, Fe and Cd levels were treated with natural absorbents, including powered orange, banana and lemon peels. Based on the results, the removal efficiency of heavy metals increased with higher concentrations of absorbents. Orange peel demonstrated the highest efficiency in removing Pb (94.19%), while banana peels were most effective in removing Cd (93.39 %) and Fe (81.70 %), bringing their concentrations within the permissible limits. Further research and optimization could enhance the efficiency of these natural adsorbents in removing heavy metals from water sources with high contamination levels.

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