© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Comparison of Selected Agro-Based Filter Media for Stormwater Quality Improvement

Awang Nasrizal Awang Ali[1,2], Nur Hanisa Awang Matusin[1], Ani Aryanie Awang Aziz[1], Nurmin Bolong[1], Nazaruddin Abdul Taha[1*]

[1]Faculty of Engineering,
Universiti Malaysia Sabah, 88400 Kota Kinabalu, MALAYSIA

[2]Faculty of Civil Engineering,
Universiti Teknologi MARA Cawangan Sarawak, 94300 Kota Samarahan, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2022.14.01.023
Received 09 March 2021; Accepted 17 September 2021; Available online 07 March 2022

Abstract: Polluted stormwater has become a severe problem in the environment as the runoff collecting various contaminants before discharged into water bodies, degrading the water quality and risking aquatic life. This study aims to evaluate selected agro-based filter media to treat stormwater through environmental laboratory works. These include kernel shell, coconut husk, coconut shell, durian shell, sugarcane bagasse, and pineapple leaves. The stormwater samples used were collected from a pond in Universiti Malaysia Sabah, whereas the filter column is configured through a combination of 80% of agro-based media and 20% of aggregate. Filter performance is evaluated for turbidity, pH, dissolved oxygen, biochemical oxygen demand, and ammoniacal nitrogen. Overall, the findings show the potential in utilizing agro-based media, particularly the shell-based media of CS300, KS300, and DS200. Further investigations are recommended to further study the application of agro-based media in improving the quality of stormwater.

Keywords: Agro-based, comparison, filter media, quality improvement, stormwater

1. Introduction

Environmental pollution has become increasingly of concern due to rapid urbanization and industrialization, and among the affected areas is stormwater. Stormwater refers to the rainwater that falls onto impervious surfaces such as road pavements, sidewalks, rooftops and becomes surface runoff in the urban area. The natural hydrological cycle changes due to the impermeable surfaces, impacting the surface runoff [1]. This runoff may pick up debris, chemicals, dirt, heavy metals [2], [3], pathogens, suspended solids, and nutrients as it flows on the landscape and goes directly to a lake, river, or streams.

Improving stormwater quality is essential to reduce pollution and minimize risks to human health as it poses significant challenges [4], [5]. It also helps in mitigating flooding and erosion in the waterways of the stormwater runoff. Besides, this also protects the ecosystem, such as green plants and aquatic life, to manage contaminated stormwater. Typically, the stormwater system's design is based on historical rainfall and landuse [6]. The drained water is retained in a pond to allow for solid-liquid separation with sorption and degradation mechanisms dominant for removing soluble contaminants [7]. However, since most stormwater pollutants are attached to suspended solids [8], especially heavy metals and nutrients [9], solids removal through stormwater filtration is emphasized.

This study aims to utilize selected agro-based filter media for stormwater filtration. Agro-based materials are the wastes produced from agricultural activities. They are usually available in abundance, can cause pollution to the environment [10], and risks to human health and the ecosystem. Hence, utilizing these agro-based materials as filter

*Corresponding author: nazardin@ums.edu.my

media would be beneficial to minimize the massive amount of wastes [11] that is hard to control while improving the stormwater quality. Indirectly this also provides alternatives to sand material, which is commonly used in the application of water filtration. The objective of this study is to compare the performance of agro-based materials, mainly from palm oil kernel shell (KS), coconut husk (CH), coconut shell (CS), durian shell (DS), sugarcane bagasse (SB), and pineapple leaves (PL) as filter media, in improving stormwater quality, based on the selected parameters. The findings are expected to enlighten more on the potential of utilizing local wastes from the agriculture sector in stormwater treatment applications.

2. Literature Review

Typically sand, coal, anthracite, or activated carbon is used either as a single or combined configuration, becoming filter media [12]. These different types of material performed variedly in removing particular pollutants [13]. However, when considering the sustainability issues [14], [15], there is a need for low-cost alternatives from other potential sustainable resources. With this, locally available materials such as agro-wastes can be exploited to benefit the most in various aspects, including the cost implication.

In Malaysia, the likes of palm oil have been the major crops grown, but other crops such as coconut, pineapple, durian, and other tropical fruits and annual crops are also rapidly growing and in-demand, both locally and internationally. Agro-wastes from these crops can be considered as a renewable source. They are primarily made from lignocellulosic fibre, consisting of cellulose, hemicelluloses, and lignin. The agro-wastes are inexpensive, always available in plenty, environmental-friendly when utilized, and show the potential to become one of the income sources for the agricultural industries [16]. Though these materials can achieve large-scale on-field application, the techniques to improve and improvise the usage of agro-wastes as alternatives for sand media in the filtration system needs to be extensively explored.

The agro-wastes can be used as raw material or processed into activated carbon. Formerly, the development of activated carbon was very costly and limited. However, it can now be derived through either physical or chemical activation methods [17] into the form of powdered, granular, and fibrous from biomass or other carbonaceous materials that is low in inorganic contents, such as agro-wastes [18]. The agro-wastes' filtration and adsorption capacity as a filter media depends on various factors, including its surface area and internal pore structure [19]. Generally, the smaller grain sizes consist of large specific surface areas, improving its pollutant removal efficiency [20]. In contrast, having a larger grain would produce a low specific surface area with a deeper filter bed depth [21], allowing more solids penetration while reducing pressure loss. Thus provides a prolonged filter life cycle.

Carbonized materials with low pores can be activated to increase the porosity and surface areas to enhance the performance in the filtration system. However, this activation process is costly, whereas utilizing the raw materials offers to be much more sustainable [15]. Additionally, not all agro-wastes suit the activated carbon production [22] as the performance may neither significantly improve nor cost-effective. Therefore, it is essential to investigate techniques and establish a comparative series, whether inactivated or fully activated carbon, for the selected agro-wastes material to evaluate overall performance. Fig. 1 shows the example of the porous state, where there are more spaces in highly porous materials and vice versa. The filter can be considered excellent with better effluent quality, economical, and possess high total running of services.

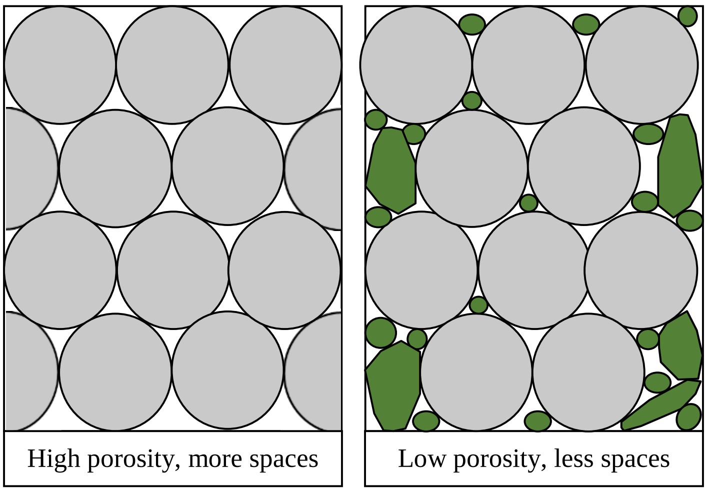

Fig. 1 - The porous state

3. Stormwater Sampling Area

The stormwater samples were collected on the 23rd of June 2020 at 10 A.M. during a dry period (no rain) from a detention pond near the Faculty of Science and Natural Resources (FSNR), Universiti Malaysia Sabah (UMS), which is located at Kota Kinabalu, the state capital of Sabah, Malaysia. This detention pond was selected mainly because of its accessibility and distance to the laboratory of approximately 1km. Equipped with safety gloves and boots, these samples were taken using several gallons and transported straight to the Environmental Laboratory, Faculty of Engineering, UMS, for characterization and experimental work. This was done immediately, within an hour, to minimize any disturbance to the collected stormwater samples. To add, UMS still restricts their campus operation during this period, following the post-movement control order (MCO) due to the Covid-19 outbreak since mid-March of the year 2020. Hence, only one sampling point is collected with a triplicate testing run. The location of the detention pond in the UMS campus is as shown in Fig. 2.

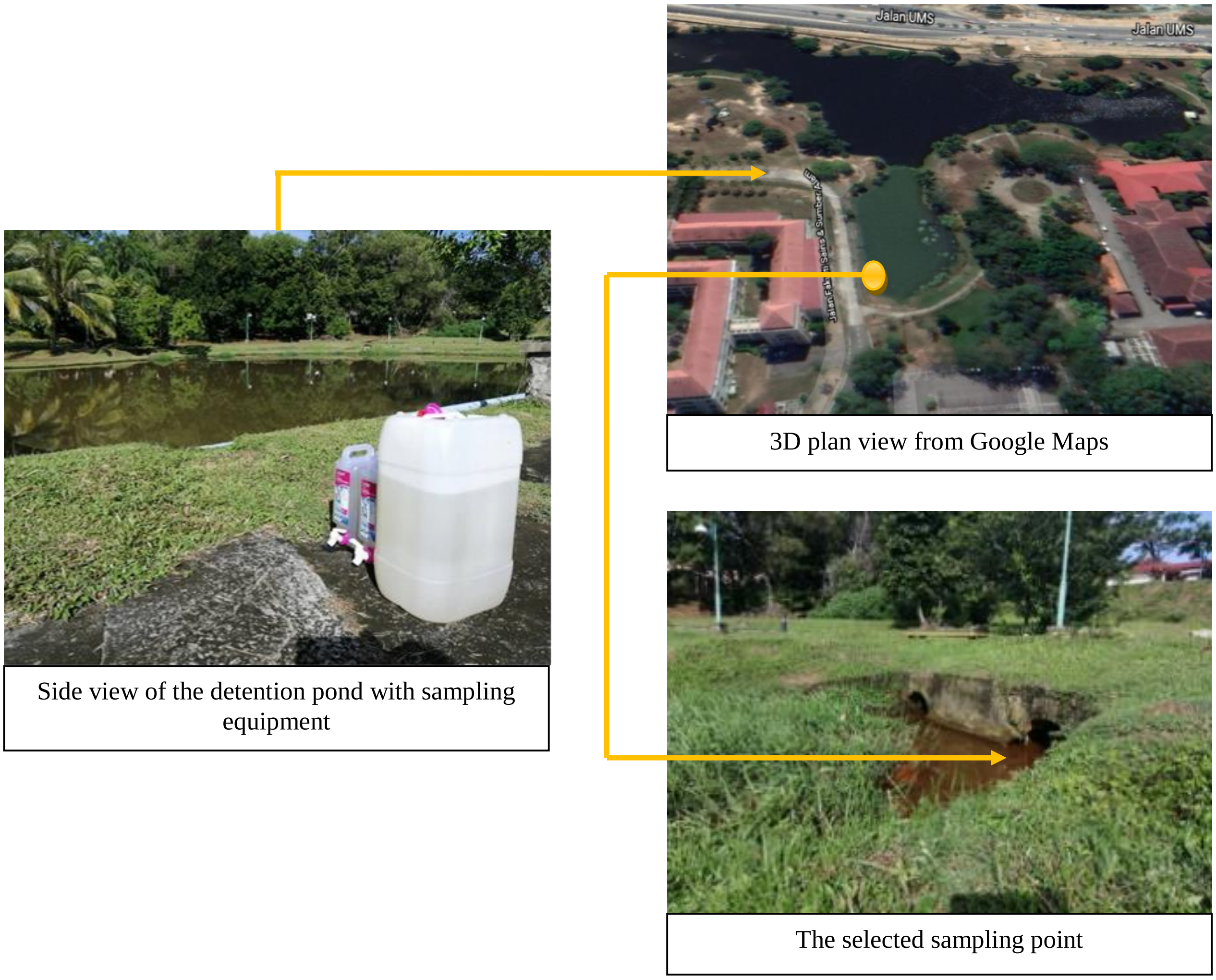

Fig. 2 - Sampling points from the selected detention pond at UMS

4. Materials Preparation

The prepared materials are shown in Fig. 3. All the agro-based materials were labelled accordingly as palm oil kernel shell (KS300), coconut husk (CH105), coconut shell (CS300), durian shell (DS200), sugarcane bagasse (SB105), and pineapple leaves (PL105). These materials were selected primarily due to their availability in the tropical state of Sabah [23]. For instance, palm oil is the local niche source of Sabah and Malaysia overall. Whereas coconut, pineapple, and durian are also among the top plantations in the country. Although sugarcane has limited cultivations locally, they have high demand, especially during festive occasions. The growth of the agricultural sector, added with continuous disposal of this waste, may create problems for the environment [24]. Previous findings [14-16] have already demonstrated the potential of these agro-wastes as media filters. Hence, utilizing these agro-wastes into a low-cost media filter would help reduce the cost of waste disposal and provide a potential alternative to the existing commercial media filters while reducing the environmental impact.

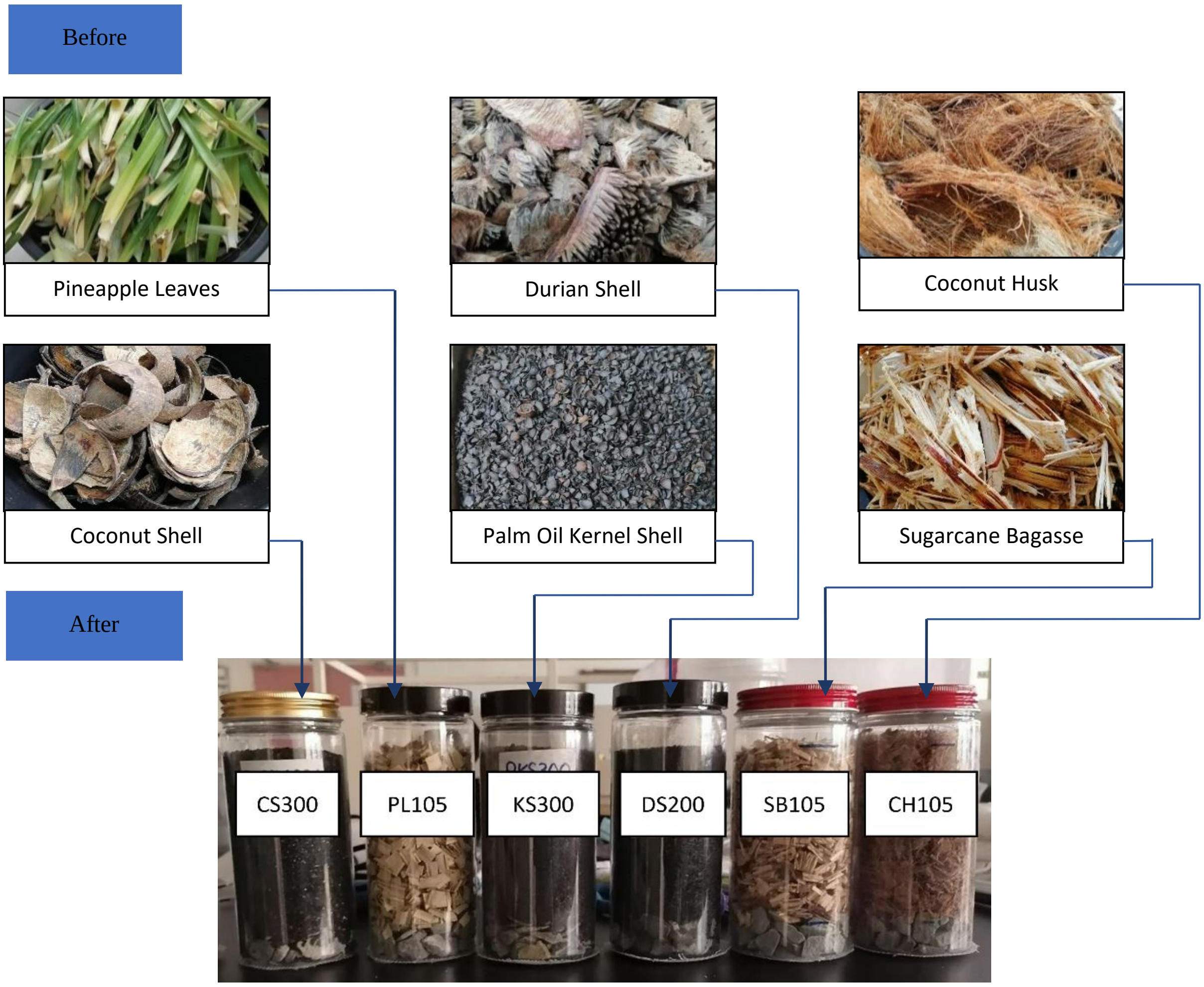

Fig. 3 - Agro-based materials for filter media

Once sufficiently collected from the local market, the agro-wastes are washed with a tap water and soaked into the distilled water until they achieve the pH ±2 before being sun-dried. The materials are then oven-dried overnight for a minimum of 24 hours, at a temperature of 103°C-105°C. Additionally, for CS, KS, and DS, they are carbonized for one hour at a temperature of 300°C, 300°C, and 200°C, respectively. After that, the materials are cooled down at room temperature, ground, and sieved using the sieving apparatus into granular size, passing 2.0mm to 0.6mm. In contrast, the fibrous CH, PL, and SB are cut into approximately 100mm^2. The flow chart of these processes is shown in Fig. 4.

Fig. 4 - Flow chart of the materials preparation process

5. Filter Model Fabrication

The hydraulic conductivity and lifespan of water filters primarily depend on the filter bed design [8]. This study uses grain sizes of 2mm-0.6mm for the granular media with the filter column setup consisting of 80mm agro-based media overlaying 20mm aggregates. Hence, it is well within the recommended ratio of experimental column diameter to media particle diameter (20-200) [26]. As shown in Fig. 5 is the filter model setup used in this study, whereby the column is connected to the influent tank attached with a stop valve and effluent tank that received the filtered water. The bottom layer act for drainage purposes before the water reaches the outflow line.

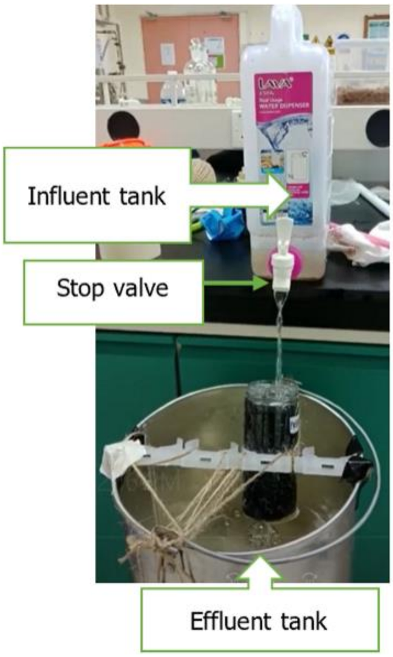

Fig. 5 - Filter model setup

Due to constraints during the recent post-MCO, only a single filtration cycle was conducted for agro-based media. After the filter has been developed, brief initial dosing with tap water was carried out first to remove any intrinsic dust that could interfere with the filter performance. The filtration cycle was then dosed manually with five litres of the collected stormwater samples. This was done by controlling the stop valve on the influent tank. Once the results have been recorded, the experimental run proceeded with other media replaced in the filter setup. Finally, the filtration performance is evaluated by analyzing their performance throughout the test. The experimental flow chart is shown in Fig. 6.

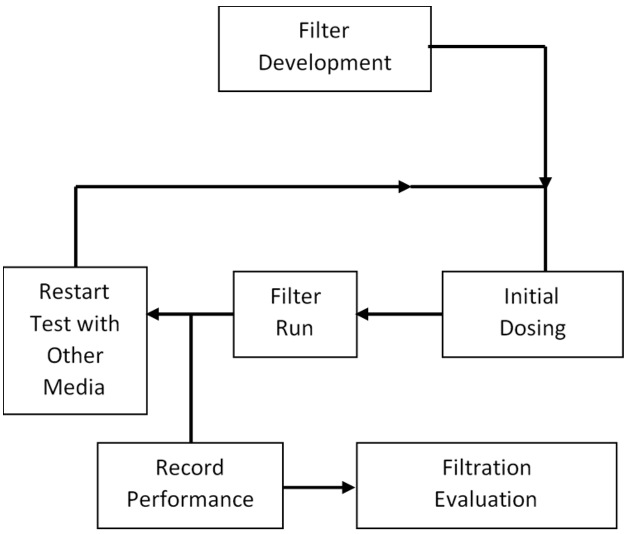

Fig. 6 - Experimental flow chart

6. Results and Discussion

Table 1 shows the initial values for the collected stormwater quality from the detention pond at UMS, based on selected parameters, including turbidity (NTU), pH, dissolved oxygen (DO) (mg/l), biochemical oxygen demand (BOD) (mg/l), and ammoniacal nitrogen (AN) (mg/l). Compared with Malaysia's national water quality standards (NWQS) [27], the raw stormwater before being filtered can be classified into Class II in turbidity (13.6 NTU), pH (6.6), and DO (10.2mg/l). Whereas, both BOD (5.5mg/l) and AN (0.5mg/l) are in Class III. It is worth noting that the stormwater quantity and quality have intermittent nature [28]. Thus, it may fluctuate.

Table 1 – Experimental result for stormwater filtration

Parameters (%)	Initial Stormwater Quality (Ave.)	National Water Quality Standards					
		Class I	Class IIA	Class IIB	Class III	Class IV	Class V
Turbidity (NTU)	13.6	5	50	50	-	-	-
pH	6.6	6.5-8.5	6-9	6-9	5-9	5-9	-
DO (mg/l)	10.2	7	5-7	5-7	3-5	<3	<1
BOD (mg/l)	5.5	1	3	3	6	12	>12
AN (mg/l)	0.5	0.1	0.3	0.3	0.9	2.7	>2.7

Turbidity is a reliable indicator for assessing the impact of existing suspended solids, which causes cloudiness in the water. High turbidity may reduce the DO value while increasing the acidity or having low pH and temperature in the water body [29], affecting aquatic life. Thus, having sufficient DO is exceptionally vital as low DO in the water would increase the BOD value. This indicates high pollutant loads and increasing the potential environmental issues [30]. As for the AN, it could enter the waterways from animal farming activities, plantations, and domestic sewage. The AN is detrimentally toxic, causing undesirable eutrophication occurrences [31].

Fig. 7 presents the experimental results for the stormwater filtration based on the selected parameters, using the selected agro-based materials. The dotted reference line refers to the initial stormwater quality. When observed, the results indicate an increase or decrease in the tested parameters. However, any changes that occurred, whether they increase or decrease, do not necessarily mean that the filtrated water is good or bad, as the context of the parameters used needs to be looked up too. For instance, a reduction in pH means more acidity the effluent is, whereas an increase in the BOD displays a lack of DO in the water body and vice versa.

When the filter performance is compared with NWQS, most media show turbidity improvement, with DS200 media the highest at 27.2% (9.9NTU), followed by KS300 (15.4%), SB105 (11.8%), and CS300 (6.6%). In contrast, the turbidity increase for the effluent from CF105 (4.4%) and PL105 (11%) media. This result was expected since both CF105 and PL105 have lower porosity characteristics (0.5-0.7) than others (0.7-0.9) when tested before filtration run. Once the media is saturated with the retained solids, it is possible for them to flow back into the water [32]. There is also a potential that this media to be insufficiently dosed with tap water before the filtration cycle. Hence, a further dosage is recommended in the future to ensure proper intrinsic dust removal. Either way, all media shows effluent turbidity in Class II, similar to the initial stormwater quality.

Next is the pH, which determines the alkalinity or acidity of the water. The pH for effluent from all media remains well within the neutral range (6.5-6.7) of up to Class I except for DS200, which inclined into alkalinity at pH 8.9, increasing approximately 34.8% (Class II-IV). Typically, a reduction in pH indicates an increase in hydrogen. Low pH impacts the aquatic life and degrades recreational practices, while too high pH would cause other pollutants' toxicity. Though the pH adjustment can be chemically applied when necessary, it will still be associated with a cost implication. Thus, it is interesting to see how well the natural alkaline biochar such as DS200 [33] can be utilized in applications of acidic samples. Nonetheless, minor pH variations show no significant effect on the filtration run and turbidity removal [34]. Hence the pH for all samples is acceptable.

Then, most media effluent shows an increase in the DO level of up to 12mg/l (17.6%) for DS200. This is followed by CS300 (14.7%), CF105 (10.8%), KS300 (5.9%) and PL105 (2.9%). Only SB105 media shows a DO reduction of 6.9% (9.5mg/l) after the filtration cycle. Despite that, all the treated effluent is in Class I. The presence of DO is essential for maintaining the stormwater quality as it can be depleted, consumed by microorganisms. Furthermore, the increase in DO is reflected by the BOD reduction and vice versa. The DS200 media shows the most notable BOD improvement to 3.4mg/l (38.2%). This is followed by CS300 (21.8%), KS300 (10.9%), and CF105 (1.8%), with PL105 showing no changes to the BOD level. Again, only SB105 shows a significant increase in BOD at 9.5mg/l (72.7%). This may be due to the functional group's presence on the pore surface [19]. However, further investigation is recommended to assess this occurrence. All media is in Class III for BOD, except for SB105, which is in Class IV.

Finally, for the AN, marginal improvements can be seen for KS300 media with 80% reduction. This is followed by CS300 (40%) and DS200 (40%), all in Class II, whereas the effluent from SB105 (20%) and CF105 (0%) media remain in Class III. In contrast, only PL105 recorded an increase (20%) for the AN, from 0.5mg/l to 0.6mg/l. It is observed that fibrous materials (CF105, SB105, and PL105) have constraints in removing the AN compared to the granular materials (CS300, KS300, and DS200). Although the fibrous thread-like bundles have the advantage of retaining their shape and remaining immobile during filter run [10], the effluent concentration may still increase or decrease due to the difference in fibre structure and clogging [35].

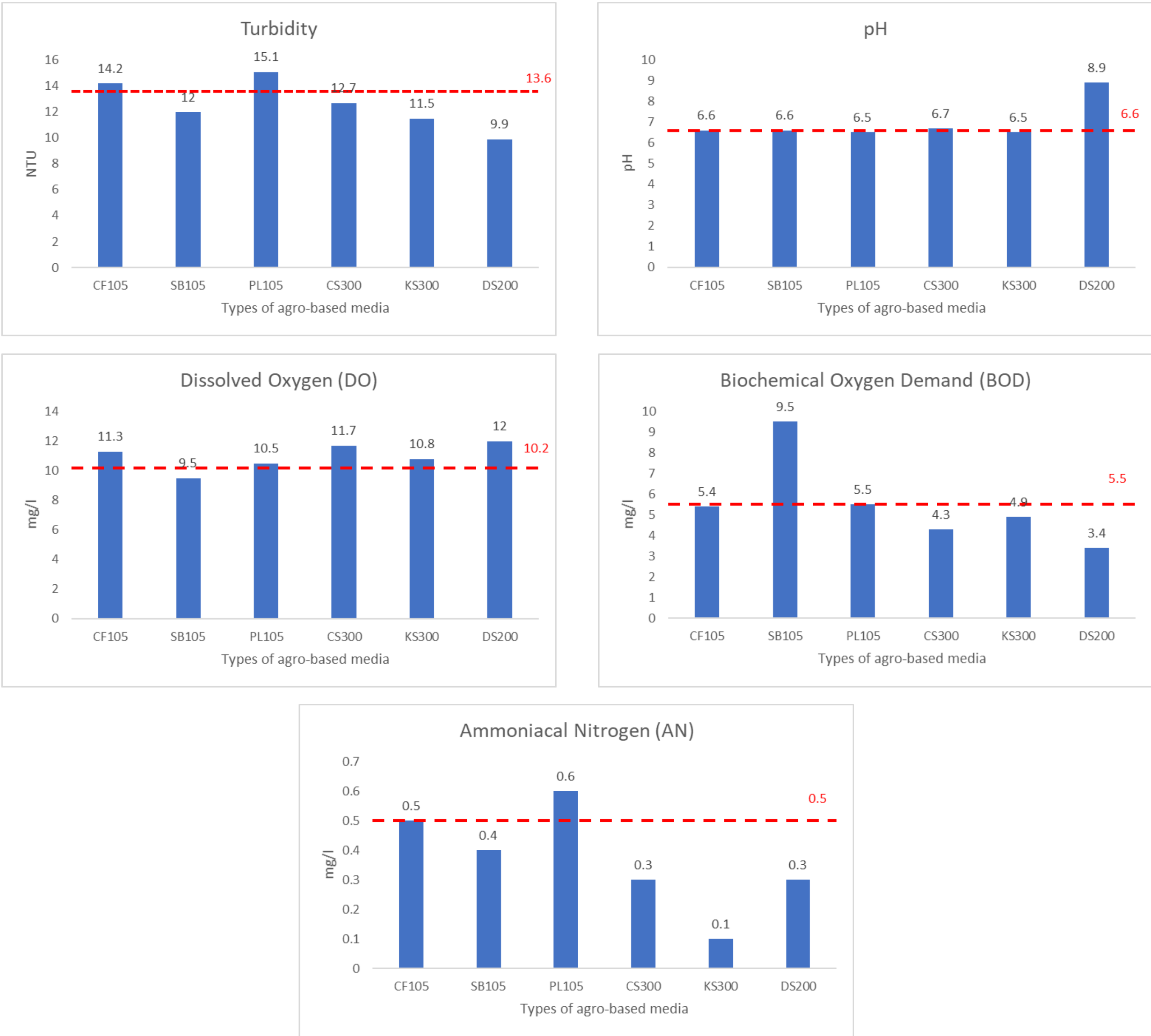

Fig. 7 - Experimental results based on the selected parameters

7. Conclusion

The experimental work using the agro-based filter media has been successfully conducted for improving stormwater quality with some recommendations for future study. In general, all agro-based media show considerable pollutant removal capabilities. It has been demonstrated that DS200 media most notably improves turbidity (27.2%), DO (17.6%), and BOD (38.2%) better than the other media. It also shows the capability to benefit in an acidic environment by increasing the pH. However, both KS300 and CS300 also have considerable potential, particularly for AN removal at 80% and 40%, respectively. Whereas CF105, SB105, and PL105 are optional for application depending on the treatment objectives. The utilization of agro-based materials as filter media in managing stormwater proves to benefits in many ways. They can be obtained easily at a lower cost and sustainable alternatives in stormwater treatment applications. Different materials used may produce varied filtration run and pollutants removal capabilities due to internal and external factors, including the media configuration and pollutants concentration. Hence, future study is recommended to investigate further the use of shell-based media such as coconut shell, kernel shell, and durian shell, and optimize the media configuration for solid-liquid separation in a controlled environment.

Acknowledgement

The authors would like to acknowledge the financial support from the Ministry of Higher Education (FRGS/1/2020/TK0/UMS/02/3) and Universiti Malaysia Sabah (GUG0441-1/2020). We also wholeheartedly thank the reviewer's input and helpful suggestions for the paper improvement.

References

[1] Phillips, R., Jeswani, H. K., Azapagic, A., & Apul, D. (2018). Are stormwater pollution impacts significant in life cycle assessment? A new methodology for quantifying embedded urban stormwater impacts. Science of The Total Environment, 636, 115–123. https://doi.org/10.1016/j.scitotenv.2018.04.200

[2] Liu, A., Ma, Y., Gunawardena, J. M. A., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2018). Heavy metals transport pathways: The importance of atmospheric pollution contributing to stormwater pollution. Ecotoxicology and Environmental Safety, 164, 696–703. https://doi.org/10.1016/j.ecoenv.2018.08.072

[3] Ma, Y., Deilami, K., Egodawatta, P., Liu, A., McGree, J., & Goonetilleke, A. (2019). Creating a hierarchy of hazard control for urban stormwater management. Environmental Pollution, 255, 113217. https://doi.org/10.1016/j.envpol.2019.113217

[4] Rahmi, Lelifajri, Julinawati, & Shabrina. (2017). Preparation of chitosan composite film reinforced with cellulose isolated from oil palm empty fruit bunch and application in cadmium ions removal from aqueous solutions. Carbohydrate Polymers, 170, 226–233. https://doi.org/10.1016/j.carbpol.2017.04.084

[5] Septevani, A. A., Rifathin, A., Sari, A. A., Sampora, Y., Ariani, G. N., Sudiyarmanto, & Sondari, D. (2020). Oil palm empty fruit bunch-based nanocellulose as a super-adsorbent for water remediation. Carbohydrate Polymers, 229, 115433. https://doi.org/10.1016/j.carbpol.2019.115433

[6] Kerkez, B., Gruden, C., Lewis, M., Montestruque, L., Quigley, M., Wong, B., Bedig, A., Kertesz, R., Braun, T., Cadwalader, O., Poresky, A., & Pak, C. (2016). Smarter stormwater systems. Environmental Science & Technology, 50(14), 7267–7273. https://doi.org/10.1021/acs.est.5b05870

[7] Liu, F., Vianello, A., & Vollertsen, J. (2019). Retention of microplastics in sediments of urban and highway stormwater retention ponds. Environmental Pollution, 255, 113335. https://doi.org/10.1016/j.envpol.2019.113335

[8] Kandra, H. S., Deletic, A., & McCarthy, D. (2014). Assessment of impact of filter design variables on clogging in stormwater filters. Water Resources Management, 28(7), 1873–1885. https://doi.org/10.1007/s11269-014-0573-7

[9] Segismundo, E. Q., Kim, L. H., Jeong, S. M., & Lee, B. S. (2017). A laboratory study on the filtration and clogging of the sand-bottom ash mixture for stormwater infiltration filter media. Water, 9(32), 1–18. https://doi.org/10.3390/w9010032

[10] Bolong, N., Saad, I., Makinda, J., Yaser, A. Z., Abdullah, M. H., & Ismail, A. F. (2016). Influence of oil palm empty fruit bunch (OPEFB) agro-waste properties as filtration medium to improve urban stormwater. Jurnal Teknologi, 78(8), 39–46. https://doi.org/10.11113/jt.v78.5357

[11] Madurwar, M. V., Ralegaonkar, R. V., & Mandavgane, S. A. (2013). Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials, 38, 872–878. https://doi.org/10.1016/j.conbuildmat.2012.09.011

[12] Budari, N. M., Ali, M. F., Kassim, J., & Omar, S. M. (2013). Burnt oil palm shell filter media for bacterial removing by single-and dual-media filtration. Business Engineering and Industrial Applications Colloquium, 465–470. https://doi.org/10.1109/BEIAC.2013.6560171

[13] Habib Abdullah, S. M., Niharul Haque, M., & Alamgir, M. (2015). Performance study of filler materials used in anaerobic baffled reactor. Global Journal of Human-Social Science, 15(2), 24–30.

[14] Dan Gavriletea, M. (2017). Environmental impacts of sand exploitation. Analysis of sand market. Sustainability, 9(7), 1–26. https://doi.org/10.3390/su9071118

[15] Grace, M. A., Clifford, E., & Healy, M. G. (2016). The potential for the use of waste products from a variety of sectors in water treatment processes. Journal of Cleaner Production, 137, 788–802. https://doi.org/10.1016/j.jclepro.2016.07.113

[16] Yahya, M. A., Mansor, M. H., Zolkarnaini, W. A. A. W., Rusli, N. S., Aminuddin, A., Mohamad, K., Sabhan, F. A. M., Atik, A. A. A., & Ozair, L. N. (2018). A brief review on activated carbon derived from agriculture by-product. AIP Conference Proceedings, 1972, 1, 1–8. https://doi.org/10.1063/1.5041244

[17] Ioannidou, O., & Zabaniotou, A. (2007). Agricultural residues as precursors for activated carbon production-A review. Renewable and Sustainable Energy Reviews, 11(9), 1966–2005. https://doi.org/10.1016/ j.rser.2006.03.013

[18] Yusufu, M. I., Ariahu, C. C., & Igbabul, B. D. (2012). Production and characterization of activated carbon from selected local raw materials. African Journal of Pure and Applied Chemistry, 6(9), 123–131. https://doi.org/10.5897/ajpac12.022

[19] Chandra, T. C., Mirna, M. M., Sudaryanto, Y., & Ismadji, S. (2007). Adsorption of basic dye onto activated carbon prepared from durian shell: Studies of adsorption equilibrium and kinetics. Chemical Engineering Journal, 127(1–3), 121–129. https://doi.org/10.1016/j.cej.2006.09.011

[20] Ratnoji, S. S., & Singh, N. (2014). A study of coconut shell - activated carbon for filtration and its comparison with sand filtration. International Journal of Renewable Energy and Environmental Engineering, 2(3), 201–204.
[21] Ghazy, M. R., Basiouny, M. A., & Badawy, M. H. (2016). Performance of agricultural wastes as a biofilter media for low-cost wastewater treatment technology. Advances in Research, 7(6), 1–13. https://doi.org/10.9734/air/2016/27926
[22] Guan, B. T. H., Latif, P. A., & Yap, T. Y. H. (2013). Physical preparation of activated carbon from sugarcane bagasse and corn husk and its physical and chemical characteristics. International Journal of Engineering Research and Science & Technology, 2(3), 1–14.
[23] A. Nasrizal, A. A., & Bolong, N. (2020). An appraisal of agro-industrial wastes and their utilization as a media filter for water treatment application. International Symposium on Carbon and Functional Materials for Energy and Environment, 49.
[24] El-Nadi, M. H., Elazizy, I. M., & Abdalla, M. A. F. (2014). Use of agricultural wastes as bio filter media in aerobic sewage treatment. Australian Journal of Basic and Applied Sciences, 8(16), 181–185.
[25] Karri, R. R., & Sahu, J. N. (2018). Process optimization and adsorption modeling using activated carbon derived from palm oil kernel shell for Zn (II) disposal from the aqueous environment using differential evolution embedded neural network. Journal of Molecular Liquids, 265, 592–602. https://doi.org/10.1016/ j.molliq.2018.06.040
[26] Kandra, H. S., McCarthy, D., Fletcher, T. D., & Deletic, A. (2014). Assessment of clogging phenomena in granular filter media used for stormwater treatment. Journal of Hydrology, 512, 518–527. https://doi.org/10.1016/ j.jhydrol.2014.03.009
[27] DOEM. (2017). Environmental quality report 2017. https://www.doe.gov.my/portalv1/en/info-laporan/laporan-jabatan-alam-sekitar/laporan-kualiti-alam-keliling/324265
[28] Barron, N. J., Deletic, A., Jung, J., Fowdar, H., Chen, Y., & Hatt, B. E. (2019). Dual-mode stormwater-greywater biofilters: The impact of alternating water sources on treatment performance. Water Research, 159, 521–537. https://doi.org/10.1016/j.watres.2019.04.020
[29] Susilowati, S., Sutrisno, J., Masykuri, M., & Maridi, M. (2018). Dynamics and factors that affects DO-BOD concentrations of Madiun River. AIP Conference Proceedings, 1–6. https://doi.org/10.1063/1.5082457
[30] Bilotta, G. S., & Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. Water Research, 42(12), 2849–2861. https://doi.org/10.1016/j.watres.2008.03.018
[31] Purwono, Rezagama, A., Hibbaan, M., & Arief Budihardjo, M. (2017). Ammonia-Nitrogen (NH3¯N) and Ammonium-Nitrogen (NH4+¯N) equilibrium on the process of removing Nitrogen by using tubular plastic media. Journal of Materials and Environmental Sciences, 8(S), 4915–4922.
[32] Danyuo, Y., Arthur, E. K., Azeko, S. T., Obayemi, J. D., & Asuo, I. M. (2014). Design of locally produced activated carbon filter from agricultural waste for water purification. International Journal of Engineering Research & Technology, 3(6), 531–540.
[33] Prakongkep, N., Gilkes, R. J., & Wanpen, W. A. (2014). Agronomic benefits of durian shell biochar. Journal of Metals, Materials and Minerals, 24(1), 7–11. https://doi.org/10.14456/jmmm.2014.2
[34] Zouboulis, A., Traskas, G., & Samaras, P. (2007). Comparison of single and dual media filtration in a full-scale drinking water treatment plant. Desalination, 213(1–3), 334–342. https://doi.org/10.1016/j.desal.2006.02.102
[35] Alam, M. Z., Anwar, A. H. M. F., & Heitz, A. (2018). Stormwater solids removal characteristics of a catch basin insert using geotextile. Science of the Total Environment, 618, 1054–1063. https://doi.org/10.1016/ j.scitotenv.2017.09.091