Eco-Friendly Treatment for the Removal Fluoride, Chloride and Hardness from Water Using Tamarind and Neem as Bio-Adsorbents

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Abstract
Water contamination due to high levels of chloride, fluoride, and hardness poses a significant threat to public health and the environment. This study explores an eco-friendly treatment method using tamarind and neem as bio-adsorbents for the removal of these contaminants. Water samples were collected from Chittur, Kozhinjampara, Kollengode, and Pallassena in Palakkad, Kerala, India. The treatment process involved using neem and tamarind individually at varying concentrations (5, 10, 15, 20, and 25 mg/L for neem; 4, 8, 12, 16, and 20 mg/L for tamarind) and in combination at different ratios (1:1, 1:2, and 2:1). Experimental results indicated that neem at 10 mg/L, tamarind at 12 mg/L, and the combination of both in a 1:1 ratio achieved the highest removal efficiency for chloride, fluoride, and hardness. This study highlights the potential of tamarind and neem as sustainable and cost-effective alternatives for water treatment, offering an environmentally friendly solution for mitigating water contamination.

Keywords: Water treatment, bio-adsorbents, neem, tamarind, chloride removal, fluoride removal, hardness reduction, eco-friendly approach.

1. INTRODUCTION

Water contamination occurs when harmful pollutants, such as heavy metals, pesticides, fluoride, chloride, and minerals causing hardness, enter water sources. These contaminants originate from industrial waste, agricultural runoff, and improper chemical disposal, affecting both human health and ecosystems. Polluted water can lead to severe health issues, including gastrointestinal infections, neurological disorders, and chronic illnesses, making effective treatment essential.

Clean drinking water is crucial for preventing diseases like cholera, typhoid, and diarrhea, ensuring proper hygiene, and supporting cognitive development in children. Contaminated water can cause malnutrition, stunted growth, and developmental delays, while safe water access enhances vels of fluoride, chloride, and hardness in drinking water can have serious health and environmental consequences. High fluoride levels may lead to dental and skeletal fluorosis, causing discoloration and damage to teeth and bones, and in severe cases, bone deformities. Long-term exposure to fluoride can also affect cognitive development in children. Elevated chloride levels can contribute to high blood pressure and gastrointestinal issues, with environmental impacts that disrupt aquatic ecosystems due to increased salinity, which affects the biodiversity of freshwater habitats. Water hardness, caused by high concentrations of calcium and magnesium, can lead to health issues like kidney stones and digestive disturbances.

The permissible limit for fluoride In drinking water, according to the World Health Organization (WHO) and the Bureau of Indian Standards (BIS), is 1.0 mg/L. Fluoride levels above this limit can cause health issues, such as dental and skeletal fluorosis. In areas where finding alternative water sources is challenging, levels up to 1.5 mg/L may be acceptable. However, exceeding the recommended limit increases the risk of fluoride-related health issues, especially affecting teeth and bones over long-term exposure. For chloride, the acceptable Concentration in drinking water is 250 mg/L. Chloride levels above this limit may start to affect the taste of water, making it salty or unpleasant. In cases where it's difficult to obtain water with lower chloride levels, concentrations up to 1,000 mg/L are allowed, though they may contribute to health issues like high blood pressure and stomach irritation. High chloride concentrations can also corrode pipes and appliances, impacting water infrastructure. Water hardness, measured as the concentration of calcium carbonate ($CaCO_3$), has an ideal limit of 150 mg/L. Hardness beyond this level can contribute to problems such as scaling in pipes and household appliances, reducing their efficiency and lifespan. Higher hardness levels may also increase the likelihood of kidney stones and digestive issues.

An eco-friendly approach using natural bio-adsorbents like tamarind and neem offers an effective, cost-efficient solution. Tamarind pulp and seeds, rich in hydroxyl and carboxyl groups, efficiently adsorb fluoride, while neem leaves contain tannins and flavonoids that help remove chloride and hardness-causing minerals. These bio-adsorbents function through adsorption, attracting and holding contaminants, after which they can be filtered out.

Using tamarind and neem for water purification is a sustainable, affordable, and environmentally friendly alternative to chemical treatments. Their widespread availability makes them ideal for rural and resource-limited areas, contributing to cleaner water, better health, and sustainable water management.

2. METHODOLOGY

2.1 Water Sample Collection

Water samples were collected from four locations: Chittur, Kozhinjampara, Kollengode, and Pallassena. Sampling points included public wells, borewells, and communal water sources. A total of five samples were collected—two from Kozhinjampara, one from Chittur, and two from Kollengode.

To maintain sample integrity, sterilized airtight plastic or glass bottles were used. Before collection, each container was rinsed with the respective source water to remove residual impurities. Samples were filled, leaving a small air space to prevent pressure buildup, then tightly sealed and labeled with location details. All samples were transported in a cooler to the laboratory and stored under controlled conditions to prevent contamination before analysis.

2.2 Initial Water Quality Analysis

The collected samples were analyzed for the following parameters before treatment:

Table.1 Initial Parameters of water samples

Parameters	Chittur	Kollengode	Kozhinjampara	Pallassena	Permissible limit
pH	8	6.6	8	6.9	6.5 – 8.5
Turbidity (NTU)	0.7	1	0.8	0.8	5
Hardness (mg/l)	112	167	92	125	150
Chloride (mg/l)	816	621	443	402	250
Fluoride (ppm)	2.7	1.9	1.5	1.5	1.5

Standard analytical methods, such as spectrophotometry for fluoride, titration for chloride and hardness, and pH and turbidity meters, were used to determine baseline values.

2.3 Preparation of Bio-Adsorbents

2.3.1 Tamarind Bio-Adsorbent

Mature tamarind pods were collected from local sources. The pods were manually opened, and the pulp was extracted, washed, and air-dried in a shaded area to retain adsorption properties. The dried pulp was ground into fine powder and stored in airtight containers.

2.3.2 Neem Bio- Adsorbent

Fresh, mature neem leaves were collected early in the morning to preserve bioactive compounds. Leaves were washed thoroughly, air-dried in shade, and ground into fine powder. The powder was stored in airtight containers for use in adsorption experiments.

2.4 Treatment Process

Adsorption experiments were conducted using different concentrations of neem and tamarind bio-adsorbents:

- Neem powder concentrations: 5, 10, 15, 20, and 25 mg/L
- Tamarind powder concentrations: 4, 8, 12, 16, and 20 mg/L
- Combined neem and tamarind ratios: 1:1, 1:2, and 2:1

Each treatment was performed by adding a known concentration of the bio-adsorbent to 100 mL of contaminated water in a beaker. The mixture was stirred at a constant speed for 180 minutes to enhance adsorption. After stirring, the solution was allowed to settle for a specified duration before being filtered.

2.5 Post-Treatment Water Quality Analysis

The treated water was analyzed for fluoride, chloride, and hardness levels using the same standard analytical methods as in the initial testing. Removal efficiency was calculated using the formula:

2.5.1 Using Tamarind Treatment

Table.2 Final parameters using Tamarind as Bio-adsorbents

Absorbent Dosage	Chittur			Kozhinjampara			Kollengode			Pallassena		
	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)
4 g/L	567	1.30	90	301	0.70	75	428	0.95	130	281	0.75	100
8 g/L	425	1.20	85	244	0.60	69	322	0.90	120	217	0.70	95
12 g/L	319	0.90	70	177	0.50	56	248	0.70	104	161	0.55	77
16 g/L	461	1.00	78	257	0.55	65	360	0.75	112	233	0.60	86

20 g/L	461	1.10	80	265	0.60	65	348	0.80	120	240	0.70	90

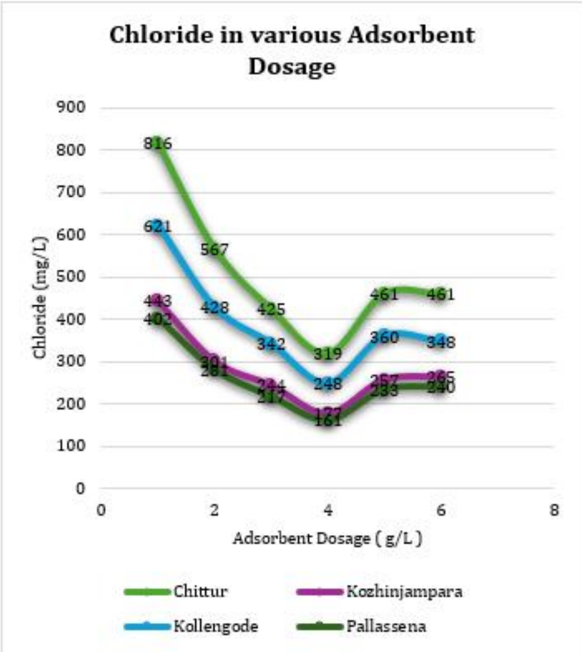

Chart 1: Chloride in various dosages using Tamarind

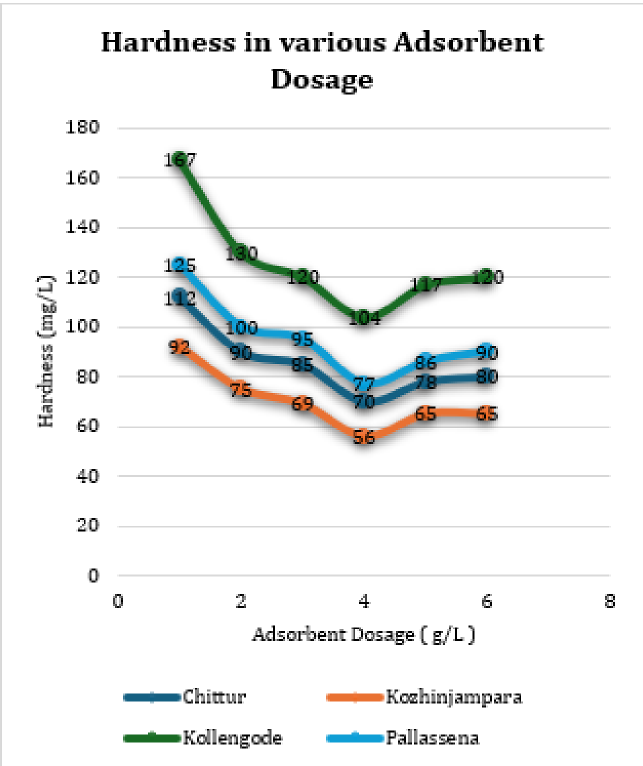

Chart 2: Hardness in various dosages Tamarind

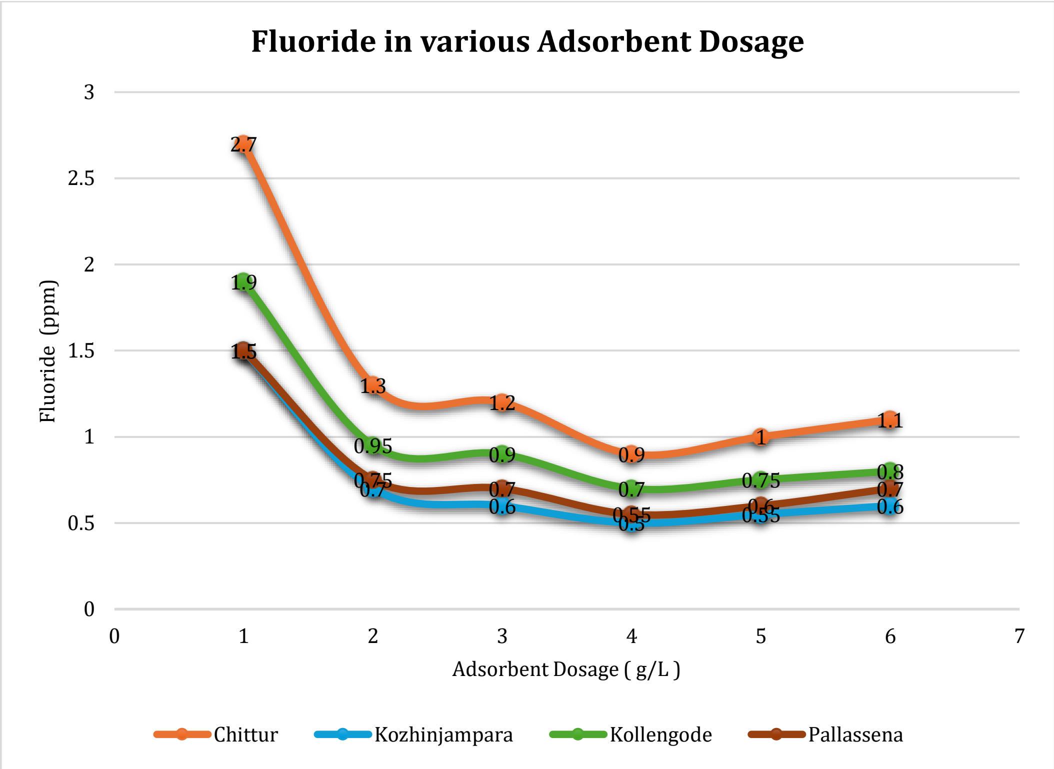

Chart 3: Fluoride level in various adsorbent dosages using Tamarind

The experimental study confirms the adsorption potential of Tamarind as a bio-adsorbent for water treatment, demonstrating its effectiveness in removing chloride, fluoride, and hardness. At an optimum dosage of 12 g/L, the removal efficiencies observed were 59–62% for chloride, 63–68% for fluoride, and 37–40% for hardness.

2.5.2 Using Neem Treatment

Table.3 Final parameters using Neem as Bio-adsorbents

Absorbent Dosage	Chittur			Kozhinjampara			Kollengode			Pallassena		
	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)
5 g/L	461	1.60	70	284	0.85	60	373	1.15	110	241	0.90	80
10 g/L	177	1.25	50	101	0.60	40	137	0.90	75	101	0.65	60
15 g/L	284	1.50	60	203	0.80	50	249	1.05	90	153	0.80	70

20 g/L	284	1.40	90	177	0.75	70	236	1.00	130	137	0.80	95
25 g/L	248	1.35	90	160	0.70	75	217	0.95	125	132	0.75	100

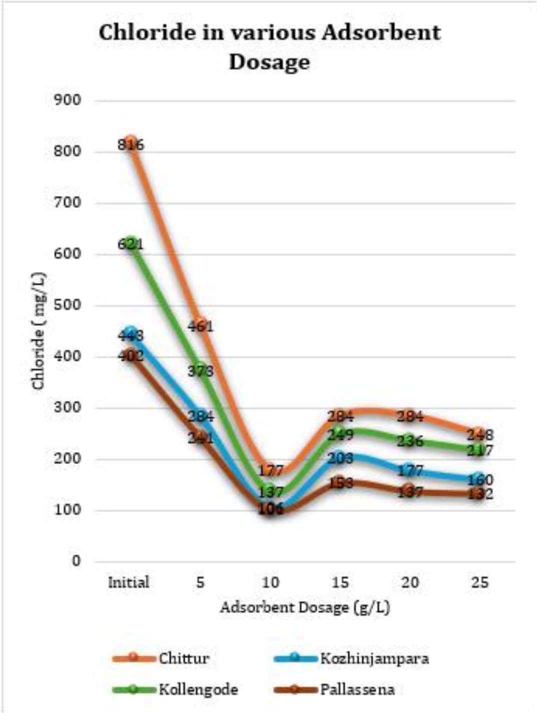

Chart 4: Chloride in various dosages using Neem

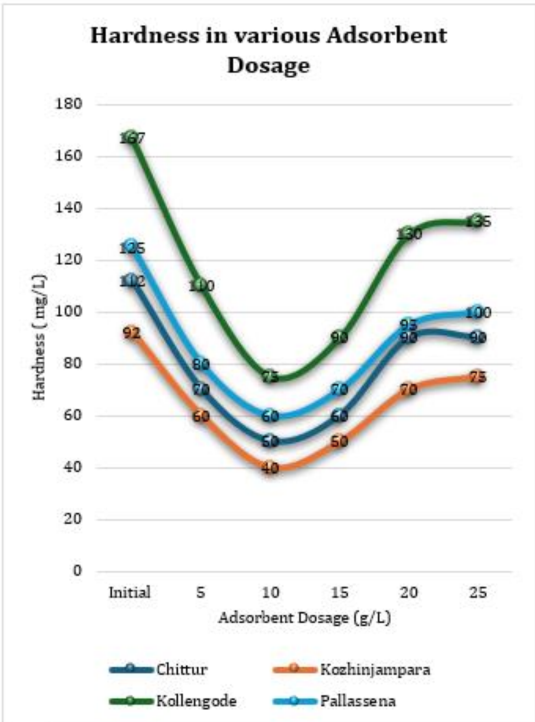

Chart 5: Chloride in various dosages using Neem

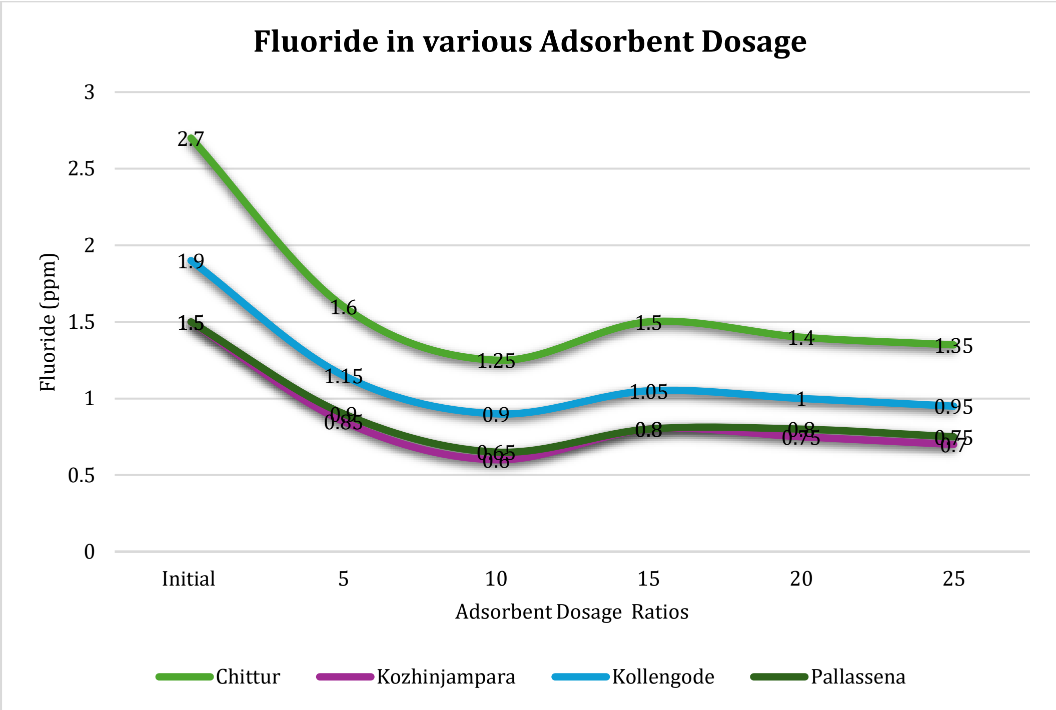

Chart 6: Fluoride level in various adsorbent dosages using Neem

Using neem as a bio-adsorbent demonstrates high removal efficiency at an optimum dosage of 10 g/L , with chloride reduction of 74–78%, fluoride removal of 52–60%, and hardness reduction of 52–57%. This indicates the strong adsorption capacity of neem for these contaminants, likely due to its active functional groups. The efficiency variation suggests that factors like adsorbent dosage, contact time, and solution pH influence performance. Optimal conditions ensure maximum removal, while exceeding dosage limits may lead to adsorption saturation or ion desorption.

2.5.3 Using Combination of Tamarind and Neem

Table.4 Final parameters using the combination of neem and tamarind

Absorbent Dosage	Chittur			Kozhinjampara			Kollengode			Pallassena		
	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)	Chloride (mg/L)	Fluoride (ppm)	Hardness (mg/L)
1:1	142	0.35	40	89	0.20	32	142	0.25	60	77	0.20	45
1:2	213	0.45	60	115	0.25	49	168	0.35	90	103	0.25	64
2:1	248	0.50	70	133	0.25	56	197	0.4,0	104	129	0.30	78

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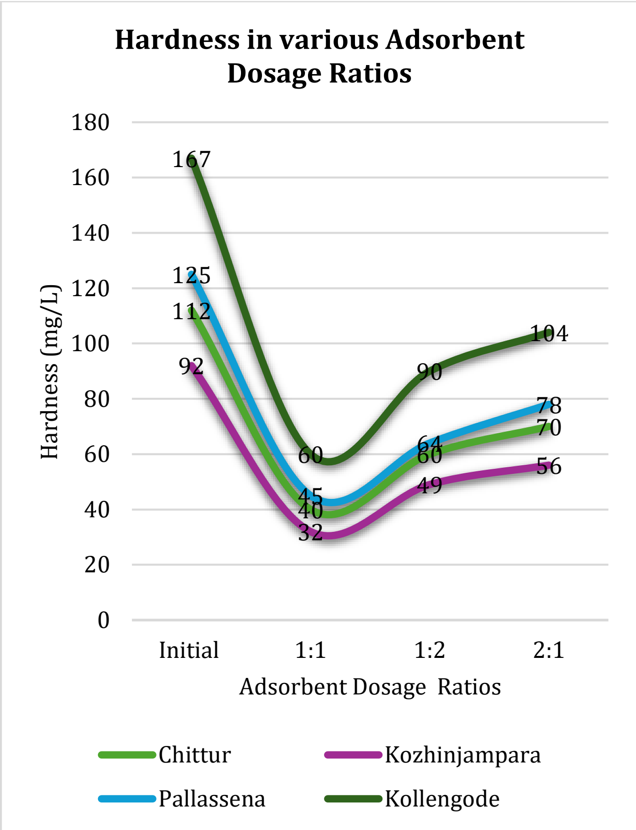

Chart 7: Chloride in various ratios of neem and tamarind

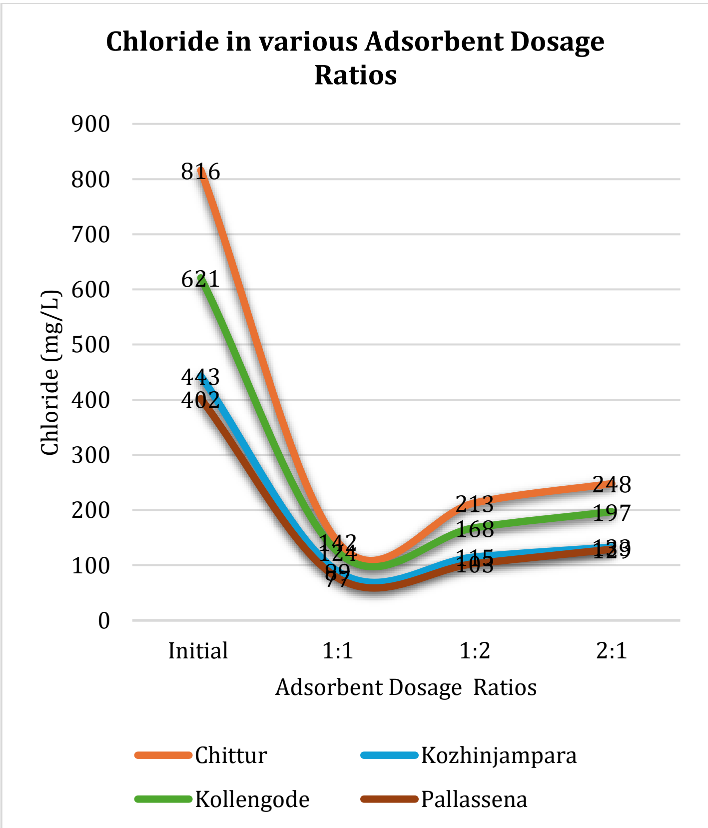

Chart 8: Hardness in various ratios of neem and tamarind

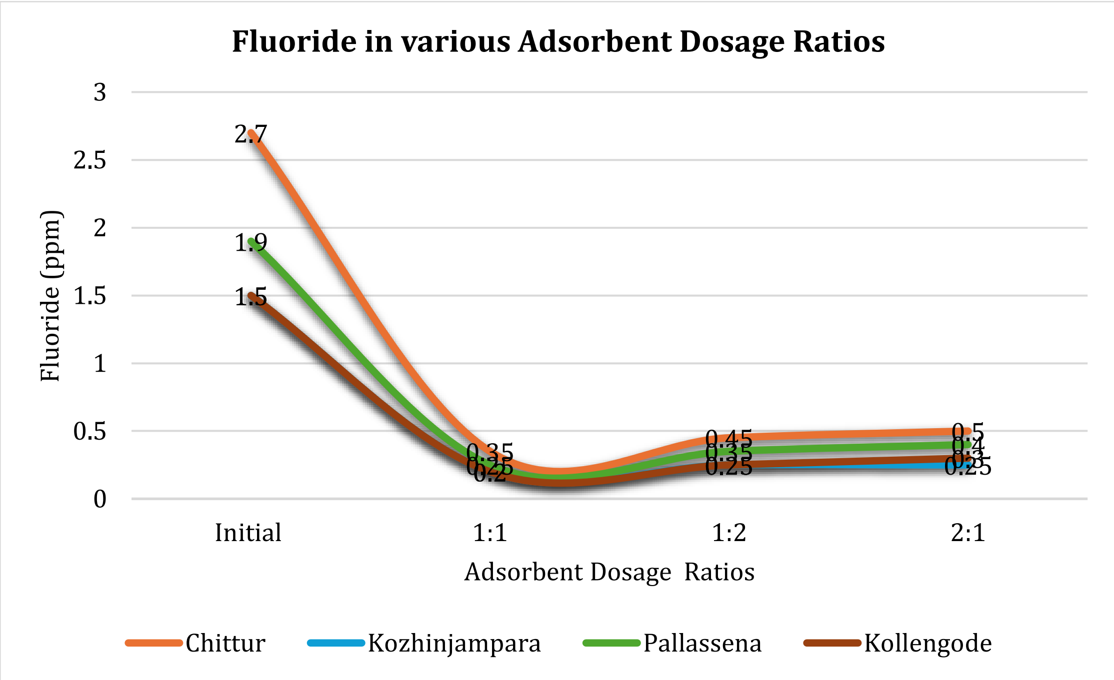

Chart 9: Fluoride in various ratios of neem and tamarind

The combination of Neem and Tamarind as bio-adsorbents significantly enhances the removal efficiency of chloride, fluoride, and hardness in water treatment. At the optimum dosage ratio of 1:1, the removal efficiency observed is 78–83% for chloride, 85–88% for fluoride, and 62–65% for hardness.

3. CONCLUSION

The study demonstrates that Tamarind and Neem are effective bio-adsorbents for the removal of chloride, fluoride, and hardness from water, with Neem showing superior adsorption capacity compared to Tamarind when used individually. At their respective optimum dosages (12 g/L for Tamarind and 10 g/L for Neem), Neem exhibited higher chloride and hardness removal, while Tamarind showed better fluoride adsorption. However, the most efficient approach was found to be the combination of Neem and Tamarind in a 1:1 ratio, which significantly enhanced removal efficiency to 78–83% for chloride, 85–88% for fluoride, and 62–65% for hardness. This improvement is due to the synergistic effect of their active functional groups, which enhances the adsorption of multiple contaminants simultaneously.

Beyond the optimum dosage, a decline in removal efficiency was observed. This can be attributed to adsorption saturation, where the active sites on the bio-adsorbents become fully occupied, preventing further contaminant uptake. Additionally, at higher dosages, particle agglomeration may occur, reducing the available surface area for adsorption. Furthermore, excessive adsorbent concentrations can lead to ion desorption or competition among adsorbent particles, negatively impacting overall efficiency.

These findings establish that the Neem-Tamarind combination is the most efficient, cost-effective, and sustainable solution for water purification, particularly in regions affected by fluoride and chloride contamination. Further studies on adsorption kinetics, desorption mechanisms, and large-scale applications can enhance the feasibility of this approach for real-world water treatment systems.

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