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Pilot Implementation of Floating Treatment Wetland Systems in Nagdaha, Nepal: Field Experience, Performance, and Lessons Learned

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Abstract

Population growth and agricultural practices, excessive nutrients, and pollutants increasingly threaten surface water bodies and ecosystems. The Floating Treatment Wetland System (FTWS) is one of the nature-based remediation technologies consisting of a floating raft that supports phytoremediation plants, allowing roots to be suspended in the water column to remediate different pollutants from water. The study was conducted in Nagdaha, Lalitpur, to test the efficacy of FTWS in remediating polluted surface water. For this, 40 floating rafts of 1.2’ × 1.8’ (2.16 sq. ft.) each were constructed and planted with *Canna indica* (CI) and *salvia Splendens* (SS) that were strategically deployed on the lake at five different points, with each point consisting of eight rafts. Water quality parameters (nitrate, ammonia, phosphate, and iron) were monitored at all the installed points, including the inlet and outlet of the lake. During the five-month test period, the maximum nitrate reduction was 94% in the rafts installed at the northeast (NE) point, while the maximum iron reduction was 95% in the southeast (SE) point. In the case of ammonia, the maximum reduction was found to be 68% at the southwest (SW) point compared to the lake inlet. Statistical analysis revealed a significant difference ($p < 0.05$) only for nitrate concentration between inlet and outlet points, suggesting minimal impact on other parameters. The study indicated better survival of CI compared to SS, and floating rafts with CI enhanced the scenic beauty of the lake after blooming. These findings thus demonstrate the potential of FTWS as a sustainable and effective solution for water quality improvement and suggest that increasing the number of rafts could optimize the efficacy for broader applications in a similar type of context.

Keywords: Floating Treatment Wetland System (FTWS), floating rafts, Nagdaha Lake, phytoremediation, nature-based remediation technology

1. Introduction

Water is important for all social, economic, environmental, and global ecosystems. Surface water bodies, such as rivers, lakes, and reservoirs, are an integral component that influences the Earth's ecosystem, affecting the climate and environment globally (Ali et al., 2019). Due to population growth and agricultural practices, excessive nutrients and pollutants increasingly threaten these ecosystems. In Nepal, surface water bodies are polluted due to inadequate treatment facilities and a lack of comprehensive planning for treatment (Karki et al., 2024). The runoff and seepage from livestock areas, agricultural lands, and sewage increase the amount of mineral and organic nutrients in water bodies. The excessive amount of these minerals supports the intense growth of aquatic plants and blue-green algae, which degrades the oxygen level in water, making the water unsuitable for the aquatic ecosystem. These conditions enhance the eutrophication of the water source (Stewart et al., 2008). Numerous technologies are being developed to create a more sustainable approach to treating polluted water (Colares et al., 2020). Many countries are using traditional ways of treating wastewater, which are costly for installation, as well as maintenance and require close supervision of professionals (Arivukkarasu & Sathyanathan, 2024).

FTWS has emerged as a nature-based remediation technology for treating polluted water bodies with less investment and maintenance (Arivukkarasu & Sathyanathan, 2024; Stewart et al., 2008). It is simple and cost-effective (Sharma, 2021). FTWS constitutes a floating raft that supports phytoremediation plants, allowing roots to be suspended in the water column. Floating mats were initially described by Pallis in 1915 and were applied for tertiary treatment of wastewater at Arcata, California in 1986. FTWS is a developed form of constructed wetlands (CWs), also named planting floating system beds, artificial or vegetated floating beds, and constructed floating wetlands (CFWs) (Yeh et al., 2015; Pallis, 1915; Sharma, 2021).

Recent studies have highlighted the importance of linking scientific research on nature-based solutions with local community understanding to ensure sustainability and ownership of such initiatives. In Nepal, Pradhananga et al. (2025) demonstrated how effective science communication can strengthen public engagement with FTWS projects, enhancing long-term community support. At the global level, Castelli et al. (2025) emphasized co-creation of water knowledge through community perspectives, underscoring the value of participatory approaches in hydrological research and water management.

This nature-based solution helps to remove both organic and inorganic pollutants like nitrogen and phosphorus from the water (Johnson, 2021). The roots of the plant grow into the water column while the shoots develop above the water's surface. Extensive root systems in the water column provide a larger surface area for intercepting sediment, absorbing nutrients, and releasing soluble carbon and other bioactive compounds that enhance the removal of contaminants (Tanner & Headley, 2011; White, 2013). The removal of pollutants from water is also significantly assisted by the biofilm that is generated by the hydrophytes' roots and rhizomes (Arivukkarasu & Sathyanathan, 2024).

Floating rafts can be prepared with a variety of materials, including bamboo, plastics, foams, etc. However, the raft, materials should be chosen wisely to make the raft more durable, effective, cost-efficient, and environmentally friendly (Dotro et al., 2017; Colares et al., 2020)

FTWS utilizes the natural filtering and nutrient uptake capabilities of plants and microbes to remove pollutants from the water. These systems offer advantages like adaptability to variable water levels, support for diverse plant species, and effectiveness in cold temperatures (Stewart et al., 2008). FTWS mainly focuses on the application of the natural capacity of plants in remediating pollutants from water bodies through physical, biological, and chemical processes (Colares et al., 2020; Winston et al., 2013; Sharma, 2021).

FTWS technology can be installed in existing ponds and drainage canals for water remediation. The rafts float freely on water bodies due to which it doesn’t require an additional area. The maximum amount of nutrients removed from the system can be gained through the timely removal of the plants that have reached optimum maturity, which can reduce the possibility of returning the absorbed nutrients to the water. This can be achieved through timely monitoring and removal of the dead plant parts (Garcia Chance et al., 2019; Pavlineri et al., 2017; Zhao et al., 2012; Locke-Rodriguez et al., 2023).

This pilot study was conducted to investigate the applicability of FTWS for remediating the surface water body at Nagdaha, Nepal. The effectiveness of selected plant species in nutrient removal was evaluated, and the aesthetic values provided by the floating rafts were assessed.

2. Materials and methods

2.1 Site description

The study was carried out at Nagdaha Lake (27° 37' 28" N 85°19' 58" E), an urban lake that holds significant historical, cultural, and ecological value in the Kathmandu Valley (Figure 1). The lake receives spring water from a stone tap on the south of the lake, originating from a small forest beside the tap. The irregular-shaped lake has an approximate area of 25,253 m^2. It is surrounded by urban settlements, agricultural lands, roads, and resorts, which contribute to runoff water, seepage, and other pollutants. Additionally, visitor activities like littering and bathing directly in the lake further pollute the water.

2.2 FTWS Design and Installation

Forty floating rafts (1.2 x 1.8 m each) were constructed using low-cost locally available bamboo frames, bamboo mats, polyethylene foam, and Styrofoam sheets to enhance buoyancy and durability. Looking at the nutrient uptake capacity, *Canna indica* (CI) and *Salvia splendens* (SS) were planted in all the floating rafts. The rafts were deployed in December 2022 at five locations (NE, NW, SE, SW, and Central), with eight rafts at each site covering an area of 18 m^2 (Figure 1). The installed rafts covered 0.34% of the lake's total area. More information on the detailed construction of rafts can be accessed through the Guidebook FTWS (Byanju et al., 2024).

2.3 Water-Sampling and Laboratory Analysis

Water quality tests were conducted on the water samples taken from around the floating rafts installed points, the inlet and the outlet to assess any changes in water quality for four months (Table 1). The samples were tested in the government-certified labs in Kathmandu. The nitrate, phosphate, iron, ammonia, dissolved oxygen (DO), and biological oxygen demand (BOD) were tested in the laboratory using standard methods from APHA, AWWA, and WEF (2017).

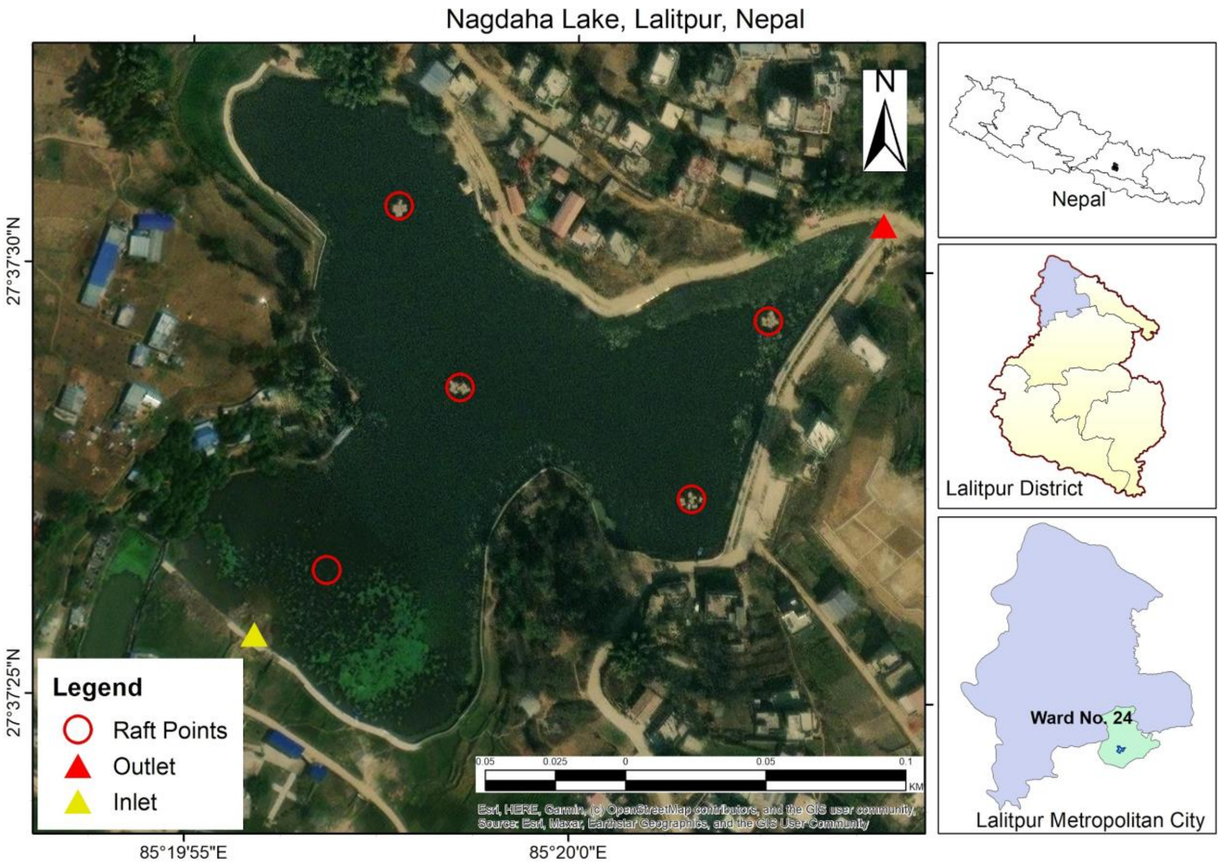

Figure 1: Location map with 5 raft installed points; inlet and outlet of Nagdaha

Table 1: Water sampling tests

S.N.	Activities	Date of the activities
1	Raft installation	December 20, 2022
2	First test	December 23, 2022
3	Second test	January 9, 2023
4	Third test	January 24, 2023
5	Fourth Test	February 22, 2023
6	Fifth test	March 18, 2023

2.4 Statistical analysis

The data normality test was done using the Shapiro-Wilk test and by observing the histogram. For pairwise comparison parameters of samples from the same site at different dates, a normal distribution was done using a student t-test. Welch's t-test was used for a non-parametric distribution. Statistical significance was determined at $p < 0.05$. All statistical analysis and data handling processes were conducted in R (RStudio).

3. Results

Among the two plant species tested in Nagdaha, only CI demonstrated good survival throughout the five-month monitoring period and five-month field observation period. SS did not survive in the open environment.

3.1 Effectiveness of FTWS

Before this study, a pilot microcosm study was conducted using the CI and TP in Lalitpur to know the effectiveness of the selected plant species and the FTWS system in remediating the pollutants from the water of Nagdaha. The study revealed that CI was effective in remediating pollutants. The microcosm study, which will be described in a separate publication (details are in Kayastha, 2024), showed the reduction of major pollutants like ammonia, phosphate, nitrate, iron, and BOD by 54%, 91%, 99%, 56%, and 41%, respectively, while an increase of DO by 50%. Besides this, a significant difference was observed between the control and plant units in the microcosm study in different treatment units. This further indicates that expanding the number of rafts could further enhance or improve the water quality of the lake.

On the first test, the inlet concentration of nitrate, ammonia, phosphate, and iron was 2.57 mg/l, 0.47 mg/l, 0.33 mg/l, and 0.52 mg/l, respectively. The maximum value of ammonia was observed on the third test with a value of 2.44 mg/l, phosphate on the fourth test with a value of 0.69 mg/l, and the highest concentration of iron was observed on the second test with 3.02 mg/l in the inlet. The concentration of nitrate, ammonia, phosphate, and iron was reduced to 0.09 mg/l in the NE sample point, 0.4 mg/l of ammonia in CN, and iron by 0.1 mg/l in all sample points in comparison to the inlet of the lake. The concentration of DO in the Inlet was 6.7 mg/l, while its maximum concentration (8.4 mg/l) was observed in the SE raft installed point. On average, the concentration of major nutrients like nitrate and ammonia has decreased at the different raft installed points in comparison with the inlet concentration, while the concentration of orthophosphate has increased in comparison with the inlet concentration. The increase of the ortho-phosphate at different raft installation points may be due to the waste materials and washing activities done in Nagdaha. The iron concentration has also decreased in comparison to the inlet concentration (Figure 2).

Compared to the inlet concentration level, the maximum nitrate reduction was 94% at the raft installed at the NE point, while the maximum iron reduction was found in the SE points at 95% during the test period. In the case of ammonia, the maximum reduction was 68% at the SW point (Figure 3). The bar graph shows the average percentage change of various parameters at different installed points compared to the inlet of the lake.

3.2 Significance Test

A notable change in the nitrate value was observed among the samples collected from different raft points, except for the SW point of Nagdaha, with respect to the inlet concentration. Nitrate and iron demonstrated significant changes, with the probability of occurrence (p) value being less than 0.05 (Table 2). DO concentration was found to be significantly different in the SW, CN, and SE points concerning the inlet concentration. Ammonia concentration was significantly different in SW, CN, and NE points compared to the inlet. Besides this, the remaining raft installed points have not shown any significant changes compared to the inlet.

In the microcosm study conducted simultaneously with the raft water quality monitoring, the majority of the plant species of CI survived, with only a few plants being replaced (one plant) per month or once in two months in the entire setup.

However, in the case of SS, as most of the plants did not survive in the microcosm study as well. However, the few SS plants that survived in the microcosm setup showed good resilience.

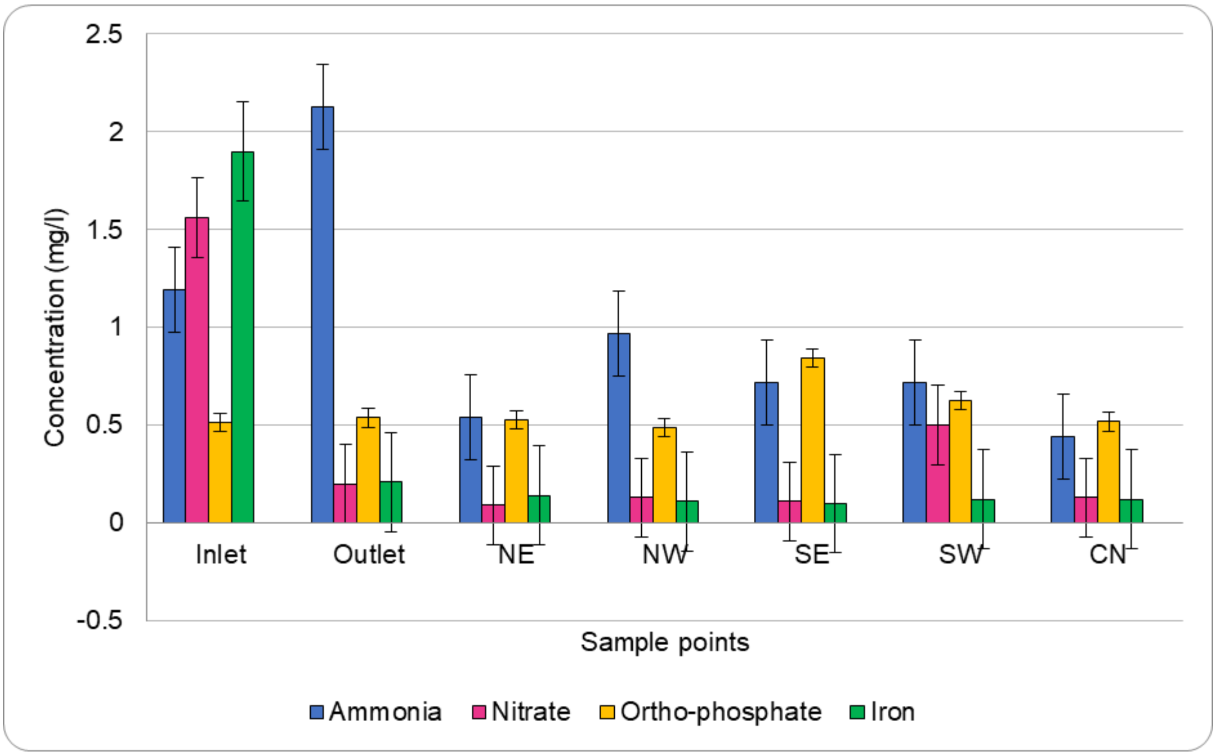

Figure 2: Average concentration at the raft sites over the sampling period. The error bars show the standard error of the mean, showing that the change of water quality fluctuated with the inlet water quality.

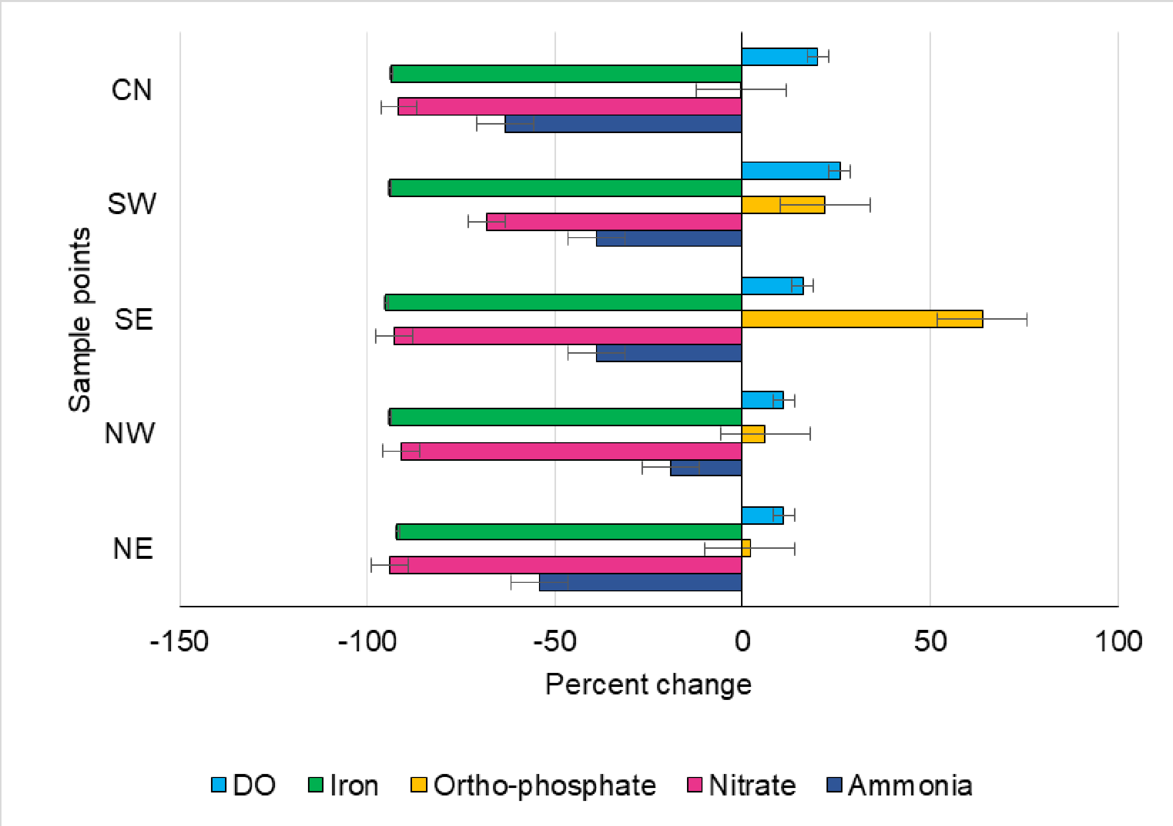

Figure 3: Average percent change of the parameters at raft sites. Error bars as explained in Figure 2.

3.4 Scenic Beauty by FTWS

The survival rate of CI was higher in comparison to SS, both in the microcosm study and floating rafts. Although CI dried in its off-season, it regenerated and blossomed, enhancing the aesthetic beauty of Nagdaha during the flowering season. In the case of SS few plants survived but the flowers were not significant in quantity to contribute to the overall beautification of the lake. To increase the number of flowers in the floating rafts, the number of plants should be increased - which will show significant and noticeable aesthetic effect in Nagdaha lake. However, there is a possible drawback to this aspect - the dried parts of the plant after flowering could decompose and potentially add nutrients back to the water. Therefore, it is crucial to regularly remove dried plant materials to maintain water quality.

Furthermore, in a questionnaire survey conducted in Nagdaha (Pradhananga et al., 2025), 97% of respondents responded that the installation of FTWS in Nagdaha has helped to enhance the scenic beauty of Nagdaha.

4. Discussion

This study was carried out to understand the effectiveness and potential of FTWS for removing excess nutrients and reducing the eutrophication of Nagdaha Lake. The microcosm study in a controlled environment using CI and TP showed promising results in removing the pollutants from water. Similarly, the pilot-scale FTWS in Nagdaha showed a reduction of 94% nitrate at the NE sampling point and a reduction of 68% ammonia at the SW sampling point in comparison to the inlet of the lake. These results show a consistent outcome that aligns with the study mentioned by White (2013) that revealed a reduction in Nitrogen concentrations by 84% in 2008 and by 58% in 2009 in effluent. Similarly, effluent phosphate concentrations were removed by 75% in 2008 and 46% in 2009. These nutrient removals from the pond were based on a variety of nutrient loading rates, plant uptake of nutrients, and percent coverage of FTWS. Based on these results, further reduction of nitrate and phosphate pollutants can be expected at Nagdaha Lake.

The overall pollutant removal efficiency was limited. The results from statistical analysis showed a significant difference in nitrate concentrations between the inlet and outlet points ($p < 0.05$), however, other pollutant parameters were insignificant. Given the extremely low areal coverage (0.34%), statistically significant changes were unlikely for all parameters. The observed nitrate reduction nevertheless indicates localised raft-zone efficiency. These results align with the previous studies by White (2013) and Tanner &

Headley (2011), where a higher FTWS coverage (5-10%) is recommended for effective nutrient remediation in ponds. Hence, we can assume that expanding the FTWS coverage in Nagdaha could significantly improve its effectiveness.

Table 2: Significant test result for nitrate at Nagdaha

S.N.	Comparison	Mean	t value (t-test)	df (Degree of freedom)	p-value, 0.05	Test Result
Significance test results of nitrate						
1	Inlet	1.554	2.689	4.718	0.046	Significant
	Outlet	0.204				
2	Inlet	1.554	1.745	7.434	0.122	Not Significant
	SW	0.504				
3	Inlet	1.554	2.941	4.099	0.041	Significant
	CN	0.132				
4	Inlet	1.554	2.963	4.197	0.039	Significant
	SE	0.112				
5	Inlet	1.554	2.934	4.107	0.041	Significant
	NW	0.134				
6	Inlet	1.554	3.020	4.093	0.038	Significant
	NE	0.094				
Significant test result of iron						
1	Inlet	0.488	3.905	4	0.017	Significant
	Outlet	2.888				
2	Inlet	0.599	4.190	4	0.014	Significant
	SW	2.953				
3	Inlet	0.565	4.076	4	0.015	Significant
	CN	2.979				
4	Inlet	0.556	4.024	4	0.016	Significant
	SE	3.032				
5	Inlet	0.556	4.031	4	0.016	Significant
	NW	3.020				
6	Inlet	0.555	4.062	4	0.015	Significant
	NE	2.953				

Likewise, the observed lack of significant differences in phosphate and iron reduction might also be related to factors beyond the coverage area. These factors could include plant selection and seasonal variations in plant activity. The microcosm study revealed that SS did not survive well, limiting its potential to contribute to the remediation of surface water bodies. Future studies could explore the performance of FTWS with different perennial plant species that are better adapted to local conditions. Additionally, a long-term study in Nagdaha is needed, as 15 months might not be sufficient to capture the seasonal variability and potential of FTWS. Despite limited pollutant removal, the project strengthened community stewardship, showing how visual and educational benefits can sustain long-term lake management. Research on the economic aspects of FTWS, like the cost-benefit analysis (CBA) in the context of Nepal, would also provide important insights to help with broader implementation.

(a) (b)

Figure 4: (a) Plants in floating rafts when they dried (b) Plants in floating rafts during the flowering season

5. Conclusion

The pilot-scale FTWS at Nagdaha, which was the first-ever FTWS study done in Nepal, achieved a maximum nitrate reduction of 94%, whereas the removal efficiency of other pollutants was limited due to a very low coverage area of just 0.003% compared to the lake area. The findings also highlighted the importance of selecting the plant species, as CI displayed better survival than SS. Similarly, the aesthetic significance of FTWS is also important to capture, fascinate, and garner the community's attention, support, and engagement in such nature-based efforts. The community showed curiosity and interest in the research activities during the raft construction phase. While FTWS enhances scenic beauty during the flowering season, it is important to regularly remove dried plant material to maintain the aesthetic value and preserve the water quality. The main limitations of this study were the minimum coverage area by FTWS and the short study period to capture the full seasonal variability and effectiveness of the plants in floating rafts. This study provided insights for implementing larger-scale FTWS in Nagdaha as these types of interventions are essential to improve the water quality by removing pollutants from the water body.

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