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Water Quality of Green Roofs by Using Oil Palm Empty Fruit Bunch Fiber as A Filter Layer

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Abstract

A green roof is a technological solution that incorporates vegetation and growing medium, which are placed on top of a filter and waterproofing membrane. Contaminants may be present in the runoff water quality originating from green roofs, either due to external factors in the surrounding environment or as a result of the green roof substrate layer. The objectives of this study are to analyze the water quality of green roofs using empty fruit bunch fiber from oil palm as a filter layer and develop the model of a green roof by using oil palm empty fruit bunch fiber as a filter layer. Oil palm empty fruit bunch fiber is appropriate for use as low materials to create roofing material despite their great number and extremely low value. The water quality parameter tests which are pH, Turbidity, Ammonia, TSS, Dissolved Oxygen, Chemical Oxygen Demand and Biochemical Oxygen Demand were conducted in the laboratory. This study involves the planting of three green roof model with three distinct types of filter layers which is sample 1 with 40mm, and sample 2 with 20mm. All the results were compared to the Water Quality Index (WQI) where the WQI results for Sample 1 is 76 (Class III), Sample 2, is 77 (Class II), and Sample 3 is 73 (Class III), It can be concluded that the water sample from Sample 2 the green roof is suitable for Fishery II (sustaining aquatic life and ecosystems) and water for recreational use, including activities such as swimming, fishing, boating, and other water-based pursuits.

1. Introduction

A green roof is a man-made structure that is installed on the roof of a building. It involves the construction of a sturdy framework with the necessary mechanical strength [1]. In addition, a green roof refers to a building roof that is covered with vegetation and a growth medium, either entirely or partially. A roof can be designed with a sloped surface or a flat surface that can support vegetation while also functioning as a fully operational roof [2].

A green roof also can increase the lifespan of a building's roof by protecting it from thermal fluctuations, UV radiation, and diurnal stress [3]. Plants located in urban areas and near buildings tend to be more appealing to people [4], while plants on gardens and roofs can provide crucial habitats for rare or endangered species. The implementation of green roofs has been found to yield potential benefits in terms of reducing heating and cooling costs. The implementation of a green roof system provides several benefits, including the ability to shield the roof from solar radiation and mitigate the adverse impacts of heat. Consequently, the service life of a green roof can be extended by up to 50% compared to conventional roofing systems. Green roofs add a layer of insulation, which cuts down on utility bills for heating and cooling [5]. Malaysia is currently facing a challenge with waste management as there is insufficient technology to recycle or repurpose waste materials for use in the construction of other materials. The green roof will utilize a waste product consisting of discarded oil palm fruits, which will have both environmental impacts and benefits. Additionally, this material can improve thermal comfort by minimizing the absorption of heat into the building.

According to a study [6], the term "empty fruit bunch fibers" refers to a mixture of fibres derived from both the bunch and fruit components of the palm fruit. The utilization of natural fiber such as coconut fiber in ceilings resulted in improved heat transfer reduction outcomes without causing any harm to the environment. Compared to conventional roofing materials like corrugated iron and aluminum, the waste of oil palm empty fruit bunch fiber as a filter layer developed in this study offers a significant improvement in terms of environmental impact. Additionally, the use of oil palm EFB as a filter layer can contribute to improved urban stormwater management and drainage, thereby enhancing the environmental sustainability of green roof systems [7]. Specifically, as the percentage of natural fiber replacement increased, so did the percentage of porosity and water absorption and the low manufacturing cost is going to be great for rural and developing country roofing material production [8]. Indirectly, this will lower the material's need for raw materials, making it a more environmentally friendly building option.

2. Material and Methods

2.1 Experimental Setup

The water quality parameter tests were conducted in a laboratory. This study involves the planting of three green roofs with two distinct types of vegetation. The growing medium used for these roofs is a combination of waste materials for example, high-density polyethylene (HDPE) [9], natural fiber as filter layer such as kenaf, banana fiber, and jute. The green roof is composed of four layers in its structure. The green roof is composed of several layers, starting from the top with the vegetation layer, followed by the substrate layer, filter layer, and finally the drainage layer at the bottom. The dimensions of the green roof are 300 mm in width, 300 mm in length, and 200 mm in depth in Figure 1 [10]. Tank bottles were installed along with the green roofs to collect water for water quality sampling.

Fig. 1: Size and Design of Green Roof.

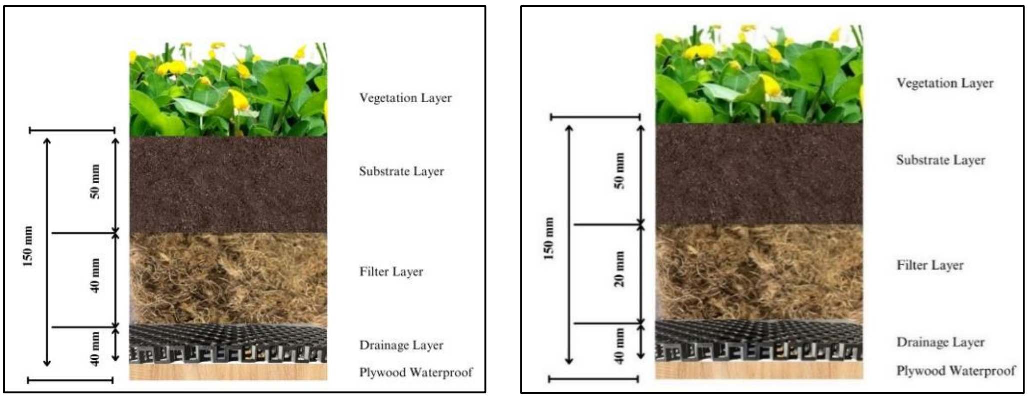
2.2 Material

The waste material and natural fibers utilized in this study were sourced from the local area of Kilang Kelapa Sawit Bukit Pasir, Johor Malaysia. The incorporation of natural fibres in green roofs entails their installation as the filter layer, which is situated above the drainage layer. The chosen natural fibres consist of oil palm empty fruit and bunch fibers. The purpose of the filter layer is to effectively prevent the ingress of suspended solids, silt, and sediments into the drainage layer. Furthermore, the filter material utilized is a non-woven geotextile, which exhibits a notable filtration efficiency in eliminating minute particles falling within the range of 1 nm to 1000 nm [11].

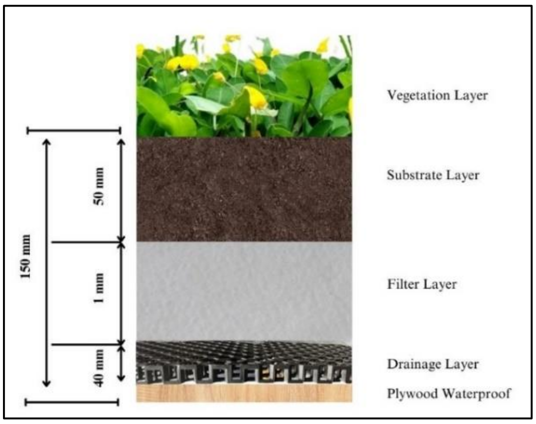
The drainage layer must possess adequate capacity to effectively transport the required volume of rainfall water and prevent the accumulation of water on the green roof [12]. Plastic trays have been used as drainage layers. Plastic trays are composed of a lightweight material and exhibit a high level of resistance to various environmental conditions. The substrate layer serves as the growth medium for the vegetation layer, facilitating water flow, aeration, water retention, and nutrient retention for the vegetation [12]. The vegetation layer serves the purpose of acting as a water catchment area and supplying nutrients to the runoff. The vegetation layer must possess the capability to withstand various weather conditions while also being easily cultivatable [13]. The plant used in the green roof system is Arachis Pintoi. The cooling properties of Arachis pintoi in the absence of rain. To evaluate the plant's cooling performance, it considers seasonal and diurnal changes. Moreover, Arachis pintoi has been shown to remove air pollutants from green roofs [14]. Additionally, many types of vegetation can be used to build green roofs. Sedum is a popular green roof plant. In contrast to vertical growth, the plants under study grow horizontally. The protective measures have shielded the roof membranes from direct sunlight. After drainage and insulation, rooftop sedum mats are easy to obtain and install [14]. Sedum vegetation supports less biodiversity than other plant species. Furthermore, of their suitability for green roof applications, native plants are primarily employed for the purpose of managing run-off water. In general, these roofs were embellished with drought-tolerant, succulent plant species that have a low-growth habit [15][16]. However, it is important to consider that these plants might not survive severe weather as effectively as Arachis Pintoi, which exhibits the ability to thrive in tropical climates in Malaysia.

This study examines three different thicknesses of filter layers for green roofs. Experiments were conducted for each filter layer type to ascertain the most efficient method for treating water runoff from green roofs. All four green roofs are equipped with substrates, with three of the roofs featuring three distinct layers of varying thickness. The remaining roof serves as a non-vegetated green roof, serving as the control in the experiment. The plant species utilized for the green roof installation encompass a variety of types. The design of green roof layers is shown in Figure 2.

a. Sample 1 – 40 mm thickness
b. Sample 2 – 20 mm thickness
c. Sample 3 – Control with non-geotextile fabric



(a) (b)



(c)

Fig. 2: The green roof with different thicknesses of filter layer

2.3 Standard Procedure

The classification of water quality for rivers in Malaysia is primarily based on the Water Quality Index (WQI) established by the Department of Environment Malaysia (DOE). The potential discharge of runoff from the green roof to the nearest drain or river necessitates the utilization of the Water Quality Index (WQI) as a means to categorize the quality of the runoff originating from the green roof. In this technical report, Table 1 displays the subindices of the parameters equation for the Water Quality Index (WQI). The value parameters listed in Table 1 should be sub-indexed into DO, SIBOD, SICOD, SIAN, SISS, and SIPH. This sub-indexing is necessary as the individual parameters are unable to independently reduce the amount of information they contain.

Table 1: The Sub-Indicates of parameters equation for Water Quality Index [18]

Sub-indices	Range	Equation
SIDO	For $x \leq 8$	$= 0$
	For $x \geq 92$	$= 100$
	For $8 < x < 92$	$= -0.395 + 0.03x^2 - 0.00020x^3$
SIBOD	For $x \leq 5$	$= 100.4 - 4.23\,x$
	For $x > 5$	$= 108\,e^{-0.055x} - 0.1\,x$
SICOD	For $x \leq 20$	$= -1.33\,x + 99.1$
	For $x > 20$	$= 103\,e^{-0.0157x} - 0.04\,x$
SIAN	For $x \leq 0.3$	$= 100.5 + 105\,x$
	For $x \geq 4$	$= 0$
	For $0.3 < x < 4$	$= 94\,e^{-0.573\,x} - 5\|x - 2\|$
SISS	For $x \leq 100$	$= 97.5\,e^{-0.00676x} + 0.05\,x$
	For $x \geq 1000$	$= 0$
	For $100 < x < 1000$	$= 71\,e^{-0.0016x} - 0.015\,x$
SIPH	For $x < 5.5$	$= 17.2 - 17.2\,x + 5.02\,x^2$
	For $5.5 \leq x < 7$	$= -242 + 95.5\,x - 6.67x^2$
	For $7 \leq x < 8.75$	$= -181 + 82.4\,x - 6.05\,x^2$
	For $x \geq 8.75$	$536 - 77.0\,x + 2.76\,x^2$

Water samples are categorized according to their properties and the Water Quality Index (WQI) in Table 2. The determination of the suitability of water samples for various uses can be achieved through classification. This classification allows for the identification of the appropriate type of treatment required to treat the water samples accordingly. The classification of water quality index for green roofs requires consideration of six parameters: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia, Suspended Solid (SS), and pH value. These parameters play a crucial role in determining the overall quality of water in green roof systems. The classification of water quality levels is categorized into six classes: Class I, Class II, Class IIIA, Class IIIB, Class IV, and Class V. Table 3 shows the index range of water parameters utilised for assessing the pollution level of water samples. The assessment is based on four main parameters, namely the Biochemical Oxygen Demand (BOD), Suspended Solid (SS), and Water Quality Index (WQI).

Table 2: The classification of water quality and its used [20]

Parameter	Units	Class I	Class II	Class III	Class IV	Class V
pH	-	> 7	6-7	5-6	< 5	> 5
DO		> 7	5-7	3-5	1-3	< 1
BOD		< 1	1-3	3-6	6-12	>12
COD	Mg/l	< 10	10-25	25-50	50-100	>100
SS		< 25	25-5-	50-150	150-300	>300
AN		< 0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
WQI	-	< 92.7	76.5-92.7	51.9-76.5	31.-051.9	>31.0

Class I	Conservation of natural environment Water supply I – Pratically no treatment required Fishery I – Very sensitive aquatic species
Class IIA	Water supply II – Conventional treatment Fishery II – Sensitive aquatic species
Class IIB	Recreational use body contact
Class III	Water supply III – Extensive treatment required Fishery III – Common, of economic value and tolerant species, livestock drinking
Class IV	Irrigation
Class V	None of above

Table 3: Index Range of Water Parameters [18]

	Index Range		
	Clean	Slightly Polluted	Polluted
BOD	91-100	80-90	0-79
NH_3N	92-100	71-91	0-70
SS	76-100	70-75	0-69
WQI	81-100	60-80	0-59

3. Result and Discussion

3.1 Concentration of Water Contaminants in Water Sample of Green Roof

Table 4 presents the measured concentration levels of contaminants found in water samples obtained from green roofs, indicating their adverse effects on the overall quality of water. Contaminants can originate from either the green roof layer or rainfall, which can be influenced by the surrounding environment. The categorization of contaminants can also be based on the National Water Quality Standard (NWQS) of Malaysia. The process of parameter classification aids in the identification of key factors that exert influence on the quality of water. Not all parameters measured are included in the National Water Quality Standards (NWQS), such as Total Solid. The parameters utilised in this study were derived from a prior investigation conducted on the established water quality standards. According to reference [15], the maximum permissible concentration of total solids in effluents that are released into the stream is 2500 mg/l. The water samples can be discharged into the stream as long as they adhere to the prescribed limitation guidelines.

Table 4: Concentration of contaminants in water sample of green roof

	Parameters	Sample 1	Sample 2	Sample 3
1	DO	8.53	8.44	8.79
2	BOD	6.48	6.24	5.88
3	COD	32	43	50

4	SS	100	50	100
5	PH	6.98	7.03	7.17
6	Turbidity	24.1	34.5	38.9
7	TDS	500	500	500
8	TS	500	1520	2000
9	Ammonia	0.51	0.66	0.76

3.2 Water Quality Classification

The determination of the Water Quality Index (WQI) value and the classification of the water sample were accomplished by consulting Table 2. As previously stated in Section 2.2, the sub-index values listed in Table 5 were subjected to sub-indexing using the categories SIDO, SIBOD, SICOD, SIAN, SISS, and SIPH. These sub-indexed values were then further converted into the Water Quality Index (WQI).

Table 4: WQI values and classification of water sample [19]

Sample	Sub Index	Sub Index Value	WQI	Class (WQI)
1	SIDO	100	76.11	Class III
	SIBOD	75		
	SICOD	61		
	SIAN	63		
	SISS	55		
	SIPH	100		
2	SIDO	100	76.65	Class II
	SIBOD	76		
	SICOD	51		
	SIAN	58		
	SISS	72		
	SIPH	99		
3	SIDO	100	72.72	Class III
	SIBOD	78		
	SICOD	45		
	SIAN	55		
	SISS	55		
	SIPH	99		

Figure 4.3, the chart shows the Water Quality Index (WQI) of water samples collected from the green roof. Sample 2 has better water quality this is because the highest value of the water quality index was 76.65 for sample 2. Although sample 1 and sample 3 are both samples classified as class III the value of WQI for class III is 51.9-76.5. Meanwhile, sample 2 can be classified as class II WQI ranges for class II between 76.5 and 92.7. Based on the data presented in Table 2, it can be concluded that sample 2 and the water samples analysed are deemed suitable for fishery purposes, as well as possessing recreational use with body contact. In addition to its other applications, this system is also suitable for water supply; however, it requires a comprehensive treatment procedure

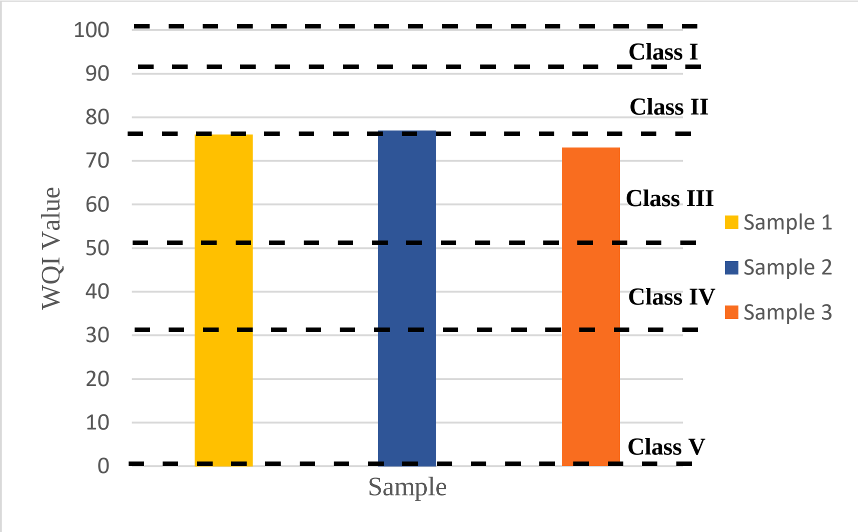


Fig. 3: Comparison of WQI and its Class

3.3 Discussion

The conducted experiments have demonstrated that the water quality from the green roof is influenced by the presence of the different thicknesses of the filter layer. In this experiment, a filter layer with a thickness of 20mm (Sample 2) was utilized, which was subsequently planted with Arachis pintoi. The effectiveness of a 20 mm thick filter layer (Sample 2) for green roof applications lies in its ability to enhance water quality. However, further improvements are necessary to mitigate the potential for green roof runoff to contribute to stream contamination.

In addition, it is recommended that employing a different vegetated for example Alternanthera Ficoidea, Sansevieria Trifasciata, and Zoysia Matrella [20] which can improve the drainage system, reduce the risk of flooding, and manage stormwater more effectively. For example, sedums and succulents are plant species known for their exceptional drought tolerance and low-maintenance characteristics. These plants are commonly employed in the construction of extensive green roofs, primarily owing to their remarkable ability to endure adverse environmental conditions, necessitating minimal watering requirements, and providing effective erosion control. The plant species under consideration possess shallow root systems, rendering them highly compatible with lightweight green roof systems.

The accuracy of the data may be compromised due to potential interference from the water sample during the data reading process. The water samples obtained from the rain harvesting system have been collected and subsequently stored for a duration ranging from a few days to a few weeks. The potential for water reactivity with the immediate environment, including the rain harvesting system container, is observed. Consequently, the water quality may experience a decline prior to its utilisation for the purpose of generating water runoff from the green roof. The collection of water samples from the green roof should be conducted subsequent to rainfall events in order to mitigate potential reactivity originating from the immediate vicinity.

4. Conclusion

The water quality from the green roofs was classified as slightly polluted for Samples 1, 2, and 3. Despite this, it can serve as a benchmark for future studies to assess the efficacy of green roofs in treating and preserving water quality prior to their release into streams. Based on the collected data, it determined that a filter layer with a thickness 20 mm (Sample 2) is most effective for green roofs. The classification of the water sample for sample 2 from the green roof indicates that both samples fall under the Class II (76.5-92.7) classification. More specifically, they are categorized as Water Supply II. The aforementioned classification indicates that the water quality requires significant treatment measures to improve its overall state. In addition to the aforementioned factors, it is important to acknowledge that the subject being discussed falls under the classification of fishery II, which has the capacity to sustain aquatic life and ecosystems. The data indicates that the water conditions are conducive to the viability and well-being of aquatic organisms, such as fish, invertebrates, and plants. The aforementioned classification serves as an indicator of the appropriateness of the body of water for recreational use, including activities such as swimming, fishing, boating, and other water-based pursuits. The aforementioned statement signifies that the water quality is generally deemed safe for human contact and presents negligible health hazards.

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