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Design and Field Application of Gabion Mattress with Granulated Filtering Media (GFM) for Remediation of Polluted Creek in Balanga City, Bataan

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In the Philippines, 180 out of 421 rivers are heavily polluted and may soon be declared biologically dead. In the province of Bataan, industrial activities lead to contamination and water quality degradation. This makes the Talisay River in Balanga, Bataan, prone to the effects of establishments activities such as sewage from commercial and residential areas. The researchers aim to utilize the Granulated Filtering Media (GFM) as an adsorbent made up of fly ash, gypsum powder, coco peat, and cement for wastewater treatment of the polluted creek at Balanga City, Bataan. This GFM was subjected to seven-day water quality monitoring and tests to obtain its pollutant-reduction capability on the study site when incorporated into gabion mattresses. Study's water quality assessment tests revealed peak reductions showing that the gabion mattresses with GFM installed significantly reduced pollutant parameters like nutrients such as phosphate (79 %), nitrate (41 %), and ammonia (65 %) as well as water quality parameters such as chemical oxygen demand (42 %), turbidity (18 %), total dissolved solids (64 %), electric conductivity (51 %), and peak increases in DO (56 %), and pH level (3 %). The significant relationships of all the pollutant parameters observed were validated through Principal Component Analysis, extracted from 2D Loadings' variance explained of 71.2 %, with 57.6 % attributed to the first principal component and 13.6 % to the second, and a 3D Biplot that explained 82.7 % of the variance, with 57.6 % from the first component, 13.6 % from second and 11.5 % from the third component.

1. Introduction

Population growth, urbanization, and infrastructure strain sustainable development. Rapid expansion and increased population challenge the environment's capacity (Qiao et al., 2020). Pollutants from human activities, particularly water, significantly impact the environment, including heavy metals, nutrients, oil, pathogens, and organics (Saravanan et al., 2021). Concurrently, point source pollution and chemical fertilizers have raised recent river nitrate levels. About 245,000 km^2 of marine ecosystems globally suffer eutrophication due to excess nitrogen and phosphorus (The United Nations Environment Programme, 2021). This degrades water quality, raising turbidity and altering chemistry. Phosphates and nitrogen compounds cause algal blooms when entering water bodies (Fadhullah et al., 2020). High nitrate levels in drinking water risk health problems (Danni et al., 2019).

In the Philippines, agriculture contributes to 37 % of water pollution, causing coastal eutrophication around Manila (Szekielda et al., 2014). This makes the potential of adsorption for removing phosphate and nitrate ions from wastewater promising due to their accessibility, economical nature, stability, and substantial adsorption capacity (Ali et al., 2021). Producing an economically viable adsorbent demands an environmentally friendly and straightforward synthesis procedure and a plentiful supply of the natural source material (Ichipi et al., 2022). Bataan's industries release heavy metals and chemicals, degrading water quality in nearby water bodies. Talisay River in Balanga, Bataan, is susceptible to pollution from commercial and residential areas, impacting Manila

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Bay (Bataan, 2006). To address these issues, researchers aim to create Granulated Filtering Media (GFM) from agricultural and industrial by-products for wastewater treatment. Previous studies showed that GFM effectively reduces nutrient concentrations and adsorbs toxic heavy metals, improving water quality (Cruz and Lingad, 2022). The researchers aimed to investigate GFM's pollutant-reduction capacity in a polluted creek in Capitol Drive, Balanga City, Bataan, through incorporation into gabion mattresses and riverbed scattering methods.

2. Methods

The optimized GFM mixture was used to test its pollutant-reduction potential in the field. Gabion mattresses were designed and incorporated with the produced GFMs, following standards and specifications. Water quality assessment tests and monitoring were also conducted 7 d after the installation of gabion mattresses. This monitoring period is crucial in establishing baseline wastewater quality data over 7 d as it provides a reference point for future assessments and helps identify long-term trends (U.S. Environmental Protection Agency, 2021). Examining parameters included pH, turbidity, dissolved oxygen, total dissolved solids, electrical conductivity, chemical oxygen demand, and nutrient levels (phosphate, nitrate, and ammonia).

2.1 Granulated Filtering Media and its Synthetization

The Granulated Filtering Media, composed of agricultural and industrial by-products such as waste coco peat, gypsum powder, cement (as a binder), and waste fly ash, can remediate poor water quality through adsorption. Research stated that GFM as wastewater treatment technology has also been proven effective in reducing nutrient concentrations such as nitrate, phosphate, and ammonia, contributing to issues like algal bloom or eutrophication (Bato et al., 2017).

For synthetization, the researchers used a designed mixture of GFM consisting of 20 % cement, 30 % fly ash, 30 % gypsum powder, 20 % coco peat, and 300 mL of water. This was granulated using a machine granulator and submerged cured for 7 d following JSCE’s Standard Specifications for Concrete Structures (Japan Society of Civil Engineers (JSCE), 2014). Based on the results and discussions of the predecessor study, the granulated filtering media has exhibited a compressive strength of 2.160 MPa with this mixture. A research investigation conducted in Japan said that a minimum compressive strength of 1.200 MPa is recommended to avoid crushing aggregates (Cruz and Lingad, 2022).

2.2 Depth Analysis of Creek

Before installation, the depth of the creek was analyzed. It was found that the study site’s water level was five (5) inches from the riverbed, which was characterized as concrete flooring. The sludge was also analyzed and ranged from 1.2 to 1.5 inches from the riverbed. This helped the researchers conceptualize and design the gabion mattresses in the study area.

2.3 Design of Gabion Mattress

Proper design adhering to governing standards was essential for installation (Bhandari, 2019). This study used Gabion mattresses as channel linings to direct water flow, reducing scours and maintaining watercourse integrity. Figure 1 (a) shows the gabion mattress's design.

2.3.1 Standards Considered for the Design of Gabion Mattress

The gabion used was a conforming mattress with a maximum thickness of 12 inches. The wire was galvanized and adhered to ASTM A 641 standards (ASTM International, 2013). The height was 6 inches, following Maine Construction Specification 464, Table 64-2, and the length was 5 feet to fit the river width (Natural Resources Conservation Service - USDA, 2017). The width was 15 inches, yielding a 1:4 ratio compared to length as per DPWH Standard Specifications for Public Works and Highways. Accordingly, GFMs could be used as coarse aggregates under specified conditions, ensuring durability and the absence of harmful substances. Mesh wire openings were 1/2" to prevent GFMs of 3/4" to 1 inch from passing through. The body wire diameter was 2.20 mm, following DPWH SSPWH. GFM sizes were 3/4" - 1 inch, conforming to Item 511 of DPWH SSPWH regarding maximum rock size (DPWH, 2018).

2.4 Field Installation Diagram

A field installation diagram served as a valuable tool for field work and on-site installations, enhancing accuracy, reliability, and the validity of research findings. In this study, the prototype was installed as a channel lining in the creek as the site for field installation. The field installation diagram is shown in Figure 1a.

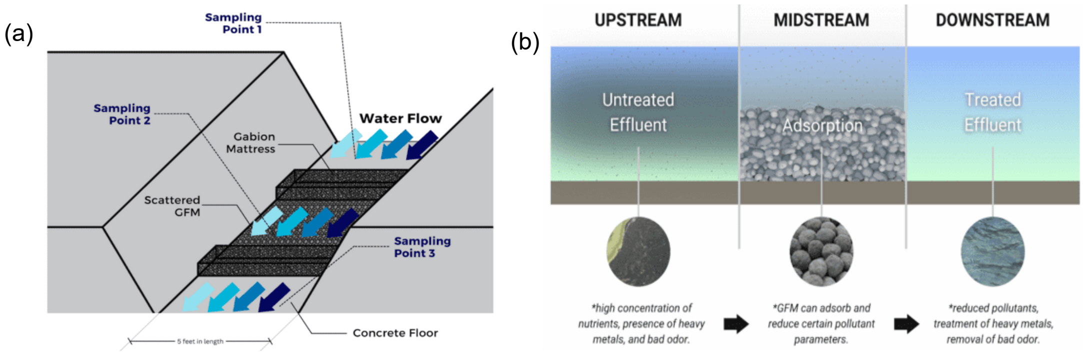

Figure 1: (a) Diagram of field installation and (b) mechanism of the prototype

2.5 Mechanism of the Prototype

The main goal of the prototype application was to allow the untreated effluent with a high concentration of polluted water to flow and proceed to the midstream, where the adsorption of pollutants occurred. The water in midstream was initially treated before going downstream of the study site, which implies holistic water treatment. This series of processes and mechanisms signified the reduction of pollutants such as heavy metals, nutrients, and bad odors. Figure 1b shows the mechanism of the prototype.

2.6 Field Application of Gabion Mattress and Scattering Method on Riverbed

Field installation assessed gabion mattress performance in real-world conditions. In this study, the incorporated GFM had already passed the ASTM C88, which implies usage and efficiency in the long run, as well as its durability and ability to withstand disintegration caused by repeated freezing and thawing, ensuring the long-term stability and structural integrity of concrete components when exposed to varying environmental conditions (ASTM International, 1999). Gabion mattresses were installed 0.750 m apart as a channel lining in the study area. GFMs were then poured into the gabion cages and spread manually using the same method as the scattering site. It was settled after ten (10) minutes and was followed by a water quality test immediately for water quality monitoring. The monitoring was recorded for 7 consecutive days to test the prototype's efficiency in terms of pollutant reduction. The adsorption of GFM was not yet covered in this study, for it needs deeper and different studies and more scientific approaches for optimal results. The field application of the gabion mattress and the installed prototype are shown in Figures 2a and b, respectively.

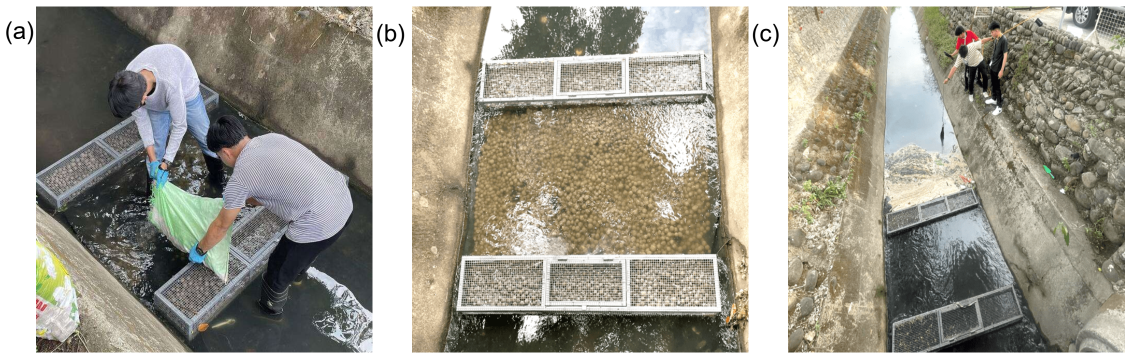

Figure 2: (a) Field application of gabion mattress, (b) installed prototype, and (c) in-situ water quality monitoring using Horiba Multi-Parameter Meter

2.7 Water Quality Assessment Tests

Water quality tests included primary baseline water quality parameters the Department of Environment and Natural Resources (DENR) set, such as pH level, dissolved oxygen, total dissolved solids, turbidity, COD, and electric conductivity. These were tested using the Horiba Multi-Parameter Meter shown in Figure 2 (c). Nutrient-based polluted parameters (nitrates, phosphates, and ammonia) were also tested using a photometer.

3. Results

The Horiba Multi-Parameter Meter was used to obtain significant results and observations for baseline water quality and nutrient parameters. The in-situ performance of the gabion mattress prototype with GFM was evaluated based on the results interpreted in this research study.

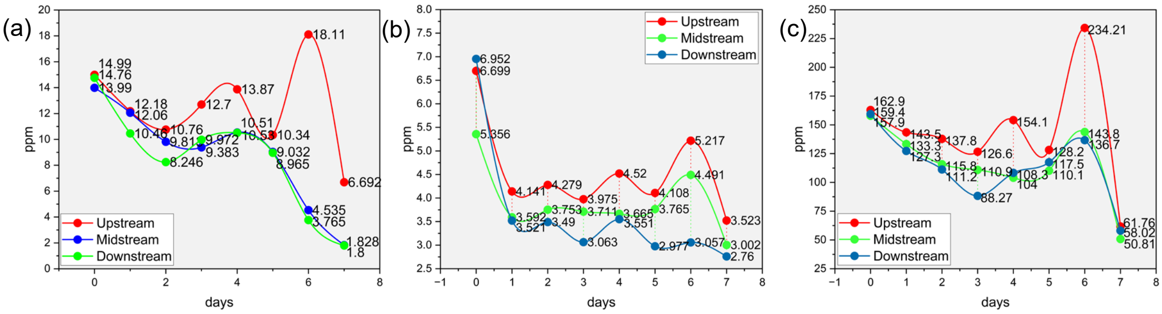

Figure 3: Water quality assessment test result of (a) phosphate, (b) nitrate, and (c) chemical oxygen demand

The highest reduction of phosphate (Figure 3a) occurred on the sixth day, with upstream data decreasing by 13.575 ppm compared to the midstream and in downstream by 14.345 ppm. The seven-day monitoring showed reductions of 8.298 ppm, 12.932 ppm, and 12.960 ppm in the upstream, midstream, and downstream, respectively. The highest decrease of nitrate (Figure 3b) occurred on the sixth day, with reductions of 0.73 ppm from the upstream to midstream and 2.16 ppm reduction in the downstream. The seven-day monitoring revealed reductions of 3.18 ppm in the upstream, 2.35 ppm in the midstream, and 4.492 ppm in the downstream for nitrate level. The sixth day exhibited the largest decrease in COD (Figure 3c), with reductions of 90.610 ppm from the upstream to midstream and a drop of 97.510 ppm in the downstream. The seven-day monitoring period revealed reductions of 101.140 ppm, 107.090 ppm, and 101.380 ppm in COD presence in the upstream, midstream, and downstream, respectively. Fluctuation of COD was recorded on the sixth day. This phenomenon can be attributed to the first flush effect. Previous research indicates that the specific impact of the first flush on COD levels can vary based on factors such as pollution sources, land use patterns, and local conditions. Dealing with rivers without proper treatment naturally contributes to elevated COD concentrations (Zeng et al., 2019). Throughout the seven-day water quality monitoring, data showed that there had been peak reductions in phosphate (79 %), nitrate (41 %), and COD (42 %).

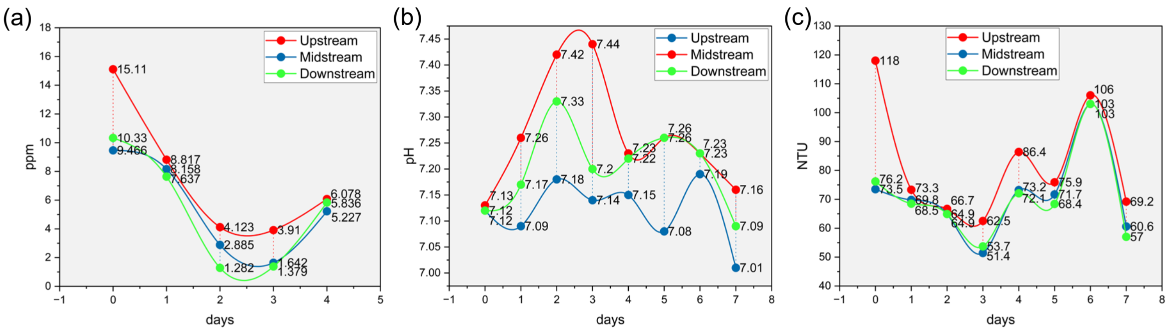

Figure 4: Water quality assessment test result of (a) ammonia, (b) pH level, and (c) turbidity

The third day demonstrated the highest decrease in ammonia (Figure 4a), with readings of 2.268 ppm decrease from the upstream to midstream and 2.531 going in the downstream. Overall, the monitoring period of ammonia revealed decreases of 9.298 ppm in the upstream, 4.239 ppm in the midstream, and 4.494 ppm in the downstream. The second day exhibited the most significant increase in pH (Figure 4b), with elevations of 0.29 in upstream, 0.5 in midstream, and 0.9 in downstream. The water quality monitoring revealed a decrease of 0.11 in the upstream, 0.03 in the midstream, and 0.03 in the downstream. The third day displayed the highest reduction in turbidity (Figure 4c), with readings of 11.1 NTU in the upstream, 8.8 NTU from upstream to midstream, and 11.1 NTU going downstream. Overall, the seven-day monitoring period revealed decreases of 48.80 NTU, 12.90 NTU, and 19.20 NTU in turbidity presence in the upstream, midstream, and downstream, respectively. The seven-day water quality monitoring data implied that there have been peak reductions in ammonia (65 %) and turbidity (18 %) and a peak increase in pH level (3 %).

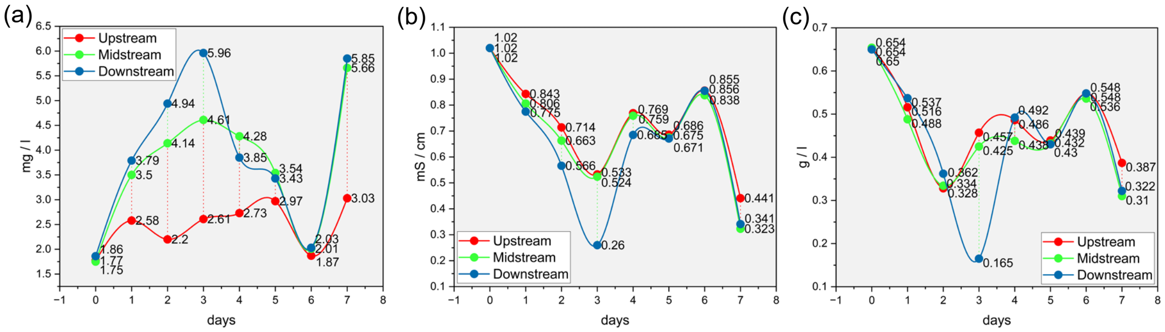

Figure 5: Water quality assessment test result of (a) dissolved oxygen, (b) electric conductivity, and (c) total dissolved solids

The seventh day displayed the highest increase in dissolved oxygen (Figure 5a). Overall, the seven-day monitoring period revealed increases of 1.26 mg/L, 3.91 mg/L, and 3.99 mg/L in dissolved oxygen presence in the upstream, midstream, and downstream, respectively. The most significant decrease in electric conductivity (Figure 5b) happened on the third day, with reductions of 0.118 mS/cm in upstream to the midstream and 0.263 mS/cm downstream. The seven-day monitoring revealed decreases of 0.579 mS/cm, 0.697 mS/cm, and 0.679 mS/cm in electric conductivity levels in the upstream, midstream, and downstream, respectively. The seventh day exhibited the most significant decrease in TDS (Figure 5c), with reductions of 0.065 g/L from upstream to the midstream and 0.077 g/L going downstream. Water quality monitoring implied declines of 9.298 g/L, 4.239 g/L, and 4.494 g/L in total dissolved solids presence in the upstream, midstream, and downstream of the creek, respectively. Seven-day water quality monitoring data revealed that there had been peak reductions in TDS (64 %), electric conductivity (51 %), and peak increase in DO (56 %).

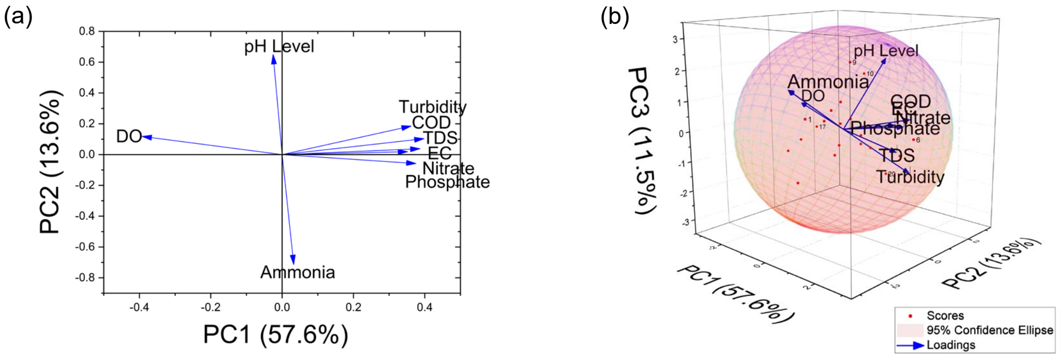

Figure 6: (a) Principal Component Analysis' 2D Loadings and (b) 3D Biplot

Principal Component Analysis (PCA) is a widely used statistical technique for dimensionality reduction and data exploration. It aims to transform correlated variables into smaller uncorrelated ones (Shlens, 2014). The 2D Loadings in Figure 6a showed a variance explained of 71.2 %, with 57.6 % attributed to the first principal component and 13.6 % to the second. This indicated high correlations among parameters like turbidity, COD, electric conductivity, TDS, phosphate, and nitrate. pH and ammonia displayed inverse proportionality through two loadings on the graph. The 3D Biplot in Figure 6b explained 82.7 % of the variance, with 57.6 % from the first component, 13.6 % from the second, and 11.5 % from the third component. Data points fell within the 95 % confidence ellipse, represented by red scores. The study also found inverse correlations between ammonia, dissolved oxygen, TDS, and turbidity. pH had minimal impact, while COD, nitrate, phosphate, and electric conductivity showed strong positive correlations and influence.

4. Conclusion

Water quality tests demonstrated reductions in nutrients such as phosphate, nitrate, and ammonia and parameters including chemical oxygen demand, turbidity, and electric conductivity. This positive effect can be attributed to the Granulated Filtering Media's adsorption process. The study area also experienced increased pH and dissolved oxygen levels due to the passage of polluted water through the prototype, which incorporated basic and cementitious porous media (GFM). Fluctuations on the graph were also observed during the 4th and

6th day caused by rainfall events. According to the study by Yuan et al. (2017), dissolved pollutants, such as ammonia and nitrate, strongly connect with the intensity of rainfall. This relationship might be attributed to releasing soluble substances from particles during heavy rain, significantly increasing pollutants on the upstream portion of the installed prototype. It was noticed that the behavior of the parameters remained relatively stable and low in the midstream and downstream parts amidst rainfall. The Principal Component Analysis exhibited that pH level and ammonia were close to zero, indicating less importance in the study. It also showed a high positive correlation among turbidity, COD, electric conductivity, TDS, phosphate, and nitrate, while dissolved oxygen showed inverse proportionality, all signifying strong relevance in the study.

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