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A Field Study of Green Roof Water Quality Performance

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Abstract: A green roof is a technology that is partially covered with vegetation and growing medium, planted over a filter and waterproofing membrane. Runoff water quality from the green roofs may have contaminants from its surrounding or from the layer of green roof substrate itself. The objectives of this study are to analyze the water quality of the green roof runoff and to investigate the effectiveness of different vegetation treatments of the green roofs. Water quality experiments were conducted on runoff of four green roof test beds' treatment. Three of the test beds were planted with three different vegetations, *Alternanthera F.* (Sample 2), *Zoysia M.* (Sample 3) and *Sansevieria T.* (Sample 4), while the other one test bed was used as a control roof that contained with only substrate known as non-vegetated roof (Sample 1). All results were compared to the Water Quality Index (WQI) and National Water Quality Standard Malaysia (NWQS) where the WQI results for Sample 1 is 59.41 (Class III), Sample 2 is 55.91 (Class III), Sample 3 is 54.03 (Class III) and Sample 4 is 61.6 (Class III), respectively. It can be concluded that the water sample from the green roof is suitable for fishery III (for livestock drinking) and water supply III which may require for further extensive treatment.

Keywords: Green roof runoff, water quality, water quality index

1. Introduction

Urbanization led to the removal of deep-rooted vegetation and change to the drainage network that impacted the watershed water balance. Urbanization has reduced the natural water catchment area [1]. In addition, water catchment areas are usually rainforests that catch rainwater whenever it rains then flow it into the nearest water body. Water catchment areas control the amount and the timing of water transported to streams [1]. When the water catchment area is reduced, uncontrolled amounts of water runoff will occur and may cause the water in the stream overflow that led to the flood. When there is a lack of water catchment area, the rainfall will flow over paved surfaces such as roads, parking lots and other paved surfaces. In consequence, it may flow with other matters that may contain water contaminants. Hence, it will reduce the water quality by changing their physicals, chemicals, and biological properties. The water will continue to flow to the nearer stream, so it may affect the water quality of the stream.

Meanwhile, rooftops are the surfaces where rainfall interacts first. A rooftop is a typical part of urban water catchment area. Green roofs can potentially be an option to act as water catchment area of urban areas because urban areas lack of surface area [2]. A green roof has a layer of waterproofing membrane that is partially covered with the vegetation medium. Green roof can potentially control the volume and delays runoff because it can mimic similar roles as the vegetation in the forests. In addition, green roofs also should have drainage and filtration systems to improve its capability in managing the water quality and quantity [4]. Green roof is a part of the Green Building Concept that can provide an aesthetic value for the building and managing rainfall at the rooftops [3].

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1.1 Problem Statement

Rainfall is one of the sources that pick up of surrounding waste and other pollutants to the stream. During rainy days, the suspended solid, animal waste and other contaminants from the ground surface will flows into the stream, which leads to increase the contamination in the stream especially during and after the rainfall. The changes in the physicality of the water bodies in the stream can be seen after rainfall where the streams are very cloudy and look brown. Furthermore, in urban areas, the rainfall quality has decreased because rainfall has been affected by the air pollution from the industry activities, vehicles and land combustion [5]. All gasses from the air pollutant may mix with the water vapor during the evaporation process. It may change the chemical properties of the rainfall and the rainfall become acidic [6]. It is important to treat rainfall to make sure the rainfall is safe to be used for daily purposes and for other organisms in the water bodies. The green roof development can be an option to treat the rainfall but the water quality from green roof should be monitored and classified as either it polluted or not to ensure that the runoff from green roof does not contribute on the reduction of the quality of water in nearest stream.

2. Material and Methods

2.1 Experimental Setup

The small-scale green roofs are constructed with four layers, vegetation layer at the top, followed by the substrate layer, then filter layer and the bottom of the green roof is drainage layer. The dimension of each small-scale green roof is 300 mm width, 300 mm length and 150 mm depth. The green roofs are installed with the tank bottles for water collection for conducting the experiments to determine water quality of the green roof.

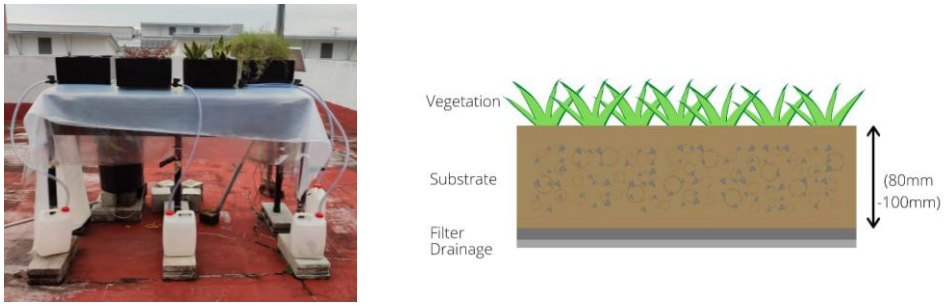

Fig. 1 - The small green roof with collection tank system and the cut-section of the layer

Drainage layer should has sufficient capacity to carry the necessary volume of water rainfall and prevent water ponding over the green roof [7]. Plastic trays have been used as drainage layers. Plastic trays are lightweight material and have high resistance toward any condition. Filter layer prevents the entry of suspended solid, silt and sediments into the drainage layer. The type of the filter material is non-woven geotextile that has high filtration efficiency to remove small particles within range in between 1 nm to 1000 nm [8]. Substrate layer is the growth media for the vegetation layer and provides a pore for water flow, aeration, holding water and holding nutrients for the vegetation [7]. The composite of the substrate is plastic waste, clay, coco peat and compost with ratio for all the composite is 20:15:25:40. The usage of plastic waste is to stabilize organic matter, slow release fertilizer and pores for water flow [9]. Vegetation layer provides a role as water catchment area and provides nutrients toward the runoff. The vegetation layer should be able to resist weather conditions and be easy to grow [10].

In this study, there are 4 different types of vegetation layers for the small-scale green roofs and experiments were conducted for each type of vegetation layer to determine which is the most effective to treat water runoff from green roofs. All four green roofs are filled with the substrates where three of the roofs are planted with three different vegetation while the other one is non-vegetated green roof as the control. The types of plant used for the green roof are:

1. Non-vegetated – Sample 1 (a)
2. *Alternanthera Ficoidea* – Sample 2 (b)
3. *Sansevieria Trifasciata* – Sample 3 (c)
4. *Zoysia Matrella* – Samp
5. le 4 (d)

(a) (b) (c) (d)

Fig. 2 - The green roof with different type of plant

During rainfall, the small-scale green roof generated runoff that were collected in the tank for water samples for lab testing to determine water quality. Due to time limitation and uneven rainfall distribution at the UTHM, rainwater from rain harvesting systems was used to generate runoff from the green roof. The water samples were tested in laboratory to measure its quality within 24 hours to avoid any reaction from the surrounding.

Most of the laboratory experiments were conducted using HACH instruments. The water quality parameters selected are water temperature, pH value, turbidity, ammonia, total solid, total suspended solid, total dissolved solid, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Phosphorus, Electric Conductivity and Total Nitrogen.

2.2 Standard Procedures

Generally, most of water quality classification for river in Malaysia is referring to the Water Quality Index (WQI) provided by the Department of Environment Malaysia (DOE). It is predicted that runoff from the green roof may flow out to the nearest drain or river hence WQI is used to classify the quality of green roof's runoff. Table 1 shows the sub-indices of parameters equation for WQI. All the value parameters in Table 1 need to be sub-indexed into DO, SIBOD, SICOD, SIAN, SISS and SIPH because the value of each parameter cannot perform themselves to reduce the bulk information.

Table 1 - The sub-indices of parameters equation for Water Quality Index [11]

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 $0.3 < x < 4$	$= 94\,e^{-0.573\,x} - 5\lvert x - 2\rvert$
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 $x \geq 8.75$	$536 - 77.0\,x + 2.76\,x^2$

Once all the sub-index have been determine, the water quality can be determine by the equation below:

WQI = 0.22(SIDO) + 0.19(SIBOD) + 0.16(SICOD) + 0.15(SIAN) + 0.16(SISS) + 0.12 (SIpH)

Table 2 shows the classification for water samples based on its parameters and the WQI. Based on the classification, the suitability of use of the water sample can be determined and suggest the suitable type of treatment to treat the water samples. There are six parameters that are needed to classify the water quality index of green roofs which are Dissolved oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia, Suspended Solid (SS) and pH value. The class of level of water quality is classified by Class I, II, IIIA, IIIB, IV and V. Table 3 shows the index range of water parameter to determine the pollution level of the water samples

based on the four main parameters: the Biochemical Oxygen Demand (BOD), Ammoniacal Nitrogen (NH_3-N), Suspended Solid (SS) and Water Quality Index (WQI).

Table 2 - The classification of water quality and its used [12]

Parameter	Units	Class				
		I	II	III	IV	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 [12]

	Index Range		
	Clean	Slightly Polluted	Polluted
BOD	91 - 100	80 – 90	0 – 79
NH_3-N	92 - 100	71 – 91	0 – 70
SS	76 - 100	70 - 75	0 -69
WQI	81 - 100	60 – 80	0-59

The contaminants also can be classified by referring to the National Water Quality Standard (NWQS) Malaysia [11] where this standard will classify the beneficial uses of the watercourse based on WQI. The classification of each parameters helps to determine which parameters mostly affect the water quality. NWQS is classified for each parameter of water quality that has in the water, there are many parameters that will be measured [12]. Besides that, Water Quality Index has been used to simplify the water quality parameter into a single value by reducing the bulk information and using a logical form of equation to analyze it.

3. Results and Discussion

Three trials of the experiment were performed for each green roof treatment to get the accuracy of data. Runoff from each green roof were collected at least 2 hours before water quality experiments were conducted, hence the water samples can be stabilized under room temperature.

3.1 Concentration of Contaminant in Water Sample of Green Roof

Table 4 shows the concentration of the contaminants in water samples of green roofs that reduce the water quality. All these contaminants may be produced by the layer of the green roof or rainfall that is affected by the surrounding area.

Not all the parameters measured can be classified based on NWQS, for example Total Solid, Total Phosphorus and Total Nitrogen, hence results from previous studies were used to understand the green roof's runoff. For the total solid, the limitation guidelines for effluents discharging into the stream is not more than 2500 mg/l [13]. Sample 1, Sample 2, Sample 3 and Sample 4 are not more than the limitation guidelines, so it is acceptable to discharge the water sample into the stream. For the total phosphorus, the rainfall has very small concentrations which was 0.04 mg/l only [14]. The source of the total phosphorus may come from the substrate layer that may contain artificial fertilizer and the limit value of the total phosphorus in the water bodies must not exceed 2.03 mg/l to avoid eutrophication. Sample 1, Sample 2, Sample 3 and Sample 4 do not exceed the limit concentration of total solid in the water.

Table 4 - The concentration of contaminant in water sample of green roof

	Parameter	Sample 1	Sample 2	Sample 3	Sample 4	NWQS	Previous Studies
1	DO	7.89	8.09	8.09	8.55	Class I	-
2	BOD	5.66	6.44	6.46	6.58	Class III	-
3	COD	27.33	29.00	35.67	21.00	Class III	-
4	Ammonia	0.47	0.78	0.72	0.38	Class IIB	-
5	SS	30	50	70	22	Class I	-
6	PH	6.26	6.29	6.45	6.39	Class IIA	-
7	Turbidity	35.98	53.83	68.69	18.38	Class IIB	-
8	TDS	167	267	167	183	Class I	-
9	EC	0.116	0.123	0.082	0.137	Class I	-
10	TS	983	1867	1917	283	-	< 2500 mg/l
11	TP	0.70	0.61	0.89	1.52	-	< 2.03 mg/l
12	TN	30.37	-6.63	3.27	nd	-	-

3.2 Water Quality Classification

The WQI value and the class of water sample were determined by referring to Table 2. As mentioned in Section 2.2, all the sub index values in Table 5 were sub-indexed into DO, SIBOD, SICOD, SIAN, SISS and SIPH; and converted into WQI.

Table 5 - WQI values and classification of water sample

Sample	Sub index	Sub index Value	WQI	Class (WQI)
1	SIDO	0	59.41	Class III 51.9 – 76.5
	SIBOD	78.53		
	SICOD	66.00		
	SIAN	64.13		
	SISS	81.13		
	SIPH	94.92		
2	SIDO	1.59	55.91	Class III 51.9 – 76.5
	SIBOD	75.16		
	SICOD	64.19		
	SIAN	54		
	SISS	72.06		
	SIPH	94.83		
3	SIDO	1.57	54.03	Class III 51.9 – 76.5
	SIBOD	75.05		
	SICOD	61.94		
	SIAN	55.8		
	SISS	64.25		
	SIPH	96.5		
4	SIDO	1.68	61.6	Class III 51.9 – 76.5
	SIBOD	74.53		
	SICOD	73.25		
	SIAN	76.53		
	SISS	85.69		
	SIPH	95.92		

Figure 4 shows the WQI of water samples from the green roof. Sample 4 has a slightly better water quality because it has the highest value of WQI which was 61.6 compared to the others. Sample 1 was 59.41, Sample 2 was 55.91 and the lowest water quality is from Sample 3 which was 54.03. However, all samples were classified as Class III of WQI since all samples were ranges between 51.9 and 76.5. Following Table 2 it can be concluded that all runoffs from the small-scale green roofs are suitable for fishery purposes and suitable for common economic value and livestock drinking. Other than that, it is still suitable for water supply, but it may need an extensive treatment process.

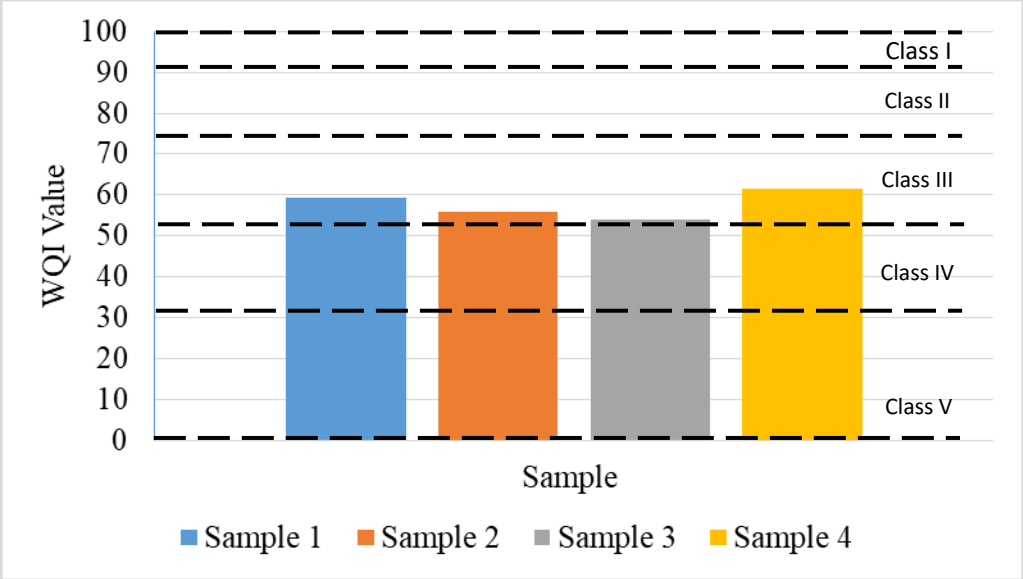

Fig. 4 - Comparison of WQI and its class

3.3 Index Range of Water Sample

Based on Table 3, the index range of water samples can be determined based on the sub-index of BOD, Ammonia and Suspended Solid and value of WQI. The index range classified the water sample of green roof into clean or slightly polluted or polluted.

Figure 5 shows the chart for determining the level index range for each sample of green roof based on the value of WQI. Based on the chart, Sample 1 and Sample 4 were slightly polluted because it exceeded the index range for slightly polluted that is between 59 and 80. The WQI concentration values for Sample 1 was 59.41 and Sample 4 was 61.6. Meanwhile, when index range is between 0 and 59, Sample 2 and Sample 3 were assumed as polluted with concentration WQI values were at 55.91 and 54.03, respectively.

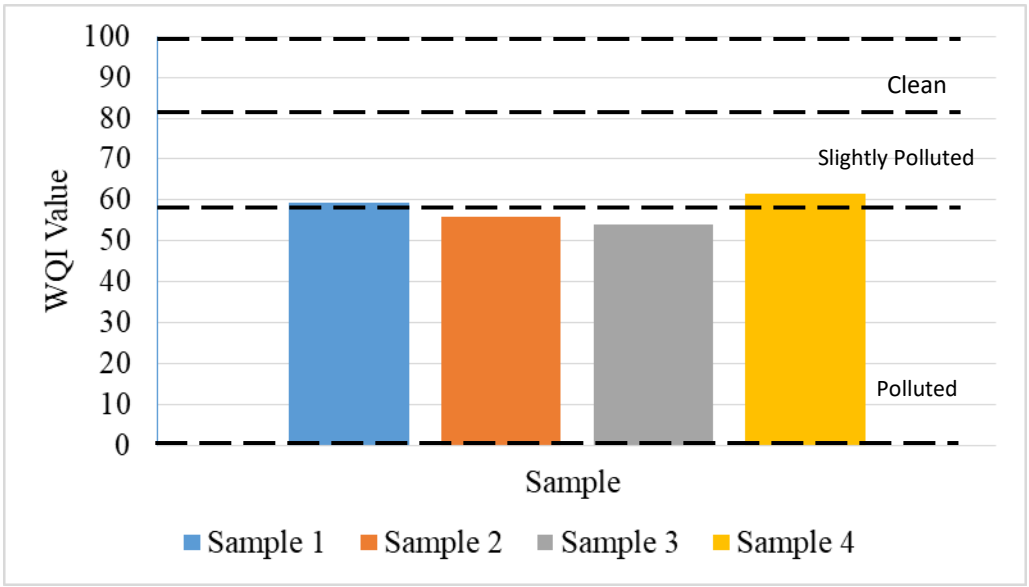

Fig. 5 - Comparison of index range for each sample of green roof based on WQI value

Figure 6 shows the chart for determining the level index range for each sample of green roof based on the concentrations of sub-index biochemical oxygen demand (SIBOD). Based on the chart, with index ranges for polluted are between 0 amd 79, all the water samples from each green roof were polluted. The concentrations of sub-index biochemical oxygen demand (SIBOD) for Sample 1, Sample 2, Sample 3 and Sample 4 were 78.53, 75.15, 75.05 and 74.53, respectively.

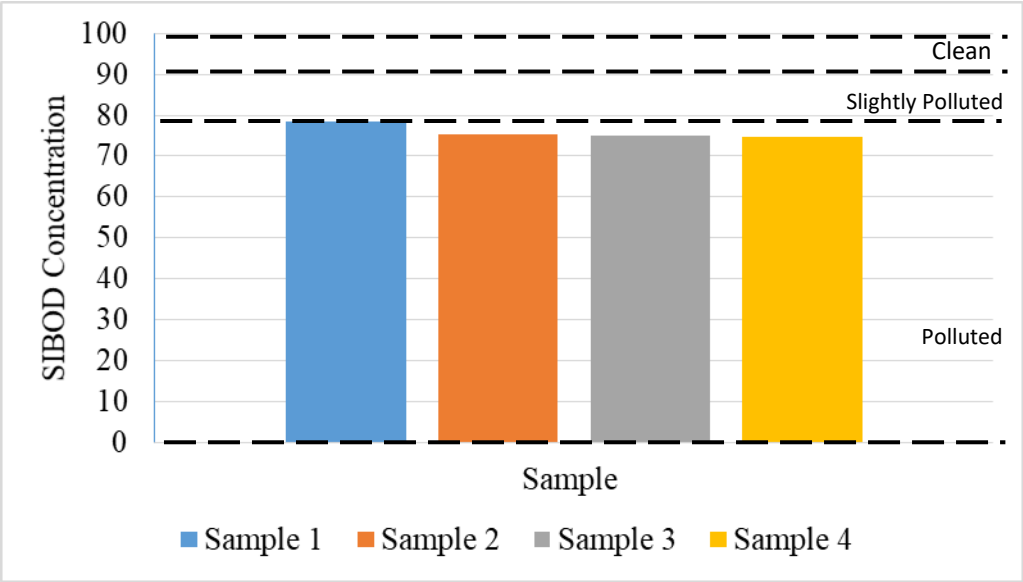

Fig. 6 - Comparison of index range for each sample of green roof based on SIBOD Concentration

Figure 7 shows the chart for determining the level index range for each sample of green roof based on the concentrations of sub-index Ammoniacal Nitrogen (SIAN). Based on the chart, the index range for slightly polluted which is between 71 to 91, hence Sample 1 was slightly polluted with value of the concentrations of sub-index Ammoniacal Nitrogen (SIAN) was 76.53. The concentrations of sub-index Ammoniacal Nitrogen (SIAN) for Sample 1, Sample 2 and Sample 3 were 64.53, 54.00 and 55.80, respectively. All values for Sample 1, Sample 2 and Sample 3 were between index ranges of 0 and 70 which are polluted.

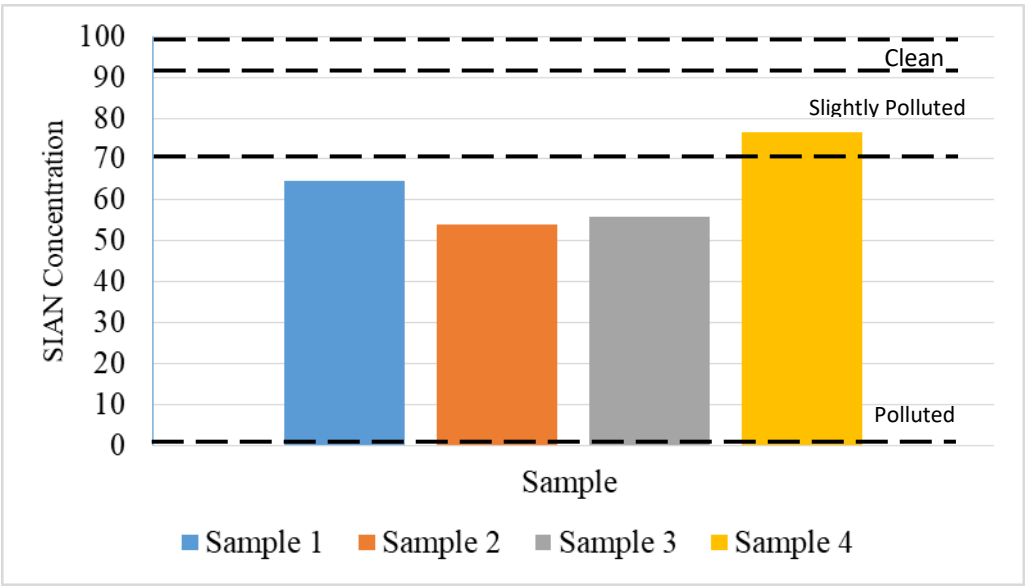

Fig. 7 - Comparison of index range for each sample of green roof based on SIAN Concentration

Figure 8 shows the chart for determining the level index range for each sample of green roof based on the concentrations of sub-index Suspended Solid (SISS). Based on the chart, index range for clean level is between 76 to 100, hence the concentrations of sub-index Suspended Solid (SISS) of Sample 1 and Sample 4 was in the clean level with value of Sample 1 at 81.03 and Sample 4 at 85.69. Meanwhile, Sample 2 was slightly polluted with value of 72.06 when the index range is between 70 to 75. Sample 3 was polluted with value of 64.25 between ranges of 0 and 69.

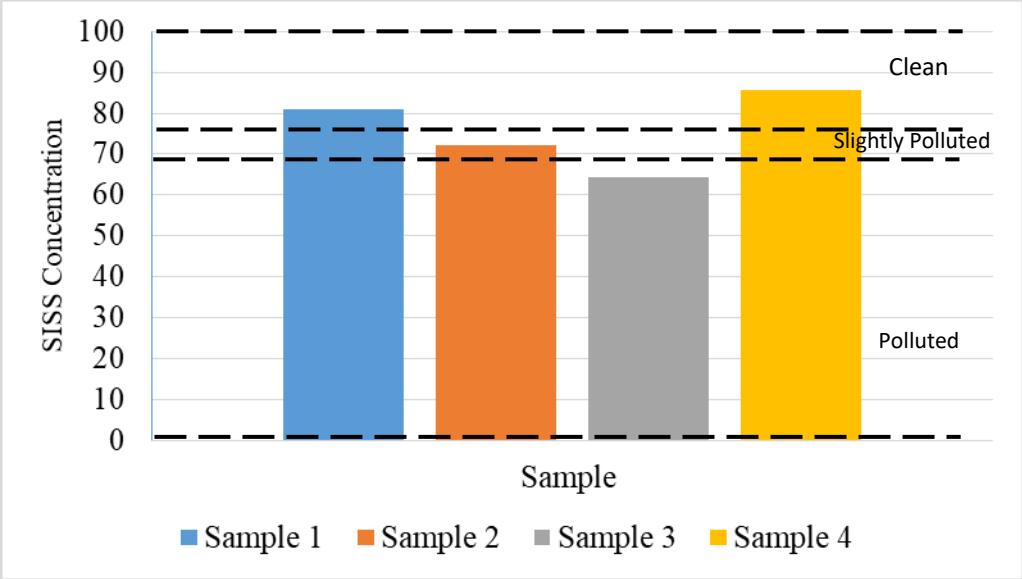

Fig. 8 - Comparison of index range for each sample of green roof based on SISS Concentration

3.4 Discussions

The experiments conducted showed that the presence of the vegetated layer affected the water quality from the green roof. *Zoysia Matrella* (Sample 4) is effective to be used as the vegetated layer for the green roof because of the ability to improve the water quality from the green roof but there still needs improvement to ensure that the water from green roof is not the factor of contaminants existed in the stream. The *Zoysia Matrella* (Sample 4) grows horizontally and provides an aesthetic value toward the building because it covers all the surface of the green roof. Furthermore, the small size of the filter layer was used to separate the fine suspended solid from the water. The fine suspended solid was removed hence had reduced the turbidity. For that reason, the water may not be polluted as the lower the turbidity of water, the lower the amount of contaminant in the water.

The usage of shredded plastic waste in the substrate layer mixture has helped the effectiveness of flow rate of water in the green roof especially in the substrate layer. The shredded plastic waste provides a pore in the substrate layer, so water can flow through it and avoid the rainfall stagnant at the surface of the green roof that may cause the vegetation to die due to the excessive amount of water on it. However, although plastic waste has helped to improve the flow rate of water in green roofs, it may also one of the sources of the contaminants in the water. When water reacts with the plastic, there will be chemical reactions between them and produce chemical pollutants in the water bodies. Choosing the suitable plastic by referring to the characteristics of plastic may help to reduce the chemical pollutant from the plastic.

In terms of accuracy of the data, the reading of data may be affected because of the water sample. The water samples from the rain harvesting system were collected and stored for a few days or few weeks. So, the water may react with the surrounding area, such as the container of the rain harvesting system and the water quality may reduce before the water is used to generate water runoff from the green roof. The water sample from the green roof should be collected after rainfall, to avoid any reaction from the surrounding area.

4. Conclusion

Even the water quality from the green roofs were classified as slightly polluted for Sample 4 and polluted for Sample 1, Sample 2 and Sample 3, it can be a benchmark for the future study to fulfill the ability of the green roof which is able to treat the water quality and save it before release to the stream. The runoff from the green roofs were classified as Class III from the water classification table based on the National Water Quality Standard for Malaysia. Class III needs extensive water treatment to reduce the concentration of pollutants in the water body. Other than that, it is suitable for fishery purposes and livestock drinking. Based on the data collected, *Zoysia Matrella* (Sample 4) is the most suitable to be proposed as a vegetation layer for green roof because it could cover most of the surface of the green roof in short time, so it may help to filter the total solid in the rainfall. This type of vegetation may have the ability to withstand the weather conditions and use less water to grow.

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