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# PERFORMANCE OF COCONUT SHELL AS AGRO-BASED MEDIA WATER FILTRATION FOR STORMWATER

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**Abstract**

It is no secret that filtration has been extensively used for water quality enhancement. However, urbanisation and uncontrollable growth increase the possibility of pollutants entering a water body or river, particularly through stormwater runoff. Numerous studies have shown a continuous improvement in the filtration mechanism's ability by using alternative sources of material as engineered soil media, such as agricultural waste or agro-based medium. Coconut shells can potentially become one of the most successful media for water filtration. In this study, the main aim is to investigate the performance of coconut shells in removing total suspended solids (TSS) and turbidity. Coconut shell samples must be carbonised to obtain the granular applied as the media filtration. Several runs were performed with varying stormwater concentrations and loading rates and different river sand and coconut shell filter configuration mix ratios ranging from 50% to 100%. For synthetic stormwater, two concentrations were prepared using kaolin powder: 150 mg/L and 1,500 mg/L (TSS) and 123.54 NTU, and 1,235.4 NTU (turbidity). Three loading rates were applied for each configuration of the design column filter. From the results, river sand (control) was the most successful media filtration in removing TSS and turbidity, with almost 100% removal. However, the combination of river sand and coconut shell can provide an efficient and effective stormwater filtering system besides encouraging green technology for water filtration.

Keywords: Clean water, Coconut shell, Pollutant removal, River sand, Stormwater, Total suspended solids (TSS), Turbidity.

## 1. Introduction

When it comes to stormwater management, the importance of filtration has been emphasized, particularly in improving water quality. Stormwater is rainfall that contains additional contaminants that may seep into the ground, remain on the surface, or runoff. Because stormwater carries pollutants from the impervious surface, urban stormwater runoff can significantly impact the quality of nearby bodies of water [1, 2]. Rainwater cannot simply seep into the ground as it does in a natural landscape due to the high imperviousness of the urban environment, resulting in floods and water pollution [3, 4]. Besides that, pollutants carried by stormwater discharge to the rivers have been a significant cause of worry during the last several decades. Certain metals are hazardous in very low quantities, whereas others are required for human health at extremely low concentrations [5]. Untreated stormwater may cause clogging and other unexpected events, such as overflows, and affect the characteristics of water bodies [6, 7]. Correspondingly, stormwater quality varies significantly according to local temperature and rainfall occurrences [8-10]. Nowadays, conventional media filtering is widely used for stormwater management. Media filtration is a method of removing suspended particles from stormwater by passing them through granular media.

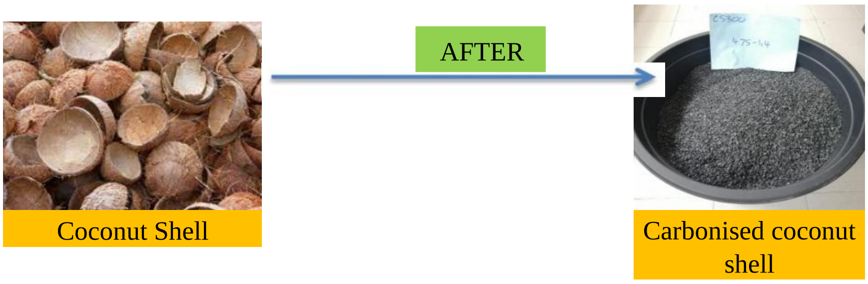
The media filtration design for stormwater purification is simple and well-defined, and the upkeep and maintenance of these filters have been thoroughly researched and documented [11]. In the past, stormwater management focused on adopting best management practices (BMPs) and creating bigger drains to reduce stormwater runoff without addressing environmental repercussions [12]. However, the current filtering system must be revamped to adapt to a more sustainable approach based on agro-based media. Agro-based media, or agro-waste material, is waste produced by various agricultural processes. Agricultural waste is frequently deemed unusable and is typically dumped in agricultural areas. The accumulation of agro-waste may endanger a person's health and safety, as well as the aesthetics of the surrounding area [13, 14]. As a result, such a situation indicates a problem that must be addressed.

Malaysia has 85,000 hectares of coconut plantations, with a yearly import of up to 220 million coconuts [15]. Previous studies have compared sand and coconut shell with activated carbon (burned) to remove BOD and COD. The results show that coconut shells with activated carbon increase the removal percentages of BOD and COD twice compared to sand filtration [16]. Besides that, coconut shells were beneficial in reducing chloride and the hardness of water [17, 18]. These agro-waste materials have been proven effective media filters [19-21]. Therefore, coconut shell has been chosen for this study as it is readily available and easily obtained. This study aims to investigate the performance of a combination of river sand and coconut shell in removing total suspended solids (TSS) and turbidity as media filtration for stormwater.

## 2. Methodology

### 2.1. Preparation of samples and materials

This study applied coconut shell as an agro-based filter media and river sand as a control. These materials were prepared at the Environmental Laboratory, Universiti Malaysia Sabah. Initially, used coconut shell was collected from several markets nearby (Kota Kinabalu), whereas the river sand was commercially obtained. The agro-waste was rinsed with tap water and drained using a plastic strainer. The process was repeated until both materials were clean in the water. Then the materials were oven-dried at 105°C for 12 hours before the self-sustained carbonization for the coconut shell sample was applied. The carbonised coconut shell was rinsed and oven-dried to remove any remaining residue. Figure 1 shows the carbonised coconut shell and the river sand sample. Sieving works were applied to obtain the required sizing for each material. Table 1 indicates the properties of both materials. Permeability tests have been applied to obtain the rate at which water can pass through the media. The produced carbonized coconut shell sample consists of sizes ranging from 1.4 mm to 4.75 mm, while the river sand obtained was 0.06 mm to 2 mm. Geotextiles were employed as separators to prevent media from escaping the filtration column and filter simulated stormwater samples. The preliminary tests show that these geotextiles do not affect stormwater filtering.




**(a) Coconut shell sample after the self-sustained carbonisation process.**

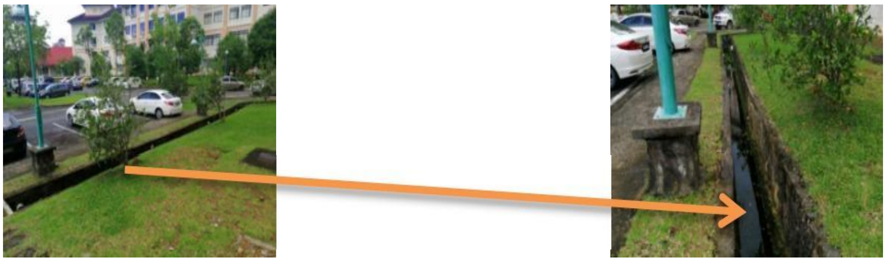

**(b) River sand sample**

**Fig. 1. Materials used as filter agro-based media.**

**Table 1. Properties of materials coconut shell and river sand.**

| Materials | Parameters | Physical Properties |
|---|---|---|
| **Coconut Shell (CS)** | Colour | Black |
| | Odour | Burnt |
| | Sizes | 1.4 – 4.75 mm |
| | Permeability | $-1.457 \times 10^{-5}$ |
| **River Sand (RS)** | Colour | White-Grey |
| | Odour | Odourless |
| | Sizes | 0.06 – 2.0 mm |
| | Permeability | $-1.567 \times 10^{-3}$ |

For the stormwater samples, two concentrations using kaolin powder were applied for the synthetic stormwater sample: 150 mg/L and 1,500 mg/L (TSS), 123.54 NTU and 1235.4 NTU (turbidity). The spectrophotometer (DR6000) and turbidimeter (2100AN) were used to determine the TSS and turbidity. Location selection for the collection of stormwater samples was based on the condition of water flow in the channel or drainage. Drainage near the Faculty of Engineering, UMS, was selected due to the suitability of the drainage gradient, which made the water flow constant during rainfall. Figure 2(a) depicts the collection area for stormwater samples. Stormwater samples were examined within an hour at room temperature to avoid excessive agitation or extended air reactivity changes. Figure 2(b) shows the preparation for synthetic stormwater using kaolin powder.



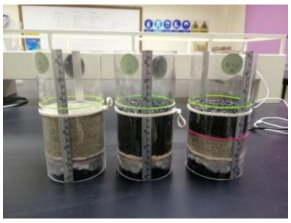
**(a) Location of stormwater samples collected**

**(b) Kaolin Powder**

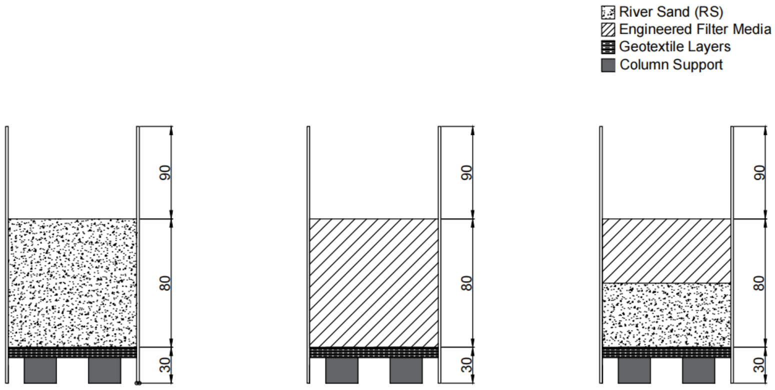
**Fig. 2. Preparation for synthetic stormwater samples using kaolin powder.**

## 2.2. Design column filter

The casing mould used in this study was an acrylic cylinder column, as shown in Figure 3(a). The size of the circular cross-section column used is 100 mm in diameter and 200 mm in height. According to the experiment's design, each filtering column has three distinct media configurations, as indicated in Table 2. The first column (a) demonstrates that only river sand was used, coated with geotextile sheets at the bottom. Simultaneously, the second column (b), which contains the engineered filter medium, was installed alongside three pieces of geotextile. For column (c), two types of material will be used: river sand and engineered filter media with 40 mm of height, respectively. The material within the filtering column will be the same height for each column, 80 mm. These columns are large enough to accommodate up to 80 mm of river sand media, 80 mm of engineered filter media, geotextile sheets, and column support underneath the column to enable water to drain out. Figure 3(b) illustrates each configuration's design sample column filter.



**(a) Samples columns filter**




**(b) Illustration column filters**

**Fig. 3. Design columns filter.**

**Table 2. Configurations of column filter sample.**

| Samples | Configuration |
|---|---|
| **RS(100%)** | River Sand (100%) |
| **RS(50%) CS(50%)** | River Sand (50%) Coconut Shell (50%) |
| **CS(100%)** | Coconut Shell (100%) |

## 2.3. Experiment setup

The experiment started with 5,000 ml of stormwater sample in each feed tank, meaning there were five filtration cycles for each configuration. This was done to obtain the average value when filtrating the stormwater samples. A magnetic stirrer was placed below the feed tank to ensure the synthetic stormwater dissolved uniformly throughout the water. Before setting up the filtration procedure, 30 ml of sample was collected from the 1,000 ml of stormwater sample in the beaker for comparison with the consequences after the initial filtration run. This volume of 30 ml was sufficient for testing the two parameters in this study: total suspended solids (TSS) and turbidity. Once the feed pump was turned on, the stormwater sample was delivered into the filter media column. The filtered water was collected using a sampling tube (30 ml) for each cycle when the stormwater sample in the feed tank decreased to 600 ml. The steps are repeated once again, utilising different configurations. The experimental setup for the filtering testing is shown in Fig. 4. In this experiment, the pump rate was applied at 24.88, 45.405, and 65.93 ml/min, as shown in Table 3.

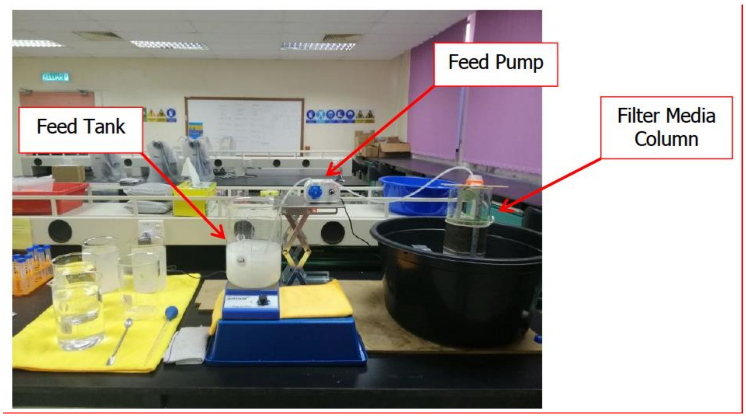



**Fig. 4. Design columns filter.**

**Table 3. Synthetic Stormwater concentration with different loading rates applied.**

| Stormwater Concentration (mg/L) | Loading Rate (ml/min) | | |
|---|---|---|---|
| 150<br>1,500 | 24.88 | 45.405 | 65.93 |

## 3. Result and Discussion

Total suspended solids and turbidity are two parameters considered when managing stormwater. The measurement of total suspended solids (TSS) is a critical component of water quality monitoring as it provides accurate and detailed information about the concentration of suspended solids in water. However, in some situations, measuring turbidity may also be useful and necessary. Turbidity measurements can be particularly valuable in monitoring changes in water quality over time, as they can change rapidly in response to changes in suspended solids concentration, whereas TSS measurements may not be as responsive. Additionally, turbidity measurements may be more practical and feasible in certain situations than TSS measurements, as they can be less time-consuming and expensive. In Malaysia, for example, the National Water Quality Standards (NWQS) set limits for TSS and turbidity in various water bodies, including rivers, lakes, and reservoirs. The NWQS limit for TSS is 50 mg/L for Class I, II, and III water bodies, while for Class IV, the limit is 150 mg/L. The NWQS limit for turbidity is 25 NTU for Class I, II, and III water bodies and 50 NTU for Class IV water bodies. Monitoring both TSS and turbidity is recommended to obtain a complete picture of changes in water quality. This research focuses on producing non-potable water that can be used for daily domestic activities such as watering plants and flowers, washing cars, washing clothes, and others. Hence, these two parameters are chosen for this filtration purpose

According to Tables 4 and 5, both configuration sets with different loading rates show a significant decrease in TSS and turbidity. Based on the previous studies by [22], the SF4 configuration consisting of sand gravel and coconut shell activated carbon shows the most effectiveness as a water filter. However, in this case, the most efficient filter configuration is the river sand (100%) because more TSS and turbidity were reduced since the river sand structure can trap suspended solids better than the coconut shell (100%) configuration alone. For a loading rate of 24.88 ml/min with river sand (100% configuration), TSS was reduced from 150 mg/L to 1.35 mg/L, while turbidity was reduced from 123.54 mg/L to 2.00 mg/L. Meanwhile, 50% river sand and 50% coconut shell configurations also show a reduction in TSS from 150 mg/L to 2.55 mg/L and a reduction in turbidity from 123.54 NTU to 4.00 NTU. Nonetheless, the coconut shell (100%) configuration also shows a reduction in TSS and turbidity, but not as much as the previous configurations, where TSS reduced from 150 mg/L to 5.15 mg/L and turbidity reduced from 123.54 NTU to 4.40 NTU. During the experimentation, no ponding was observed due to the low loading rate. The stormwater could be filtered out, and the cleanest stormwater was obtained from the river sand (100%) configuration.

On the other hand, the loading rate of 65.93 ml/min for the river sand (100%) configuration obtained the highest reduction of TSS and turbidity. TSS was reduced from 150 mg/L to 1.81 mg/L, while turbidity was reduced from 123.54 NTU to 2.20 NTU. However, a slight ponding in the middle of the media material was observed during the filtration run. The next configuration of river sand (50%) and coconut shell (50%) shows a reduction of TSS from 150 mg/L to 3.70 mg/L and turbidity from 123.54 NTU to 6.10 NTU. Pondering was also observed during the experimentation. The last configuration of coconut shell (100%) shows the lowest reduction, where TSS decreases from 150 mg/L to 5.55 mg/L while turbidity reduces from 123.54 NTU to 13.0 NTU. No ponding was observed during this time as the void or porosity of the coconut shell was larger and could drain stormwater faster but could not retain much of the suspended solid contained in the stormwater. Hence, the result shows that with a stormwater concentration of 150 mg/L, ponding or clogging may happen when the loading rate increases, especially when the media's particles are small and low in porosity. This is because once the filtration cycle has progressed, the bed becomes loaded with dirt and contaminants. Thus, it loses its effectiveness as a filter.

**Table 4. Experimental results for 150 mg/L synthetic stormwater concentration.**

| Samples | Loading Rate (ml/min) | TSS (mg/L) | | Turbidity (NTU) | | Remarks |
|---|---|---|---|---|---|---|
| | | Before | After | Before | After | |
| RS(100%) | 24.88 | 150 | 1.35 | 123.54 | 2.00 | No ponding |
| RS(50%) CS(50%) | | 150 | 2.55 | 123.54 | 4.00 | No ponding |
| CS(100%) | | 150 | 5.15 | 123.54 | 4.40 | No ponding |
| RS(100%) | 45.405 | 150 | 2.00 | 123.54 | 2.00 | Slightly ponding |
| RS(50%) CS(50%) | | 150 | 3.00 | 123.54 | 5.00 | Ponding |
| CS(100%) | | 150 | 5.00 | 123.54 | 10.00 | No ponding |
| RS(100%) | 65.93 | 150 | 1.81 | 123.54 | 2.20 | Slightly ponding |
| RS(50%) CS(50%) | | 150 | 3.70 | 123.54 | 6.10 | Ponding |
| CS(100%) | | 150 | 5.55 | 123.54 | 13.0 | No ponding |

Figures 5 and 6 show the reduction in percentage removal of TSS and turbidity in synthetic stormwater. The highest percentage removal of TSS and turbidity can be seen in the River Sand (100%) configuration, with 99.10% and 98.38%, respectively, having the lowest loading rate of 24.88 ml/min. While the 50% River Sand and 50% Coconut Shell configurations achieved the highest percentage removal of TSS and turbidity with 98.30% and 96.76%, respectively, they also had the lowest loading rate, which was 24.88 ml/min. Coconut Shell (100%) configuration achieved the lowest percentage removal of TSS and turbidity, with 96.30% and 89.48%, respectively, having the highest loading rate of 65.93 ml/min. The graph shows that as the stormwater concentration and loading rate increased, the percentage removal of TSS and turbidity was lower. Hence, the effectiveness and efficiency of the filtration system are highly affected by both the stormwater concentration and the loading rate applied.

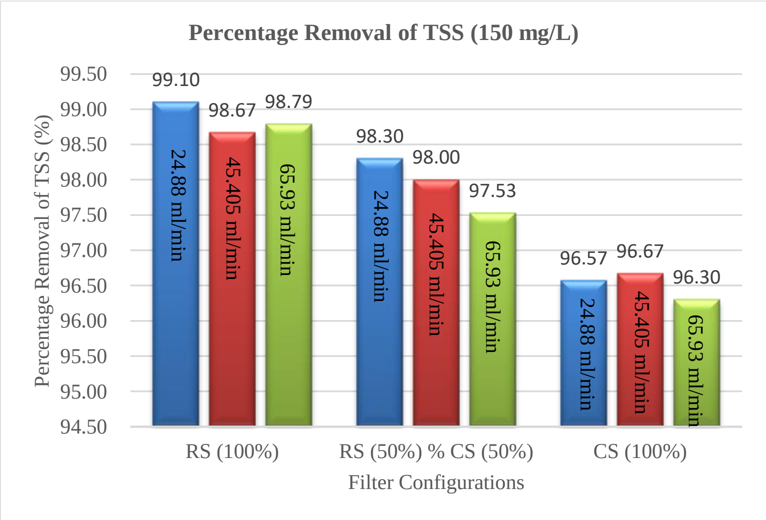



**Fig. 5. Percentages of removal total suspended solid (TSS) with concentration (150 mg/L).**

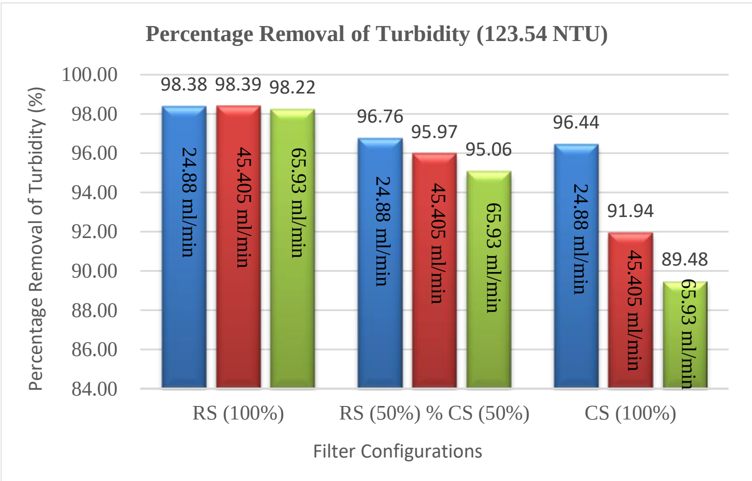



**Fig. 6. Percentages of removal turbidity with concentration (123.54 NTU).**

Based on Table 5, the synthetic stormwater concentration was increased to 1,500 mg/L and kept constant for each configuration. Both configuration sets with different loading rates also show a significant decrease in TSS and turbidity. The 24.88 ml/min loading rate with river sand (100% configuration) shows that TSS reduced from 1,500 mg/L to 1.65 mg/L while turbidity reduced from 1,235.4 NTU to 2.00 NTU. However, ponding was observed. This is because as the synthetic stormwater concentration increased, more dirt particles were retained inside the river sand, causing it to clog as the filtration cycle progressed. Meanwhile, 50% river sand and 50% coconut shell configurations also show a reduction in TSS from 1,500 mg/L to 13.42 mg/L and turbidity from 1,235.4 NTU to 16.30 NTU. Nonetheless, the coconut shell (100%) configuration also shows a reduction in TSS and turbidity, but not as much as the previous configurations, where TSS reduced from 1,500 mg/L to 262.98 mg/L and turbidity reduced from 1235.4 NTU to 319.30 NTU. After the experimental works were done, no ponding was observed for the 50% river sand, 50% coconut shell, and 100% coconut shell configurations. The stormwater could be filtered out, and the cleanest stormwater was obtained from the river sand (100%) configuration.

The 65.93 ml/min loading rate for the river sand (100%) configuration obtained the highest reduction of TSS and turbidity. TSS was reduced from 1,500 mg/L to 12.35 mg/L, while turbidity was reduced from 1,235.4 NTU to 15.00 NTU. However, ponding was observed during the run of filtration. The ponding starts in the third cycle at a depth of 0.2 cm and increases to 2.9 cm when it reaches the fifth cycle. The next configuration of river sand (50%) and coconut shell (50%) shows a reduction of TSS from 1,500 mg/L to 15.73 mg/L and turbidity from 1,235.4 NTU to 19.10 NTU. Pondering was also observed during the experimentation. The ponding starts in the fifth cycle at a depth of 0.4 cm. The last configuration of coconut shell (100%) shows the lowest reduction, where TSS decreases from 1,500 mg/L to 307.0.4 mg/L while turbidity reduces from 1,235.4 NTU to 372.80 NTU. There was no ponding observed during this time as the porosity of the coconut shell was larger and able to drain stormwater faster but was unable to retain much of the suspended solid or dirt contained in the synthetic stormwater. Figures 7 and 8 show the percentage removal of TSS and turbidity from the synthetic stormwater.

**Table 5. Experimental results for 1500 mg/L synthetic stormwater concentration.**

| Samples | Loading Rate (ml/min) | TSS (mg/L) | | Turbidity (NTU) | | Remarks |
|---|---|---|---|---|---|---|
| | | Before | After | Before | After | |
| RS(100%) | 24.88 | 1,500 | 1.65 | 1,235.4 | 2.00 | Ponding |
| RS(50%) CS(50%) | | 1,500 | 13.42 | 1,235.4 | 16.30 | No ponding |
| CS(100%) | | 1,500 | 262.98 | 1,235.4 | 319.3 | No ponding |
| RS(100%) | 45.405 | 1,500 | 2.00 | 1,235.4 | 2.00 | ponding |
| RS(50%) CS(50%) | | 1,500 | 14.00 | 1,235.4 | 18.00 | Ponding |
| CS(100%) | | 1,500 | 285.00 | 1,235.4 | 349.0 | No ponding |
| RS(100%) | 65.93 | 1,500 | 2.47 | 1,235.4 | 3.00 | ponding |
| RS(50%) CS(50%) | | 1,500 | 15.73 | 1,235.4 | 19.10 | Ponding |
| CS(100%) | | 1,500 | 307.04 | 1,235.4 | 372.8 | No ponding |

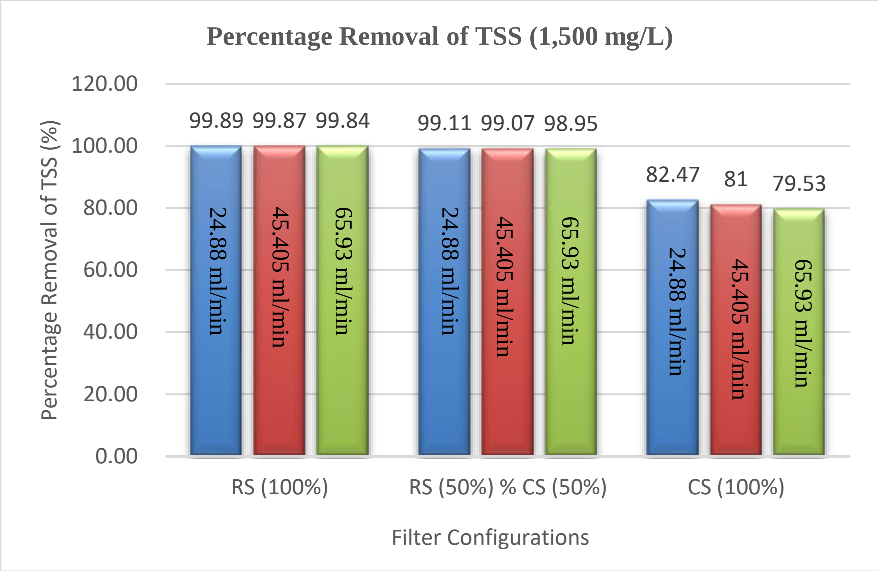



**Fig. 7. Percentages of removal total suspended solid (TSS) with concentration (1,500 mg/L).**

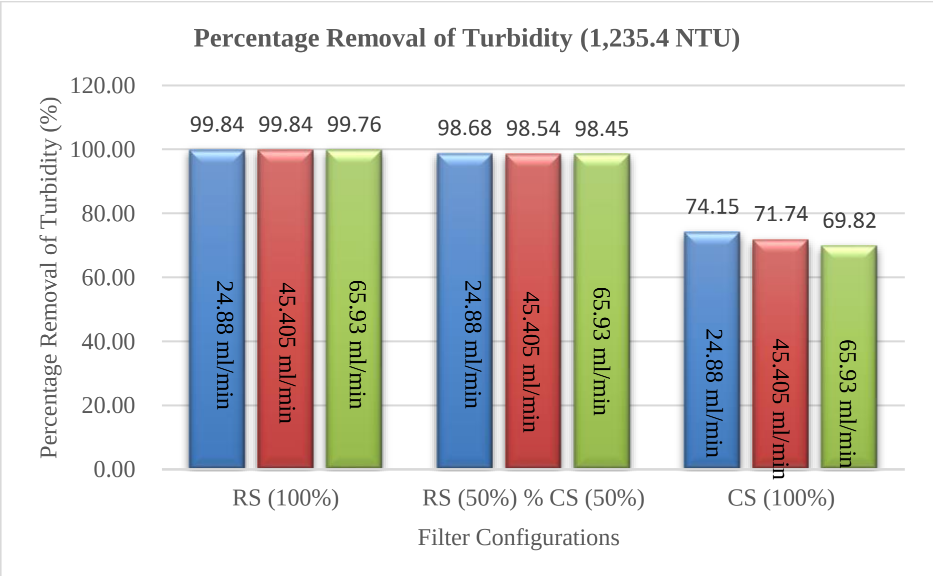



**Fig. 8. Percentages of removal turbidity with concentration (1,235.4 NTU).**

## 4. Conclusions

In conclusion, this study demonstrates the potential of self-sustained carbonized coconut shell as an eco-friendly filter medium for removing pollutants such as TSS and turbidity from stormwater. Utilizing low-quality agro-based material like coconut shell for filtration offers a sustainable solution to reduce the usage of sand production and solve environmental pollution. While the results show that river sand alone was the most effective and efficient for removing TSS and turbidity, it comes with the potential risk of water ponding. However, a combination of river sand and carbonized coconut shell filtration produced similar results to river sand alone and can be a viable option for low loading rates. Moreover, using carbonised coconut shell alone as a filter medium was not as effective as using river sand or a combination of river sand and carbonised coconut shell, but it came with the added advantage of having a minimal potential for water ponding.

Overall, this study demonstrates that carbonized coconut shell has the potential to be a valuable filter medium for stormwater treatment. However, more research is needed to explore its effectiveness for treating other types of pollutants and for higher loading rates. By exploring the potential of carbonized coconut shell as a filter medium, this study contributes to developing sustainable and cost-effective solutions for stormwater treatment that can benefit both the environment and society.

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