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CARBONIZED COCONUT SHELL MEDIA APPLICABILITY FOR STORMWATER POLLUTION CONTROL

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ABSTRACT

Conventional sand is commonly used in water and wastewater treatment as filter media. However, such effective media may fully or partially replace agro-based materials for less critical applications, including stormwater quality control. This paper highlights the potential use of carbonized coconut shells (CS) as efficient filter media, tested on synthetic and actual stormwater. Three media configurations were used: fully river sand (RS) (100%) as a control, half RS and CS (50%:50%), and CS (100%). The RS has the highest average for TSS removal (99.2%), albeit the combined 50% RS and CS achieved higher peak TSS removal (99.6%). However, 100% CS also showed considerable (98.1%) TSS removal. When tested with actual stormwater, the 50% RS and CS demonstrate substantial improvement in TSS and turbidity from Class II to Class I (NWQS). The findings also highlight the influence of porosity with the combined media configurations on the filter performance, with small-size filter grains less porous being more effective than larger ones in removing pollutants.

Keywords: Carbon, Coconut shell, Filter media, Porosity, Specific gravity, Stormwater

INTRODUCTION

The degradation of streams, habitats, and water pollution are environmental challenges due to anthropogenic activities (Hazourli et al., 2007; El Ouali Lalami et al., 2010; Belghiti et al., 2013; Djabri et al., 2015). Additionally, the ongoing problems with stormwater quality management are jeopardized by rapid development, which generates more surface runoff due to impervious surfaces. Urbanization escalates stormwater runoff, impacting flooding and increasing sediment, heavy metal, and nutrient pollutants (O'Sullivan et al., 2015). Combined with the effect of climate change, this leads to the need to establish a more functional stormwater infrastructure system (Li and Davis, 2016).

Stormwater quality degrades due to untreated surface runoff that runs straight into drainage systems. It may accumulate pollutants of both natural and anthropogenic origin, which are carried away from the air and surface. Contaminants such as dust, metals, and nutrients may cause blockages and silt transport, affecting aquatic bodies (Awang Ali and Bolong, 2021). Controlling contaminants in stormwater is vital to prevent the influx of nonpoint source pollutants into nearby water bodies, particularly in dense urban areas. Thus, stormwater management must emphasize controlling both its quantity and quality.

Previous studies have indicated the potential use of agricultural wastes in water filtration, including bioretention applications. However, further research is still needed, particularly when the media preparations are varied. This paper presents the potential use of carbonized coconut shells (CS) as filter media. The porosity and specific gravity properties of the media were studied. Synthetic and actual stormwater samples were used to evaluate pollutant removal effectiveness (total suspended solids (TSS) and turbidity). Additionally, this lab-scale study uses three media configurations for the experiments: fully river sand (RS) (100%), half RS and CS (50%:50%), and fully CS (100%). It is hoped that the potential usage of agro-based media may benefit local authorities and the environment while promoting sustainable development.

LITERATURE REVIEW

Malaysia's growth in the agriculture sector consequently leads to more agricultural waste. Approximately 998 million tons of agricultural waste are produced annually worldwide, with 1.2 million tons disposed of in Malaysia's landfills (Agamuthu, 2009). Thus, sustainable practices have become crucial for environmentally acceptable agricultural waste disposal.

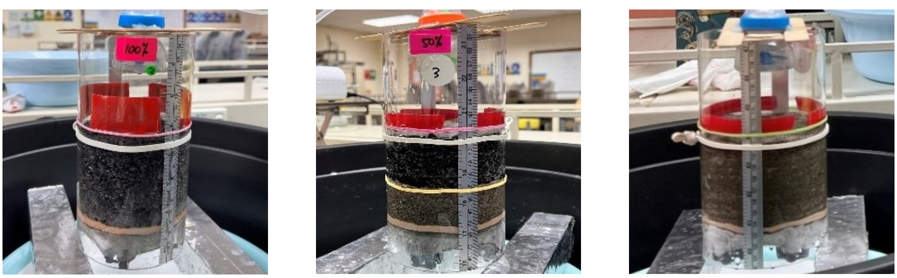
Previous studies have indicated the potential of agricultural wastes in water filtration applications. For instance, sugarcane bagasse and banana pith remove metals, oil, and grease from surface water and wastewater, respectively (Abdul Hamid et al., 2016; Kakoi et al., 2016). Tota-Maharaj and Cheddie (2015) stated that factors such as availability, low cost, environmental friendliness, permeability, ease of handling, and efficacy in water contamination removal should be considered when using agro-based material as a filter media. Awang Ali et al. (2022) compared several agro-based filters, including durian shell, coconut shell, and kernel shell, whereby all showed improvement (17-80%) in turbidity, dissolved oxygen, biochemical oxygen demand, and ammoniacal nitrogen.

Although these agricultural wastes are abundant, more work is still required to explore their potential capabilities. When processed into granular media and combined with sand in a dual media configuration, the coarser flocs can be removed from the top bed depth. Simultaneously, the bottom bed depth will remove finer flocs. A large mass of coconut shells and fibers are frequently disposed of in landfills once consumed. The recent finding also shows that the CS processed under one-step low-temperature carbonization without activation successfully produces a high surface area (Samsudin et al., 2019), which means a higher porosity. Thus, this work adds more perspectives to its application in the field, indirectly promoting the use of agricultural-based media in stormwater filtration sustainably while reducing costs in managing stormwater.

MATERIAL AND METHODS

Preparation and characterization of CS media

The raw CS was carbonized in a reactor, washed with distilled water, and oven-dried (103-105°C) overnight. Then, it was sieved and grouped based on its sizes into C1 (large), C2 (medium), and C3 (small). Characterization was conducted to determine the porosity (direct measurement) and specific gravity (jar test method) of the materials and compared with the RS (control). Then, three designs of media configuration were set up, as shown in Fig. 1. The column dimensions are 200 mm (height) x 100 mm (diameter), with a filter bed depth of 100 mm.



100% CS | 50% CS + 50% RS | 100% RS

Figure 1: Designs of media configuration

Stormwater sample preparation and properties

Five liters of synthetic stormwater of 150 mg/l and 300 mg/l (Class III-IV) concentrations were used in each experimental run before being tested with actual stormwater. The synthetic stormwater samples were prepared from kaolin powder and distilled water. Then, actual stormwater samples were collected at a designated drainage catchment near

Kolej Kediaman Rafaie, Universiti Malaysia Sabah (UMS), as shown in Fig. 2. The samples were collected early morning after an overnight rain stopped and were evaluated within an hour to minimize disturbance toward the samples.

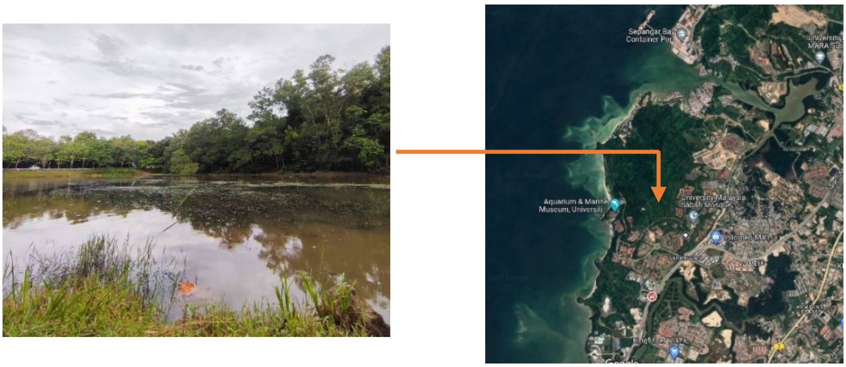


Figure 2: Catchment area near the outlet from Kolej Kediaman Rafaie, UMS

Experimental run

Five liters of synthetic stormwater sample per run were initially used for each filter column configuration of river sand (RS) (100%) as a control, half RS and CS (50%:50%), and CS (100%). Only C2 was used in the configuration for this testing purpose. Each configuration was tested under 150 and 300 mg/l TSS concentrations. Then, the results are analyzed and compared. One configuration is then selected to demonstrate and assess the media performance using the actual stormwater sample. The parameters include TSS and turbidity using a spectrophotometer (HACH DR6000) and turbidity meter (HACH 2100AN), as shown in Fig. 3.

Spectrophotometer (HACH DR6000) Turbidity meter (HACH 2100AN)

Figure 3: Equipment for analyzing TSS and turbidity

RESULTS AND DISCUSSION

Influence of porosity and specific gravity on filter performance

The CS media were characterized and compared to the RS (control). The results are shown in Fig. 4. Overall, the CS media has a higher porosity than RS (0.47), indicating that the void structure is more open. C1 (0.63) has the highest porosity for CS samples, followed by C2 (0.58) and C3 (0.53).

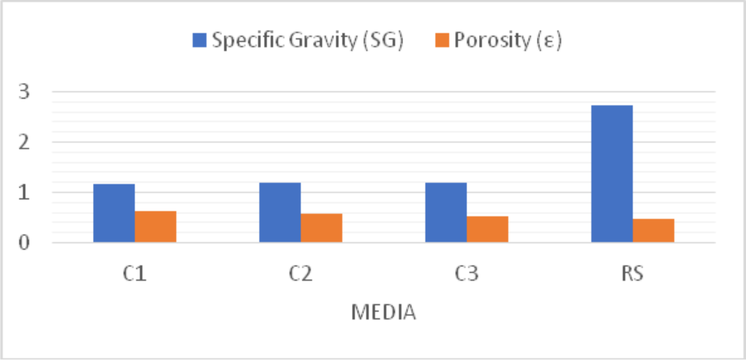


Figure 4: Porosity and specific gravity

The role of porosity in filtration is significant, as it directly influences the media's pollutant removal efficiency. Filters with decreasing porosity with depth are more efficient than those with a constant porosity (Dalwadi et al., 2015), as a highly porous medium has a more open structure that allows for greater flow with lower pressure drops. Hence, small filter grains that are less porous can be more effective than larger ones in removing pollutants (Khelladi et al., 2020) but may risk being washed out during heavy flow. Conversely, RS (2.72) has a higher specific gravity than CS (followed by C3 (1.20), C2 (1.19), and C1 (1.18)), which allows it to retain the other filter layer and maintain its shape in a dual media configuration.

Table 1 summarizes the porosity, specific gravity, TSS removal, and turbidity removal efficiency. The carbonized CS media are more porous than RS (0.58>0.47), resulting in the control RS with the highest average pollutant removal, followed by the 50% RS and CS combination and the 100% CS. Nonetheless, TSS removal by other media configurations is also considerably high (>95%), almost similar to the control RS. For these synthetic stormwater filtrations, the detailed removal efficiencies of TSS and turbidity are presented in Figs. 5 and 6, respectively.

Table 1: Porosity, specific gravity, TSS removal, and turbidity removal efficiency on synthetic stormwater

Media Configuration	Porosity	SG	TSS Removal	Turbidity Removal
RS (100%) (Control)	0.47±0.02	2.72±0.02	99.26%±0.41	99.25%±0.39
50% RS and CS	-	-	98.82%±0.92	98.97%±0.69
CS (100%)	0.58±0.05	1.18±0.04	98.1%±0.71	98.54%±0.66

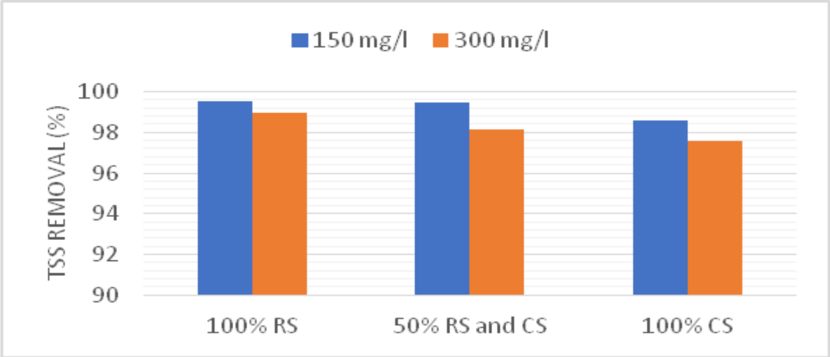


Figure 5: TSS removal from synthetic stormwater

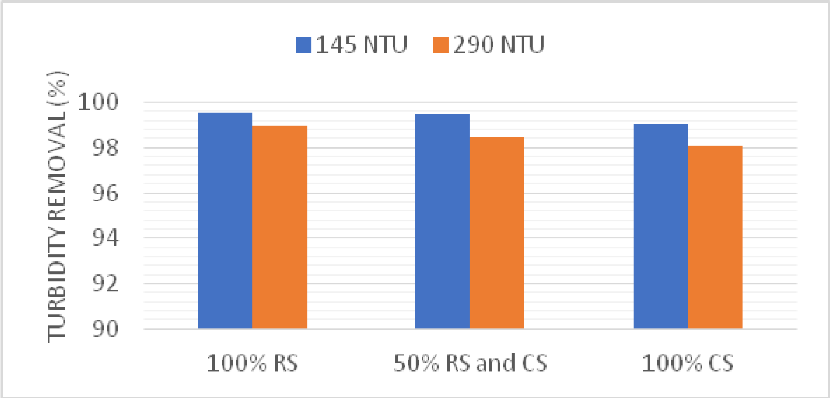


Figure 6: Turbidity removal from synthetic stormwater

Testing with actual stormwater samples

The 50% RS and CS media configuration was tested on actual stormwater for demonstration, and the results are summarized in Table 2. There are notable changes in TSS and turbidity, indicating improvements in stormwater quality after filtration from

Class II to Class I. Should the stormwater be considered for nonpotable reuse, these parameters are within the acceptable limit of the National Water Quality Standards (NWQS).

Table 2: The 50% RS and CS media on actual stormwater

Parameter	Filtration (Average)		Pollutant removal (%)	NWQS
	Before	After		
TSS (mg/l)	50.46±1.88	1.42±0.39	97.18±0.81%	Class II→1
Turbidity (NTU)	48.53±1.65	1.26±0.29	97.39±0.64%	Class II→1

Fig. 7 shows the apparent decrease in the bar trend toward improving TSS and turbidity in the actual stormwater samples. The 50% RS and CS media configuration reached 97.18% for TSS removal and 97.39% for turbidity removal. The pollutant removal capabilities are comparably higher than those reported in other studies, such as 72% for TSS (Wahid et al., 2015) and 85% for turbidity (Ramavandi, 2014) for stormwater and water treatment, respectively. The result is similar to Abdulsalam et al. (2018), where the CS biosorbent shows 71.3-91.4% TSS and turbidity removal efficiency. This filter performance is considered efficient when it exceeds 80% pollutant removal (Kumar et al., 2010). The details on TSS and turbidity removal efficiency for each filter run are shown in Table 3.

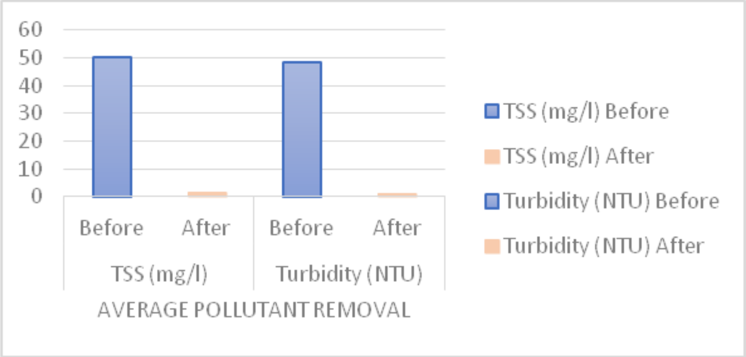


Figure 7: Average filtration using 50% RS and CS media

Table 3: Pollutant removal efficiency for each filter run

Filter Run	TSS (%)	Turbidity (%)
1	97.00	96.51
2	97.89	97.50
3	96.99	97.96
4	98.00	98.00
5	96.01	97.01
Average	97.18%±0.81	97.39%±0.64

CONCLUSION

Carbonized CS utilization for stormwater pollution control is achieved, potentially replacing it fully/partially with common RS filter media. From the experiments, the RS has the highest average for TSS and turbidity removal, 99.26% and 99.25%, respectively. The 100% CS also shows considerable 98.1% TSS removal and 98.54% turbidity removal. When tested with actual stormwater, the 50% RS and CS demonstrate substantial improvement in TSS (97.18%) and turbidity (97.39%) from Class II to Class I (NWQS). These results indicate the potential of carbonized CS as an agro-based media for stormwater filtration and that the porous structure of the material influences the filter performance. Hence, smaller media sizes are less porous and are more effective, albeit they risk being washed out. Having RS media with high specific gravity as a bottom layer may aid in maintaining media layering configuration from such problems. It is also recommended to include filter bed depth and flow rate as variables in a future study to address their impact on pollutant removal efficiency to increase the potential of utilizing agro-based materials in practice.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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