CONSTRUCTED WETLANDS: A SUSTAINABLE SOLUTION FOR TREATING RAW WATER USING RECYCLED CONCRETE WASTE MEDIA TO ACHIEVE SDGS

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ABSTRACT

In Bangladesh, construction and demolition waste is rapidly increasing due to a surge in construction activities such as infrastructure projects, commercial buildings, and housing programs. Moreover, it is noteworthy that recent large-scale ventures like the third terminal of Dhaka's Hazrat Shahjalal International Airport, Padma Rail Bridge, and the Agargaon-Motijheel section of Dhaka Metro Rail have contributed significantly to the accumulation of construction waste. Despite this, the ongoing implementation of projects such as the Chattogram-Cox's Bazar rail link, Matarbari 1200MW coal-fired power plant, the Payra deep-sea port, and the Bangabandhu Sheikh Mujibur Rahman Railway Bridge over the river Jamuna is anticipated to generate an even greater volume of construction waste. Dhaka city alone generated 1.28 million tons of waste in FY 2016, with concrete waste constituting the largest proportion at 60%. Concrete is the second most consumed material after water, and globally, there is a challenge of disposing of 12 billion tonnes of demolished concrete waste annually. So the generated construction waste from the ongoing mega projects will be a concern for the future. This emphasizes the urgency and relevance of exploring sustainable solutions for these concrete waste. This research may offer a sustainable solution to this current pressing problem, simultaneously serving as a means to address another challenge — the enhancement of water quality prior to its discharge into the environment or surface water. This study presents a successful demonstration of using recycled concrete waste as a medium for wetlands, which can be used to treat municipal or any raw wastewater. Moreover, provides a comparison between the other two media with concrete waste media. The strength and potential of the material have been evaluated, and the study investigates the effectiveness of wetlands in removing *E. coli*, pH, color, turbidity, total solids, total dissolved solids, and total suspended solids from raw water. The system employs Canna indica, an aquatic plant, to purify water, while concrete waste, coal, and sawdust are used as media. This paper sheds light on how concrete waste can be reused as an efficient tool for sustainable solutions in treating raw water as a media for constructed wetlands. Recycling and reusing concrete waste can tackle environmental degradation and be a potential measure for converting waste into wealth. Furthermore, integrating concrete waste into initiatives aimed at enhancing the quality of untreated water before its release into the environment or surface water contributes an additional optimistic dimension to this solution. This dual-purpose approach not only addresses environmental concerns by managing waste effectively but also introduces a positive aspect by leveraging concrete waste to positively impact the quality of raw water, aligning with the overarching goals of the paper. The utilization of recycled concrete waste presents an opportunity to advance various Sustainable Development Goals (SDGs) outlined by the United Nations, which include SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 11 (Sustainable Cities and Communities).

Keywords: *Concrete Waste, Recycling, Water Treatment, Wetland, SDG*

1. INTRODUCTION

Bangladesh has made some remarkable achievements related to development in recent times (Islam et al., 2021). Presently Bangladesh is taking a multiple megaproject for continuing the legacy of this development. However, there is a significant lack of attention and disregard for research and technical resources concerning the management of construction waste in Bangladesh (Chowdhury, 2016). The production of construction and demolition (C&D) waste in Bangladesh surpasses that of numerous developed and developing nations. The primary reasons for this elevated waste generation include a lack of public awareness, ineffective law enforcement, insufficient community sensitization, and the utilization of outdated technologies (Chowdhury et al., 2016). It's important to recognize that a lot of construction waste is being generated due to the fast-paced development in the construction sector. Also, the impact of this waste on the environment is no longer just a local problem; it affects broader regions (Islam et al., 2019). This underscores the immediate need to investigate sustainable solutions for concrete waste. Conversely, Bangladesh as a developing country has a high population density and is facing a significant problem of water pollution, which poses a serious threat to public health (Schwarzenbach, 2010). Similar to other growing nations worldwide, this country is also confronting significant water contamination as a result of swift urbanization and industrial operations (DoE, 2016; Islam et al., 2020). This country is highlighted by a multitude of rivers, totaling more than 230, ranging across scale from major to minor (Hasan, 2019). Regrettably, the pollution in these rivers is a direct consequence of human activity and has significantly obstructed their flow (Majumder, 2009). The surface water is heavily polluted due to the unrestricted discharge of untreated municipal wastewater (Afrin, 2021). It is imperative to subject municipal wastewater to treatment prior to its discharge into surface water. Prior to discharging wastewater into the environment, it is necessary to undergo preliminary treatment if there is a significant presence of suspended particles or soluble organic matter, and the treatment method can be carried out by using hybrid wetlands (Moshiri, 1993). Additionally, hybrid-constructed wetlands exhibit higher efficacy in the overall removal of nitrogen (Vymazal, 2013). However, the wetland's design needs to be modified depending on the type of wastewater. Hybrid-constructed wetlands (HCW) were first introduced by Seidel in Germany as early as the 1960s (Vymazal, 2013). HCW established in the recent past, indicate that these treatment systems are predominantly employed in Europe and Asia (Vymazal, 2013). In artificial wetlands, two types of flow can be separated subsurface flow and surface flow. Here planted flora substantially aids in the removal of pollutants and other nutrients, meanwhile the filter bed, which is typically made of locally sourced or created materials, also plays a fundamental role (Moshiri, 1993). In this experiment, it was tested whether locally made hybrid wetlands were effective at removing contaminants such as *Escherichia coli* (*E. coli*), pH, color, turbidity, total solids (TS), total dissolved solids (TDS), and total suspended solids (TSS) from municipally produced raw water. It is conceivable that the expenses associated with constructing water treatment facilities could be significantly reduced by incorporating local materials such as the reuse of the C&D waste as media of constructed wetlands. Therefore, this study has the capacity to offer a feasible and enduring solution to these pressing challenges. More precisely, it focuses on the processing of untreated water and the utilization of concrete debris as a means of purifying municipal water prior to its release. The proposed methodology not only enhances water treatment efficacy but also repurposes concrete waste, thereby making a valuable contribution to environmental cleanliness.

1.1 Study Objectives

The objective of this study is outlined as follows.

- To evaluate the potential of recycled concrete waste as a sustainable and cost-effective medium in constructed wetlands, specifically examining its effectiveness in treating raw water and eliminating contaminants.
- To investigate the efficiency of recycled concrete waste in comparison to other media in constructed wetlands to determine its effectiveness in water quality improvement.

2. METHODOLOGY

2.1 Study area and raw water collection

In this study, municipal wastewater samples were collected from Alir Ghat (in **Figure-1**), an unauthorized connection of domestic sewer in the Buriganga River, functioning as a non-point or diffuser source of discharge. This unregulated connection leads to the substantial release of untreated municipal wastewater directly into the Buriganga River.

Figure 1: Location of collection point (Alir Ghat canal)

For the collection of wastewater, sunlight-insulated barrel drums with a capacity of 30 liters per container were used. Each tank was filled with 45 liters of wastewater, resulting in a total collection of 135 liters per week. The water collection process was meticulously conducted during the morning hours, specifically from 6 AM to 9 AM. This deliberate and systematic methodology ensured the acquisition of representative raw water samples, providing a comprehensive and accurate dataset for our study's analysis.

2.2 Dosing Mechanism

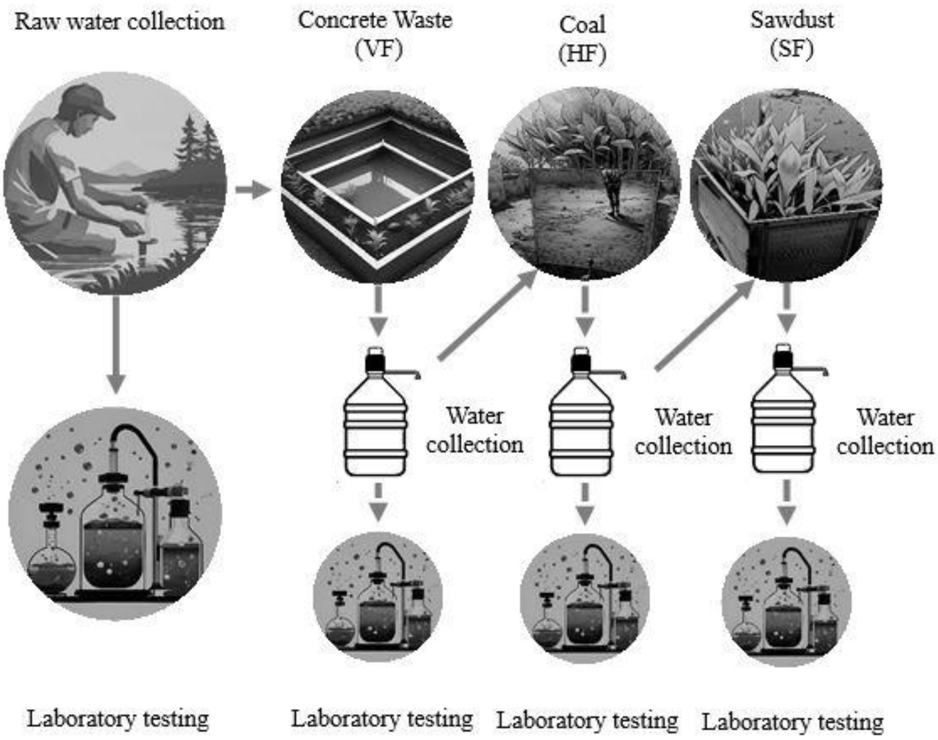

Figure 2: Process flow and dosing system for hybrid constructed wetland

The collected municipal wastewater samples were dosed three days a week in the experimental wetland units. The hybrid wetland system consisted of three stages: Vertical Flow (VF), Horizontal Flow (HF), and Surface Flow (SF) (in **Figure 2**). The raw water was manually dosed into the first stage VF wetland unit. The wastewater then flowed vertically via gravity toward the outlets of the first-stage wetlands in approximately 30 minutes. Subsequently, it was transferred by gravity into the second-stage HF wetland units, allowing for a 48-hour retention time in each unit. After this period, the water from the second stage was transferred by gravity into the third-stage SF wetland unit, producing the final effluent for the entire hybrid system. The outlet is first left open for two minutes to test the effectiveness of the filtration procedure. Treated wastewater samples were collected weekly from inlets and outlets across each stage of the wetland system and promptly analyzed at the laboratory.

Figure 3: Weekly dosing for wetland System

Every Saturday, Monday, and Wednesday, the dosage was given. The weather might occasionally modify the dosage. Due to evapotranspiration, plants require more water throughout the heat. The weekly dosing of raw water to the wetland system is shown in **Figure 3**. The experiment was run for 3 weeks.

2.3 Water retention tank’s dimensions and specifications

Square-shaped tanks were used for vertical flow (VF), whereas rectangular tanks were used for horizontal flow (HF) and subsurface flow (SF). The steel used to construct these tanks is quite strong. The reactor's outflow was positioned one meter from the base. As the reactor's outflow, a 2-inch valve is utilized. The VF had a square-shaped tank. This tank is made with high-strength steel materials. The dimension consists depth of 3 ft11 inch, a width of 1ft 7 inch, and a length of 1 ft 7 inch shown in **Figure-4,** Figure A presents an overhead perspective of the tank, while Figure B depicts a lateral view.

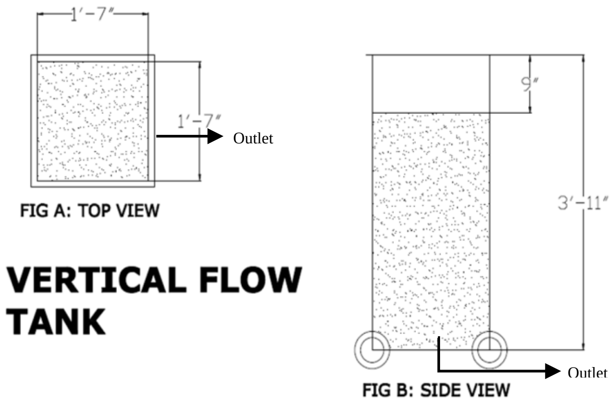

Figure 4: Vertical flow tank for wetland system

The outlet was located at 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor.. In the outlet, the water came out and passed into a further stage of the hybrid system. Another outlet pipe is used to remove excess water from the tank and to provide a certain level of water for the research.

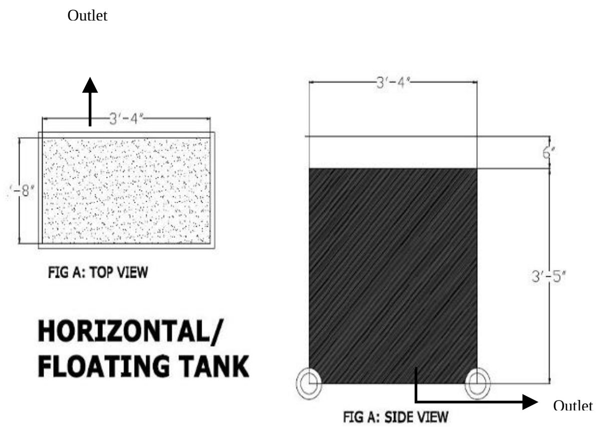

Figure 5: Horizontal flow tank for wetland system

The HF had a rectangular shape tank. The dimension consists depth of 3 ft 5 inch, a width of 8 inches, a length of 3 ft 4 inches shown in **Figure 5,** where Figure A presents a top the perspective of the tank, while Figure B depicts a side view. The outlet was located at 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor. Two-inch valve is used as the outlet of the reactor. In an outlet similar mechanism as before was used to maintain a certain level of water. The SF had a rectangular shape tank (Shown in **Figure 6**). The dimensions consist depth of 1 ft11 inches, a width of 1ft 8 inches, and a length of 3 ft 4 inches shown in Fig. The outlet was located at 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor. Two-inch valve is used as the outlet of the reactor. In the outlet, the water came out to collect as final effluent. Another outlet pipe is used to remove excess water from similarly mentioned before.

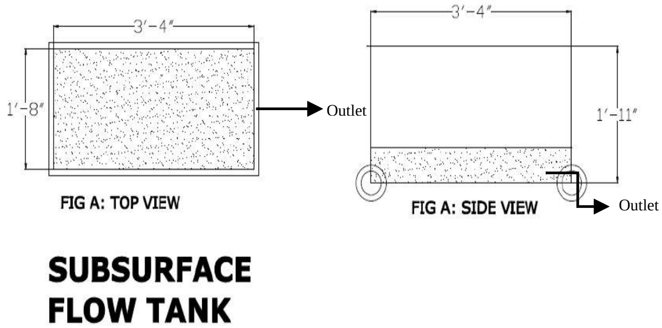

Figure 6: Subsurface flow tank for wet land system

2.4 Wetland vegetation

In this experiment, water is purified using *Canna indica (*local name Kolaboti*)*, a cost-effective and widely distributed aquatic plant chosen for its availability throughout the country and resilience in an adverse environment. Macrophytes, such as *Canna indica*, play a pivotal role in wastewater treatment. Similar successful research has been published in other countries using this species. For example, a pilot-scale wetland utilizing cana indica demonstrated its efficacy in wastewater treatment, making it a viable solution for irrigation in rural and small communities in Egypt (Abou-Elela, 2012). The biomass of these plants serves as a guide for wastewater, enhancing solids sedimentation. *Canna indica*, illustrated in Figure 7, aids in the removal of wastewater components for safe environmental disposal. The extensive root network provides a substantial surface area, acting as a filter for dirt and suspended particles. Additionally, the root zone fosters bacterial attachment and offers ample surface area. Oxygen diffuses through the root zone membranes into the water, creating an oxygen-rich environment that facilitates chemical transformations, ultimately breaking down pollutants. This oxygen-rich zone propels various chemical reactions, contributing to the degradation of contaminants.

Figure 7: Canna indica as wetland plant

2.5 Wetland Medias

In this research, the HCW system incorporates a unique combination of three distinct media: concrete waste, sawdust, and coal. Each material contributes specific properties that synergistically enhance the overall efficiency of the wetland system for water treatment.

Concrete Waste Media: The foundation of our HCW system is recycled concrete waste, a readily available and abundant material that offers several advantages for water treatment. Concrete waste possesses a high specific surface area, providing ample adsorption sites for the removal of pollutants. Its porous structure facilitates the growth of microbial communities that play a crucial role in biodegradation processes. Additionally, concrete waste exhibits high pH buffering capacity (Yousuf, 2020), maintaining the optimal alkalinity required for effective water treatment.

Sawdust Media: Sawdust is incorporated into the HCW system to enhance the filtration and adsorption capabilities of the media bed.

Coal Media: The addition of coal media serves to enhance the removal of organic pollutants and heavy metals from the raw water. Coal's porous structure and high surface area provide ample adsorption sites for the attachment of contaminants.
By combining these three distinct media, the HCW system creates a synergistic environment that maximizes the removal of pollutants from raw water.

3. RESULTS AND DISCUSSIONS

Our research methodology involved the examination of physicochemical parameters in the raw municipal wastewater samples obtained from Alir Ghat Canal. The study focused on evaluating the efficiency of a prototype treatment plant utilizing a constructed wetland system capable of handling a greater hydraulic load compared to surface flow wetlands. The laboratory analysis assessed the effectiveness of these wetlands in treating various wastewater parameters, including *Escherichia coli (E. Coli)* ,total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), turbidity, pH, color, among others which are presented in Table 1.

Table 1: Water parameter values of raw municipal wastewater

Water Quality Parameters	Unit	Surface Water Quality Standards (ECR, 23)	Raw Water On 1st week	Raw Water On 2nd week	Raw Water On 3rd week
E-coli	(CFU/100 ml)	0	25	375	30
pH		6.5-8.5	8.7	7	7.1
Color	co/pt	15	120	90	180
Turbidity	NTU	5	144	117	253
Total solid	mg/l	1000	65	88	95
Total Dissolved solid	mg/l	1000	84	84	84
Total Suspended solid	mg/l	10	10	10	10

The laboratory test results for various water quality parameters in the raw water with varying levels of contaminants over a three-week period were compared with the established surface water quality standards (ECR, 2023). The raw water E. coli level was detected at 25, significantly increasing to 375 in the second week before decreasing to 30 in the third week exceeding the Bangladesh threshold of 0. This disparity raises serious health concerns, emphasizing the necessity for effective water purification procedures. Additionally, the pH level in the raw water was recorded at 8.7 in the first week, exceeding the upper limit of the Bangladesh standard range (6.5-8.5) but approaching the acceptable range in subsequent weeks. A higher pH may affect the water's taste and potentially compromise its potability (Adams et al.,2022). The color measure showed a significant variance as well, exhibiting fluctuations, ranging from 120 in the first week to 90 in the second week and peaking at 180 in the third week, above the Bangladesh norm of 15 co/pt. Excessive pigmentation may suggest contaminants, demanding adequate treatment solutions. Turbidity, a measure of water cloudiness, was found to be exceptionally high from 144 NTU in the first week to 253 NTU in the third week, surpassing the standard limit of 5 NTU. High turbidity levels can be a sign of suspended particles and can make water treatment procedures less efficient. The total solid and total dissolved solid contents in the raw water were both lower than the respective Bangladesh standard of 1000 mg/l. According to these results, treatment procedures must be implemented to improve the water quality to a level that satisfies accepted guidelines for safe drinking water.

Overall, the testing is intended to assess the system's effectiveness in eliminating impurities and generating treated water that meets or exceeds specified quality criteria. The research examines the distinct performances of three media types Vertical (Concrete), Horizontal (Coal), and Subsurface (Saw Dust), in reducing wastewater parameters. Evaluating each media's efficiency, the hybrid system employs a combination of biological and physical-chemical treatments. The goal is to identify the most effective configuration for comprehensive wastewater treatment, informing the optimization of future hybrid constructed wetland systems.

E. Coli values are reduced in the first, second, and third weeks by the hybrid flow-created wetland employing concrete media (in Figure 8). Moreover, the sawdust media used in the hybrid flow-built wetland lowers the value of E. coli in the first two weeks. In the 1st week the E.coli removal efficiency of the hybrid flow-created wetland was 92%, in 2nd week 100% and in the 3rd week it was 93%.

The performance of the created wetland may need to be adjusted or maintained, depending on the desired pH range for water treatment. There were variations in the sawdust and coal media wetlands' trends compared to the concrete media wetlands. Among the three media, coal media has the highest pH removal percentage for hybrid flow constructed wetlands . In the 1st week the pH removal efficiency was 14%, in the 2nd and 3rd week it was 1% .(in Figure 9).

The different media types show varied effects on color reduction, suggesting that the properties of the media influence the treatment process (Figure 10). The fluctuations in color reduction over the three-week period may indicate dynamic interactions within the constructed wetlands. The color reduction values are relatively consistent over the three weeks in concrete media, whereas sawdust media Shows a higher reduction in color values compared to concrete media. For a hybrid flow constructed wetland, the concrete media has a higher color removal percentage among the four. The color removal efficiency was 17% in the 1st week, 33% in the 2nd week and 22% in the 3rd week.

Concrete Media maintains consistently low turbidity (in Figure 11), suggesting effective removal of suspended particles. Whereas Sawdust Media Shows a gradual decrease in turbidity, indicating an ongoing improvement in water clarity. We find that when sawdust and concrete media are used, the turbidity removal percentage for the hybrid flow constructed wetland is 100%. Turbidity removal efficiency was 91% in the 1st week, 100% efficiency was shown in the 2nd and 3rd week.

Over a three-week period, the introduction of hybrid flow constructed wetlands using various media such as concrete, sawdust, and coal proved to be highly effective in reducing Total Solids (TS) concentrations (in Figure 12). This consistent decrease emphasizes the effectiveness of the hybrid flow wetland system with concrete as a medium. Similarly, the use of sawdust as a medium in the hybrid flow constructed wetland reduces TS significantly. The coal-based system demonstrates its effectiveness in reducing Total Solids. This finding emphasizes the adaptability of various media types in achieving water purification goals in constructed wetland systems. The physical and chemical properties of concrete media allow for superior solid removal efficiency in the hybrid flow constructed wetland. When it comes to water purification, concrete's rigidity and porosity outperform sawdust and coal media in terms of filtration and sedimentation. In the 1st week the TS removal efficiency was 28% and 32% in the following 2 weeks.

The varied media types—sawdust, coal, and concrete—exhibited distinct impacts on total dissolved solids (TDS) reduction in the hybrid flow-created wetland (in Figure 13). The unpredictable behavior of sawdust over weeks added a creative dimension to the wetland's performance. Coal, on the other hand, consistently acted as a reliable hero, steadily reducing TDS. In an unforeseen twist, concrete contributed to a gradual increase in TDS, introducing an element of surprise to the narrative. Concrete media's distinct composition and structure have shown it to be more effective than other media alternatives for removing dissolved particles from water. Concrete is the medium that performs best at removing total dissolved solids (TDS). The TDS removal percentage was 7% in the 1st week, 37% in the 2nd week and 32% in the 3rd week.

Across a three-week period, the hybrid flow constructed wetland system, employing coal, sawdust, and concrete media, displayed positive outcomes in lowering total suspended solids (TSS) (in Figure 14). The sawdust-centered system exhibited a gradual enhancement, the coal-centered system maintained consistent performance, and the concrete-centered system showcased ongoing efficiency with minimal fluctuations. Concrete media outperformed sawdust and coal in a hybrid flow constructed wetland, boasting a 70% TSS removal rate. This superiority is likely due to the concrete's durability and favorable surface characteristics. The TSS removal efficiency of the hybrid flow constructed wetland was 40% in thw 1st and 3rd week, highest removal efficiency being 60% in the 2nd week.

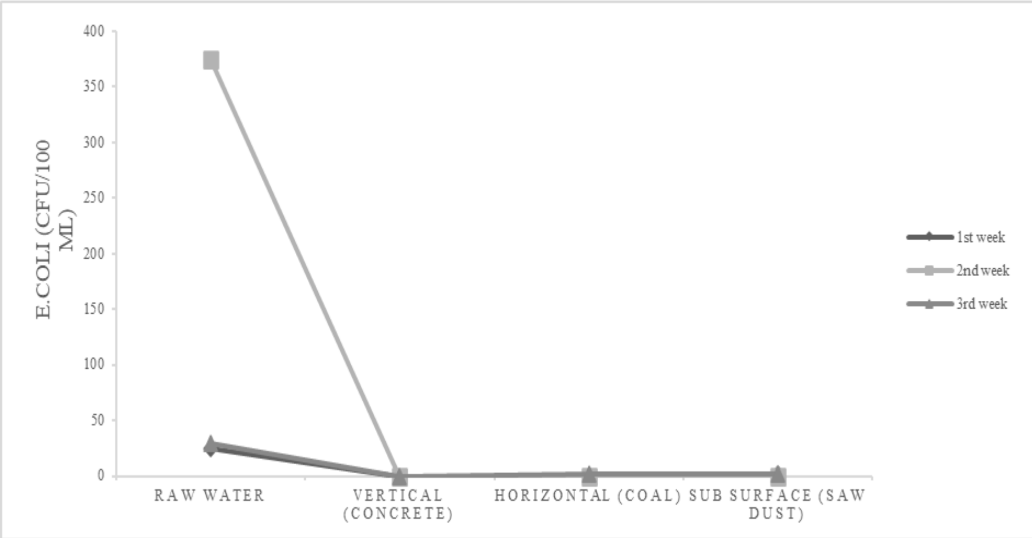

Figure 8: Weekly dosing for wetland system

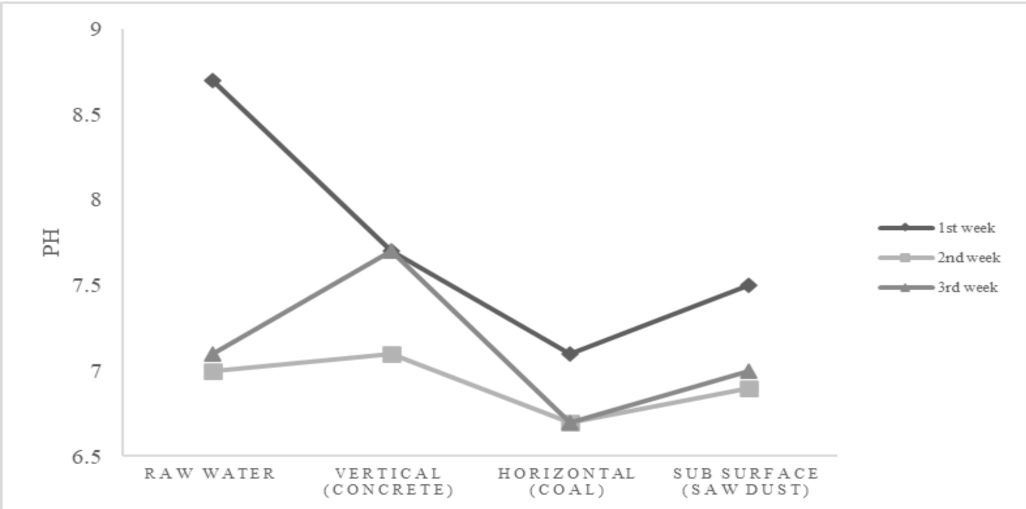

Figure 9: Weekly dosing for wetland system

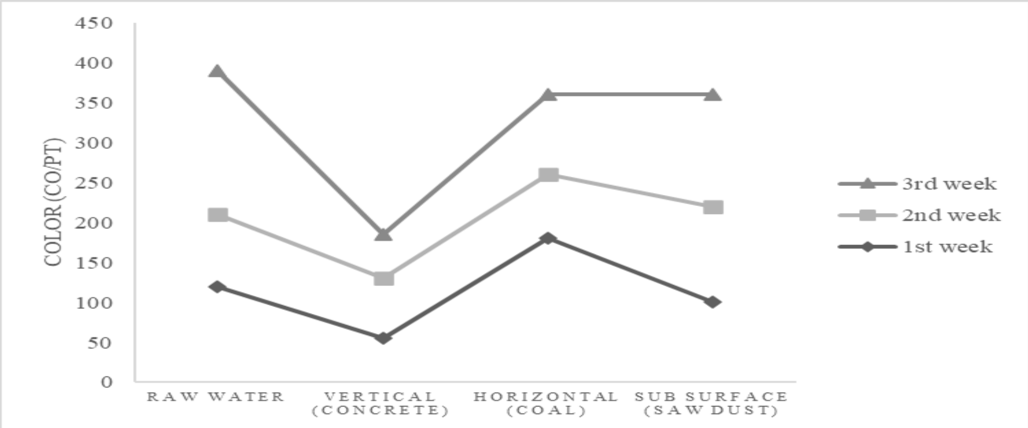

Figure 10: Analysis of the value of color for a three-week water sample

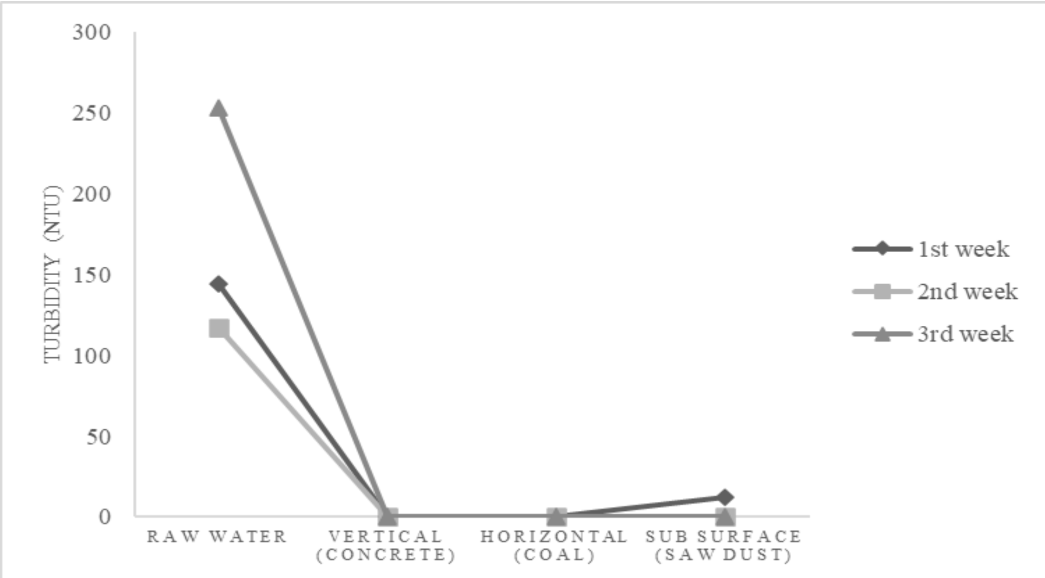

Figure 11: Analysis of Turbidity value for a three-week water sample

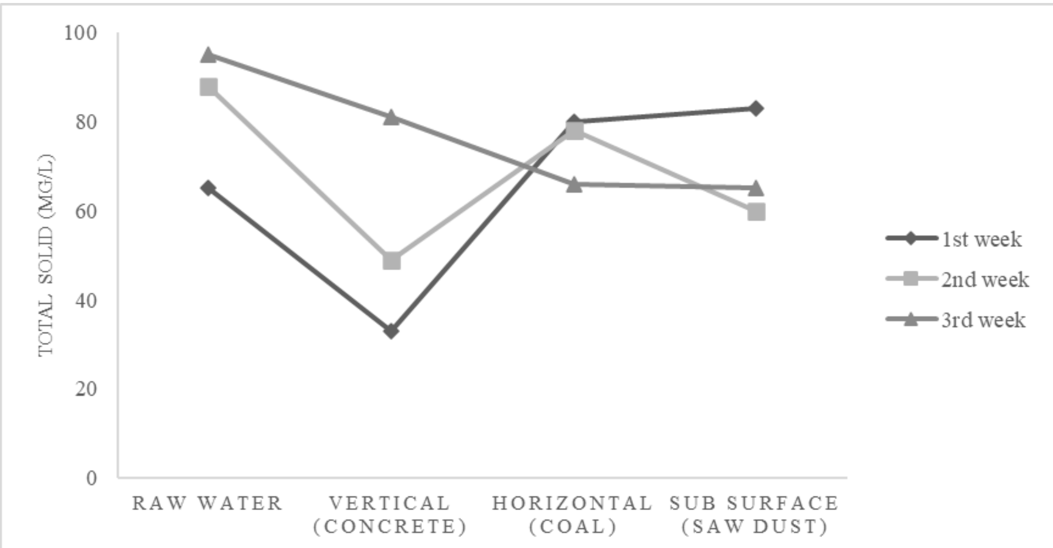

Figure 12: Analysis of Total solid value for a three-week water sample

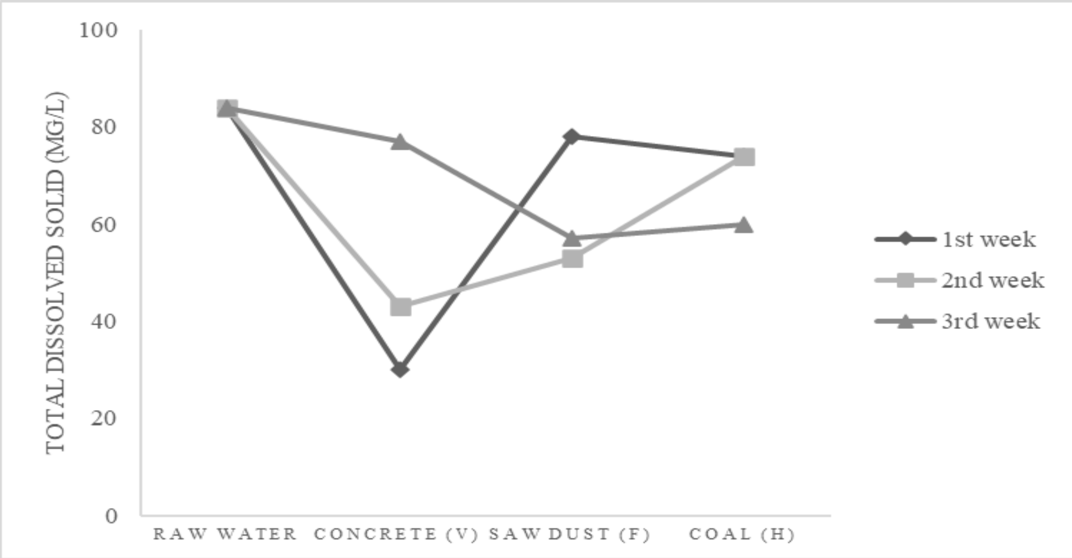

Figure 13: Analysis of Total dissolved solids value for a three-week water sample

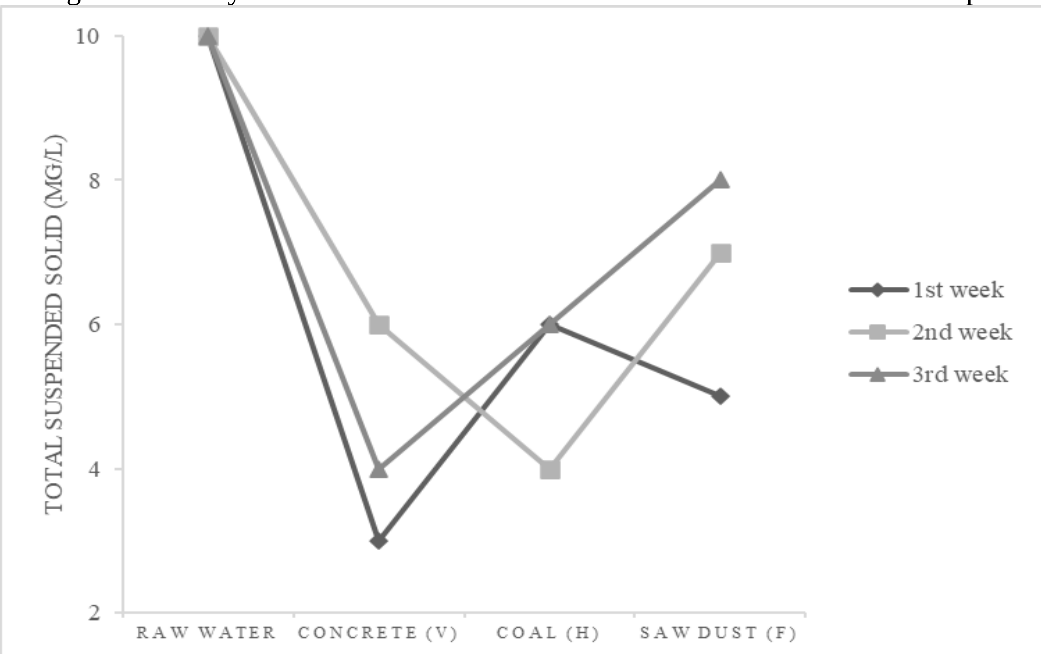

Figure 14: Analysis of Total suspended solid value for a three-week water sample

An extensive analysis of a hybrid flow-built wetland system with coal media, sawdust, and concrete indicates the more effective and consistent performance of concrete in several important areas. Despite concrete's excellent durability, decision-makers should consider project-specific considerations including cost and local conditions to ensure that the chosen medium satisfies the project's unique requirements. Concrete's outstanding performance and versatility make it a preferred option for achieving water treatment.

4. CONCLUSION AND RECOMMENDATION

This study highlights the potential of concrete waste media in hybrid-constructed wetlands for treating raw water. The main objective of this study was to achieve the efficiency of recycled concrete waste compared to other media to determine its effectiveness in water quality improvement. The performance of concrete waste was superior to other materials, positioning it as a sustainable solution for the treatment of raw water as the water quality parameters adhere to the permissible limits according to Bangladesh's surface water quality standard level. This study contributes valuable insights into the intersection of environmental conservation and waste management, providing a foundation for future endeavors aimed at both water quality improvement and responsible utilization of construction-related waste materials. The integration of recycled concrete waste in constructed wetlands emerges as a promising and sustainable pathway forward for effective water treatment and recycling of construction waste. The integration of recycled concrete waste in constructed wetlands is a strategic and multifaceted approach that not only minimizes the environmental impact of construction waste but also actively contributes to Sustainable Development Goals (SDGs). Leveraging recycled concrete serves as a valuable resource, fostering innovation, supporting sustainable urban growth, and protecting water resources by utilizing it as a media of constructed wetlands to treat raw water before disposing it in surface water. In particular, its use in constructed wetlands aligns with SDG 6 (Clean Water and Sanitation) by reducing surface water pollution. Additionally, the recycling of concrete aligns with SDG 9 (Industry, Innovation, and Infrastructure) by turning discarded material into a resource and promoting the development of sustainable building practices and eco-friendly materials. This practice further resonates with SDG 11 (Sustainable Cities and Communities) by contributing to resilient and environmentally friendly urban development as it is used in treating municipal wastewater. In due course, progressing towards sustainable infrastructure and safe surface water necessitates the widespread adoption of recycled concrete waste as an economic and sustainable media in constructed wetlands. This will help in treating municipal wastewater before it is released into surface water bodies.

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