

A REVIEW ON THE APPLICATION OF GRANULAR FILTER MEDIA AND THE UTILIZATION OF AGRO-INDUSTRIAL WASTES FOR STORMWATER QUALITY IMPROVEMENT

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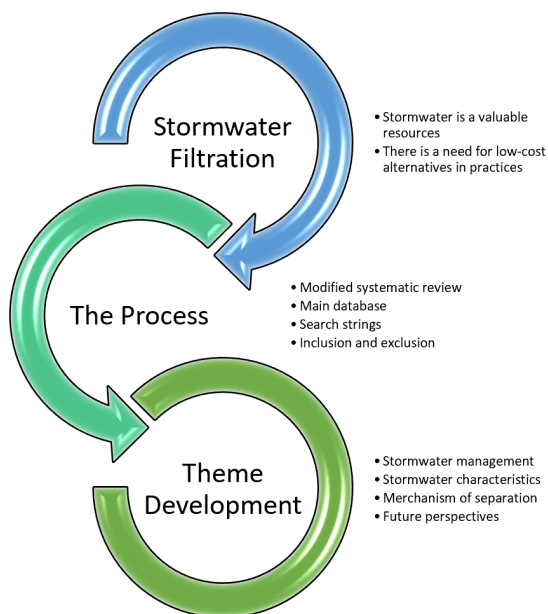
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Abstract

The stormwater management practices have changed from conveyance-oriented to storage-oriented, as part of the Best Management Practices (BMPs). Still, uncontrolled development increases potential pollutants in the stormwater, which conveys into a water body or river. Continuous improvements in the filtration mechanism would complement stormwater management. For the past decades, there is progress in applying granular filter media for stormwater quality improvement. However, the reports were not systematically reviewed. In this paper, the recent five years research that utilizes granular filter media for improving stormwater quality was retrieved and reviewed. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was referred to, where Scopus and Web of Sciences, two primary journal databases, were used. Initially, keywords searching strings have resulted in 467 articles, which were further screened. Four themes have been formed: stormwater management, stormwater characteristics, separation mechanisms, and future perspectives. Next, two sub-themes and two sub-sub-themes were further established. Then, 65 articles were included manually to complement the themes developed to explore the potential agro-industrial wastes as sustainable filter media. Therefore, this review has proven that the relatively inexpensive and renewable resources from the agro-industrial wastes can remove pollutants efficiently from the stormwater. Four main criteria affecting filter media performances are also highlighted, including the grain sizes of the media, media bed configuration, hydraulic loading rate, and the suspended solids concentration. Further study on these variables can be beneficial to explore the impact of utilizing agro-based media in stormwater filtration.

Keywords: Agro-industrial wastes, filtration, granular filter media, stormwater quality improvement, stormwater runoff

Abstrak

Pengurusan larian air hujan telah berubah dari berorientasikan laluan sahaja kepada konsep penyimpanan, sebagai sebahagian dari *Best Management Practices* (BMPs). Namun, pembangunan tidak terkawal meningkatkan potensi pencemarannya, yang kemudiannya mengalir ke dalam kolam atau sungai. Penambahbaikan berterusan pada mekanisma penapisan dijangka membantu pengurusan larian air hujan.

Sejak beberapa dekad, telah ada kemajuan pada aplikasi media penapis berbutir untuk peningkatan kualiti air ini. Walaubagaimanapun, pelaporan hasil kerja tersebut tidak dikompilasikan secara sistematik. Dalam artikel ini, hasil penyelidikan untuk lima tahun terkini berkaitan penggunaan media penapis berbutir dalam meningkatkan kualiti larian air hujan telah dikumpul dan diulas. Penggunaan *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) telah diadaptasi, dan dua pangkalan data jurnal utama, iaitu Scopus dan Web of Sciences, dirujuk. Pada awalnya, hasil carian menemukan 467 artikel, yang kemudiannya disaring. Empat tema utama telah dibentuk: pengurusan larian air hujan, sifat larian air hujan, mekanisma penapisan, serta perspektif aplikasi untuk masa hadapan. Seterusnya, dua sub-tema dan dua lagi sub kepada sub-tema turut dibentuk. Sebanyak 65 artikel dimasukkan secara manual bagi menyokong tema yang dibentuk untuk mengembangkan isi perbincangan mengenai potensi sisa industri pertanian sebagai media penapis lestari. Hasil rumusan menunjukkan sumber sisa yang murah dan boleh diperbaharui ini boleh menapis kotoran dari larian air hujan secara efisien. Empat kriteria utama yang mempengaruhi prestasi media penapis ini juga dibincangkan, termasuk saiz media berbutir, konfigurasi media, kadar pemuatan hidraulik, dan kepekatan pepejal terampai. Kajian lanjut pada pemboleh ubah ini bermanfaat untuk melihat kesan penggunaan sisa dari industri pertanian dalam penapisan larian air hujan.

Kata kunci: sisa industri pertanian, penapisan, media penapis berbutir, peningkatan kualiti larian air hujan, larian air hujan

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1.0 INTRODUCTION

Initially, the management of stormwater was about controlling the surface runoff to mitigate floods by draining high peak flows. Unfortunately, this only dislocates high water loads, leading to flash floods in urban areas. The modern approaches have since adopted storage-oriented mitigation, emphasizing control on sediment erosion, stormwater quantity, and stormwater quality. It involves the Best Management Practices (BMPs) by storing the runoff through retention basins, recharge groundwater through infiltration basins, and reuse the collected water for landscape irrigation. Since there is a competition between irrigation and domestic usage [1], allocating and designing water resources becomes challenging. With the potential of reuse in the future, improving stormwater quality would provide a green alternative for water resources.

There are continuous issues with managing stormwater quality where rapid urbanization generates more surface runoff due to increases in impervious areas. Stormwater quality deteriorates because surface runoff usually conveys into the drainage without treatment, accumulating potential hazardous pollutants, including dust, nutrients, and metals, causing silts and clogs before eventually carrying them and affecting the water bodies. The impact worsens during heavy precipitation [2], which delays the groundwater recharge and accumulates the suspended solids. The increase in suspended solids would raise the temperature while reducing the oxygen concentration in the water bodies. Thus, affect the ecology system.

The need to redesign the stormwater management systems may arise to achieve the desired stormwater quality [3]. It will be costly [4] due to constraints, such as the availability of the areas to extend or build new ponds. Instead, the utilization of granular filter media at the point source of the pollution allows for more control on the stormwater quality and reduce dependencies on the other subsequent treatment systems. The migration of water supply from upstream to downstream [5] would also benefit from these applications since the treatment of the less polluted stormwater can be used for irrigation, road washing [6], gardening, and any other non-potable purposes. Hence, a sustainable filtration approach is desired.

Typically sand media is used in the filtration [7] for solid-liquid separation. Although the surface area of the media and its adsorption can be improved using additives [8], the sand is still depleting [9], and the efficiency limitations of a single sand media remain. Besides, the use of anthracite and coal to complement the sand media is costly and not sustainable [10]. As an alternative, sand media can be used in conjunction with other techniques [11], such as dual- and mixed-media configuration, which could improve the filter performance further.

For the past decades, various researchers have been working on improvising granular media configuration through filtration approaches. However, these reports were not systematically reviewed. In this paper, the research within the last five years was reviewed systematically to determine recent works that utilize granular filter media for stormwater quality improvements.

2.0 MATERIALS AND METHODS

The use of systematic review enables the evaluation of screened accessible data to produce quality documentation and significant analysis. There are three sub-sections for methodology: database resources, systematic searching strategy, and analysis of abstracted data, referring to the main research question: What are the current research that utilizes granular media for stormwater filtration? The primary focus of the study is on stormwater quality improvement that utilizes granular materials as filter media.

2.1 Database Resources

The present study refers to two primary databases with varying environment fields covered, namely Scopus and Web of Sciences. Specifically, Scopus indexes 2,501 journals associated with environmental science, whereas Web of Sciences covers 510 journals related to the scope of environmental studies and water resources. It is possible that the number does not include other relevant publications since the scope for water purification is broad, encompassing many types of filter media, techniques, target contaminants, and applications. Thus, it is worth noting that none of the available databases at present is perfect. Therefore, additional searching efforts using several recognized sources, including Science Direct, Taylor & Francis, Springer, and Sage, were included. For the record, Science Direct and Taylor & Francis have 266 journals and 304 journals, respectively. In contrast, Springer and Sage have 67 journals and 50 journals, each, and they include environmental engineering, environmental studies, environmental sciences, and environment and sustainability.

2.2 Systematic Searching Strategy

This paper adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a published standard that provides guidelines for the authors to evaluate and examine the literature systematically. The flow in PRISMA can be breakdown into three stages. They are search strings identification, screening with inclusion or exclusion criteria, and selection eligibility. These processes are further elaborated in the following sub-sections.

2.2.1 Search Strings Identification

The first stage is identifying the search strings related to the topic and research question. Table 1 shows the search strings developed on the primary databases using relevant keywords that have been determined. A total of 189 articles managed to be retrieved using these search strings. As previously stated, searching in other databases, Science Direct, Springer, Taylor & Francis, and Sage using similar keywords have resulted in an additional 278 articles. These searching

efforts include keywords such as stormwater, runoff, drainage, media, filter, filtration, quality, and granular. Hence, 467 articles were able to be retrieved.

Table 1 The search strings

| Database | Search Strings |
|-----------------|---|
| Web of Sciences | TS=((stormwater OR runoff OR drain*) AND (media OR medium) AND (filt* OR adsor*) AND (quality OR improv* OR treat* OR purif* OR remov*) AND (grain* OR granular)) |
| Scopus | TITLE-ABS-KEY((stormwater OR runoff OR drain*) AND (media OR medium) AND (filt* OR adsor*) AND (quality OR improv* OR treat* OR purif* OR remov*) AND (grain* OR granular)) |

2.2.2 Screening with Inclusion and Exclusion Criteria

The removal of duplicate articles is done in the screening process. Here, 10 duplicate articles were omitted. Whereas another 375 articles were removed accordingly to the selected criteria. The first criterion is the type of publication, in which authors only focus on the research articles from journals as the primary sources. Thus, removing the articles published as a review paper, conference proceeding, and chapter in a book. Also, for the second and third criteria, only the articles that use the English language and published within the last five-year period, from 2015 to 2019, are considered. Table 2 summarizes both the inclusion and exclusion criteria used in this work.

Table 2 The inclusion and exclusion criteria

| Criteria | Inclusion | Exclusion |
|------------------|--------------------|---|
| Publication Type | Articles (Journal) | Review article, conference proceeding, chapter in a book. |
| Period | The year 2015-2019 | <2015; 2020 |
| Language | English | Non-English |

2.2.3 Selection Eligibility

The third stage is selection eligibility. In this stage, the documents title, abstracts, and the main contents are scrutinized to ensure the criteria are fulfilled and sufficient to achieve the aim of this review work. Hence, 46 articles were further excluded because they mainly did not focus on stormwater filtration. Some are also excluded due to non-article documents and review papers. It should be noted here that, based on the authors' experience, Scopus enables the users to export the list of articles in CSV format directly, which allows for duplicate elimination easily done. Whereas Springer, at the moment, cannot separate the review paper from the other research articles. As for the other databases show

almost similar performance. Finally, a total of 36 articles remain to be analyzed. Figure 1 shows the overall processes involved in the systematic searching strategy opted for this study.

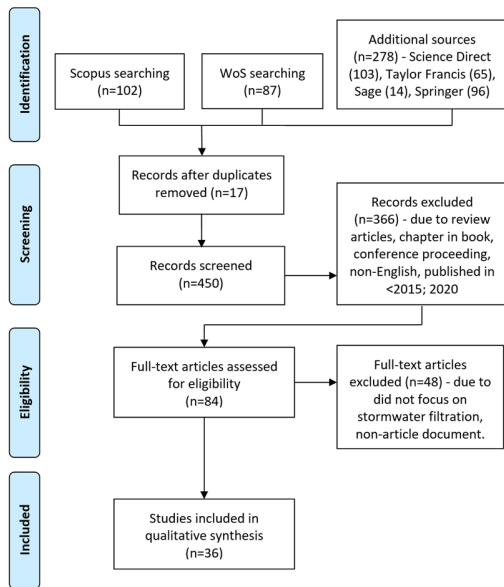


Figure 1 Flow diagram of the systematic searching strategy

2.3 Data Abstraction and Analysis

The process of developing themes and their sub-themes is done by compiling and scrutinizing information where authors analyzed all the 36 screened articles earlier to abstract data or statements that fulfil the research question's needs. Then, the directive groups were created according to the connections of the raw data. As a result, four themes, namely, stormwater management, stormwater characteristics, mechanism of separation, and future perspectives, have been developed. These themes are further extended to two sub-themes and two sub-sub-themes, as explained in the following sections. Lastly, 65 articles were manually added to complement the themes developed that addressed the potential of agro-industrial wastes as sustainable filter media, following the authors' subsequent research interests.

3.0 RESULTS AND DISCUSSION

3.1 Stormwater Management

Stormwater refers to the precipitation received on land that becomes surface runoff and conveys into the drainage before it goes into a water body or river. Increases in runoff hinder the groundwater recharge, thus causes a flood. Stormwater management in Malaysia previously focussed on managing these surface runoffs during a heavy downpour for flood

mitigation by draining the high peak of the flood flows. However, poor urban planning may cause flash floods [12], picking up the potential pollutants along its pathway, comprising litter, nutrients, heavy metals from automobiles exhaustions, oil and grease from the commercial sector, sediments from construction activities, and bacteria from animal droppings.

As a result of uncontrolled development, the retention of pollutants in the urban area has deteriorated as nutrient transport via stormwater runoff from street to river increases [13]. Their concentration during early rain was the highest, indicating the first flush effect, with a potential of the second flush effect due to the leached nutrients from flooding [14]. The stormwater runoff also acts as a pathway of microplastics (MP) [15], the waste of plastic particles of less than 5mm in size, which has become an emerging interest for urban areas in recent years [16]. Harmful chemicals absorbed by the MP that is already toxic could have adverse health effects on humans, as they made their way into marine and freshwater species. Nevertheless, the management of stormwater becomes more complicated when it involves nonpoint source pollution [17]. Stormwater is also associated with aesthetics, aquatic life, impaired recreational use, and public health and safety issues.

The modern approaches towards stormwater management have changed from conveyance-oriented into storage-oriented by rebuilding the natural water cycle [18]. The practices in mitigating stormwater runoff are known as low-impact development (LID), where it involves the interconnection of multiple stormwater management practices (SMPs) that distribute and retain the stormwater flow on-site, compared to the traditional practices of conveyance-oriented [19]. These include storing the surface runoff through retention basins, utilizing infiltration facilities for recharge zone, stormwater recycling for irrigation purposes, and applying sustainable drainage systems (SuDS).

The SuDS treat stormwater before it infiltrates or discharged, and is typically categorized into the permeable pavement (PP), filter channel system (FCS), and the filter shaft system (FSS) [20]. PP is similar to traditional concrete block pavement that allows infiltration through the pores and fillers of the pavers. FCS, drainage with filter media that can be integrated with a sedimentation trap, has a specific retention volume in which the stormwater infiltrates and drained at the bottom of the channel. Similarly, FSS integrates sedimentation and filter unit with the optional operation of downflow, upflow, or radial mode. It can be permanently submerged and vice versa.

Another type of SuDS is swales. Standard conveyance swale is a broad and shallow vegetated channel. It is effective in conveying runoff and improve soil infiltration. Dry swales consist of a soil bed that overlays the underdrain system for additional capacity. Whereas wet swales maintain

combines shallow gradients and underlying impermeable soil or a liner that prevent infiltration. It has less impact on groundwater than the previous two [21].

The variedly quality of stormwater depends on how impervious the land areas are and whether it consists of point sources or nonpoint sources of pollution. Still, this stormwater is a valuable resource because it is less polluted than wastewater, and stormwater harvesting for any less demanding usage would benefit local authorities in a long term plan. It is also worth noting that expanding the existing water resources infrastructure is challenging, particularly to supply urban areas, where there is an increase in water demand with the growing population. The conventional method of using chemical and osmosis is costly and energy-consuming, whereas recent applications only partially and insufficiently remove contaminants [22]. For instance, the denitrification process for converting nitrate to nitrogen gas requires considerable storage, anaerobic conditions, and adequate residence time [23]. The extended residence time improves the flow attenuation and quality treatment, but it requires a larger storage area [24]. Insufficient storage area and low infiltration capacity of soil generate outflow, which led to more runoff passing at high velocity on the topsoil, causing erosion and low water retention [25]. When surface stormwater combines with the groundwater, the subsurface drainage outflow infiltrate to retention basins. Thus, have biofouling potential with moderate clogging, which requires treatment [26]. The higher pavement slopes generate more drainage capacity, irrespective of rainfall intensity and stratigraphy [27]. Hence, alternatives for improving stormwater quality should be further explored and developed.

3.2 Stormwater Characteristics

The composition of stormwater runoff, quality, and quantity is highly variable in space and time as it has intermittent nature [28]. This stormwater quality fluctuates and is influenced by the interrelation of several factors, primarily by heavy precipitation [2], runoff that is generated irregularly [17], rainfall duration, antecedent dry days, landuse [29], the surface type and imperviousness, atmospheric and climate conditions, total population, waste disposal practices, the construction activities and rapid urbanization. For instance, the stormwater quality from relatively clear surfaces, such as a rooftop, is generally better than the one that flows over heavy traffic roads. The stormwater runoff is more polluted during the first flush [29]. Contamination from the upstream drainage directly affects receiving water bodies [30], and there is a higher potential for pollutant accumulation during long dry periods [31]. This eventually implies the threats to the quality of both surface water and shallow groundwater [32].

Typically, the quality, as mentioned earlier, can be defined through physical, chemical, and biological parameters. Among all parameters, the

properties of biochemical oxygen demand (BOD), ammoniacal nitrogen (AN), and total suspended solids (TSS) mainly affect the quality of surface water [33]. This BOD determines the concentration of dissolved oxygen (DO) used by the aerobic microorganisms to decompose waste in the water at a specified temperature. The presence of sufficient DO is vital to maintain the quality of the water. An increase in temperatures during the hot season and excessive nutrients carried by stormwater can reduce DO concentration in the water body [34], thus causing stress to the aquatic life.

Then, the concentration of nitrogen that presents as both ammonia (NH_3) and ammonium (NH_4^+) is known as ammoniacal nitrogen (AN). Although it is essential as plant fertilizers, AN could enter waterways through the point source discharges such as animal farming activities or domestic sewage, which is also harmful to aquatic life. The relative concentration of the soluble ammonia depends on both pH and temperature, whereby the formation of toxic ammonia is favoured at a higher pH and temperatures [35].

The total suspended solids (TSS) refer to the solid particles that remain in suspension within the water and are considered a significant cause of water quality deterioration. TSS inputs were highest when large rainfall events coincide with dryer antecedent conditions [24], whereas in other findings, the TSS influent from small rainfall events is statistically higher than large storms [29]. High TSS leads to aesthetic issues and would affect both ecological and aquatic environments. Thus, higher costs of treating the water. The increase in TSS may reduce the penetration of sunlight and increase the water temperature. Furthermore, the TSS with high organic content can deplete DO concentrations, increasing the BOD value.

Compared to the wastewater, though, the physical clogging is generally much more pertinent in stormwater due to its lower organic content. For instance, the high intensity of rainfall and aerodynamic drag of large vehicles convey large particles known as road-deposited sediment (RDS) from agriculture or roads with poor service conditions to the edge of the road. Then the road runoff flushes and overloads the filter drain in an exaggerated horizontal flow regime. As maximum capacity is reached, the cake layer is formed on the filter surface. In the long term, it impedes the management of surface water runoff from the road and causes ponding hence clog [36]. Another study [37] focuses on partitioning the heavy metal from the urban stormwater runoff that enters and leaves the LID systems. Although metals such as Cu and Zn are present in the dissolved form, they are primarily particulate-bound [38]. The removal of heavy metals depends on media types, and the grain size selection must be based on the dominant pollutant [39]. There is a strong heavy metals affinity with the suspended solids, whereby heavy metal concentration increases proportionally with the TSS concentration [37]. Higher

metal contents were found in the media top layer in the field, where most solids were retained [20]. Since most stormwater pollutants are attached to TSS [40], particularly heavy metals and nutrients [41], TSS would be an essential parameter for pollutant removal when designing for the stormwater filter and its media configuration.

3.3 Mechanism of Separation

Typically, water purification can be categorized into primary and secondary treatment. Primary treatment usually involves physicochemical processes. It starts with physical separation through the screening mechanism. Then, the addition of chemicals is made during coagulation before continued with the flocculation and sedimentation stage. Sedimentation before filtration minimizes clogging concerns [29]. Then, the disinfection process is applied to reduce microorganisms. Dealing with wastewater will require secondary or biological treatment. It is to remove the impurities from the water that remains after primary treatment through filtration. When necessary, preliminary and tertiary treatment can be integrated into the system. Preliminary treatment usually involves aeration process, oil, and grease removal. As for tertiary treatment is used when there are specific parameters such as ammonia that need to be safely lowered.

Stormwater does not require complicated treatment as wastewater, and certainly not for potable uses. A moderate filtration technique can separate the suspended solids (SS) using distinctive physical properties such as the density and size of the solids. The use of filter media is required for the solid-liquid separation process, where both mean particle size and solids distribution significantly influence the filter media selection [42].

The principal particle removing mechanisms are straining, attachment and detachment [43]. Now, consider an accumulation of solid grains, fibres, or powder is used as filter media. The porous void between them is then occupied by the water flow containing SS. Once the water flows through the voids, SS that is brought close enough to the solid interface will be attracted to the media until contact is made and remain still due to convection and diffusion, and then adsorbed, albeit with [44] or without electric charges on media or particle [45].

Generally, the concentration intensity of the competing adsorbates will be less than the target adsorbate, when the competing adsorbates exceed the target adsorbate, and vice versa. Thus, poorly adsorbing substances would have competitor-concentration intensity less than the target adsorbate. However, these poor adsorbates tend to have high concentration intensity, so even if its competitor-concentration intensity is less, it could still be large [46]. The higher pollutant removal efficiency produces a lower Pollution Index (PI), which improves the effluent quality, but continuous adsorption of pollutants may saturate, thus decreasing the filtration

efficiency, altering the flow, and leads to surface clogging over time [21].

3.3.1 Granular Media Filtration

Granular media filtration (GMF) applied a simple process of water passing through the beds of granular media. The SS gets rejected from the water and trapped on top and within the granular media layer, producing cleaner effluent. Generally, there are three types of GMF technologies, the traditional slow sand filter (SSF), the alternate rapid sand filter (RSF), and the advanced use of granular activated carbon (GAC).

Fine sand media and supporting gravel layers are commonly used in SSF. Particles with larger sizes are separated at the top of the sand layer and removed for maintenance periodically. Whereas, RSF utilizes coarser sand media with support from gravel layers. Particles with diverse sizes are separated throughout the deep bed filter. Backwash, the process of flowing water or air from the opposite direction, is typically used for maintenance. The GAC works via an adsorption mechanism, whereby different carbon sources produce diverse pore structures consisting of micropores, mesopores, and macropores, which can filter ranging pollutant sizes.

In the early development of activated carbon (AC), it was costly and limited only for small scale usage. However, advancements in technology have elevated its potential application. AC can be derived from biomass or other carbonaceous substances such as coal and tar. Carbonization converts the selected precursors to AC at high temperatures from 300°C to 1,300°C (for lower performance) and up to 3,000°C (for high-performance) to eliminate non-carbon elements as volatile gases [47]. It is then activated to increase the material's surface area, allowing the media to adsorb contaminants at a higher capacity. It has fine and low volume pores and can be powder, granular and fibre. These AC can be physically or chemically activated or both. Compared to the physical activation, the chemical activation may offer effectiveness in the porosity improvement, which increases the adsorption capability. However, using a chemical is only tolerable at the laboratory scale and may generate environmental problems when used at the industrial scale [48] and involves high cost. Other than activation, it can be chemically impregnated to improve the performance in capturing specific chemical substances [49, 50].

Powdered AC is usually applied in physicochemical treatment processes, which are then removed and treated together with the produced sludge. In contrast, granular or pelleted AC is used in an open or closed filtering method. Closed filters are designed so that the effluent is pumped through the filter columns under pressure. They are mostly used in industrial applications. When the columns become saturated, they can be thermally regenerated and reused. On the contrary,

open filters are commonly used to produce potable water where the water flows through the active carbon filter beds under gravity.

The efficiency and effectiveness of filters depend on various factors and their interaction with the variables. For instance, the climate significantly affects filter effectiveness, and low filtration media is inefficient for heavy rainfall areas unless the filter to drainage area ratio increases [51]. During high rainfall intensity, the high hydraulic conductivity reduces potential ponding and flood [52]. The extended dry periods also correlate with better pollutant removal performance [51]. However, the longer intervals of rainfall recurrence decrease the bioretention system capacity [53], predominantly of sand media and covered with a vegetated soil layer at the top [51].

Generally, a more refined material for filter media possesses considerable high adsorption capabilities. When particles are deposited on media, the resistance for the fluid increases, and media porosity decreases [43]. Dual or multilayered media may provide better adsorption than a single media layer, which performs a better filtration mechanism [54]. Although single, dual and multilayered filters are known, further studies are required to optimize the filter media based on the type of materials and the configuration used. For example, the stormwater quality can be significantly improved when passing through a natural or man-made filtration system that removes pollutants before discharge into a water body [55].

As for the hydraulic conductivity is the highest without the use of geotextile. Conversely, the integration of geotextile at the top and bottom layers had a statistically significant difference [55] and outperform the others with and without a single geotextile layer in terms of filter effectiveness [56]. Using a nonwoven geotextile layer increases pollutant removal efficiency but causes clogging potential in the long term [57]. The sediment is not static after initial flux from the cumulative rainfall-runoff events and may resuspend within and through the SuDS [58]. Due to the sporadic influx of stormwater pollutants, high hydraulic loadings, and maintenance issues, the geotextile scoured and may allow the removal of active biofilm zones, reducing system retention effectiveness.

Conventional Filter Media

Sand is the most mined resource on earth and is commonly used as filter media. The rise of sand depletion issues [9] has increased the need to explore alternative substitutes. Furthermore, the use of anthracite and coal, with the sand in multilayered filters, are costly and unsustainable [10]. Thus, it is necessary to consider alternatives with low capital and operating costs for water treatment, highlighting the existing media limitations. For example, compared to GAC, sand quickly reached equilibrium and has little impact on removing nitrate [23]. Researchers have gathered to investigate other

potential sustainable sources, such as incorporating expanded shales to partially replace sand while maintaining engineering requirements and improves the landscape [19]. Some opting to utilize the agro-industrial wastes due to inexpensive, renewable sources, readily available, environmental-friendly, and may become one of the income sources for the agriculture sector [59].

For the past decades, there has been considerable growth in the agriculture sector of Malaysia, which received benefits both in the previous 11th Malaysia Plan and the current 12th Malaysia Plan, and this subsequently would imply substantial disposal of agro-industrial wastes. The utilization of agro-based media in stormwater filtration would increase sustainability through the concept of transforming waste into wealth. Table 3 shows the statistics of cultivation for the selected agriculture sectors in Malaysia [60-67]. The approximate cultivation area is given in hectare (ha), whereas the production is in tonne (t).

Table 3 Production of the selected agriculture sectors in Malaysia

| Types | Area (hectare) | Production (tonne) |
|--|----------------|--------------------|
| Palm oil (<i>Elaeis guineensis</i> Jacq.) | 5,810,100 | 98,419,400 |
| Coconut (<i>Cocos nucifera</i> L.) | 85,000 | 5630,000 |
| Durian (<i>Durio zibethinus</i> Murr.) | 139,476 | 300,000 |
| Pineapple (<i>Ananas comosus</i>) | 16,000 | 340,721.95 |
| Sugarcane (<i>Saccharum officinarum</i>) | 1,668 | 29,990 |

Agro-Based Filter Media

Table 4 summarises the comparison between conventional filter media and agro-based filter media regarding advantages and disadvantages. The existing sand media for filtration is consistently effective and provenly used, particularly in a larger-scale application. They can also be directly applied without needing any complicated or activation-related process. However, exploring other low-cost alternative and renewable materials could address its limitations, such as removing specific pollutants. These wastes from the agriculture industries are acknowledged as promising filter media materials for various water treatment applications with highly adsorbent capabilities. However, some selected materials may be harmful and exhibit poor filtration performance, limiting their applications in the field. Therefore a study on cost-efficient materials with favourable porosity and capacity is significant for continuous stormwater quality improvement [13].

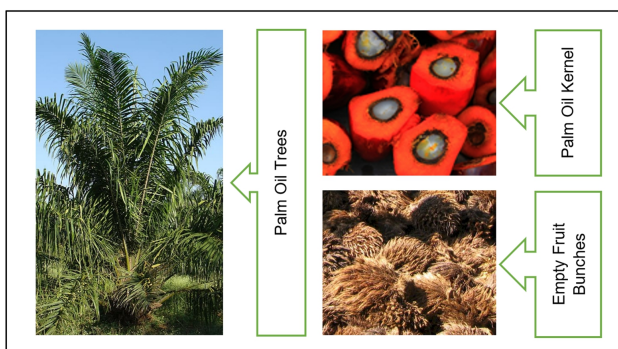
Table 4 Comparison between conventional filter media and agro-based filter media

| Types | Conventional | Agro-Based |
|---------------|--|--|
| Advantages | <ul style="list-style-type: none"> • Effective and provenly used • Have known consistency • Large scale application • Direct applied | <ul style="list-style-type: none"> • Alternative local resources • Inexpensive initial and operating cost • Availability in abundance • Highly adsorbent |
| Disadvantages | <ul style="list-style-type: none"> • Not sustainable • Costly • Limit usage • Media constraints | <ul style="list-style-type: none"> • More to explore • Limit application • Area constraints • May need activation |

This section reviews the recent utilization of agro-industrial wastes, including palm oil, coconut, durian, pineapple, and sugarcane, to explore viable and cost-effective alternative materials for stormwater filtration. There is a potential for these media to be applied in stormwater filtration. It is mainly due to their natural eco-friendly features, cheap, available in abundance, and favoured filter media properties. Also, the requirement for stormwater quality effluent is lower than for potable water. Recommendations from these reviews include utilizing local niche sources, which gives advantages to developing countries enriched with agricultural value, such as Malaysia, as it overcomes the barrier of transferring high technologies, which are costly.

Palm Oil

Palm oil is the largest agricultural activities in the Malaysian industry. Malaysia holds 28% and 33% of world production and exports for palm oil [68], respectively. The local production of fresh fruit bunches (FFB) in Malaysia is approximately a 98.4million tonnes. About 4 tonnes of dry biomass is produced from each tonne of extracted palm oil, whereby a third is disposed of as empty fruit bunch (OPEFB), kernel shell (POKS), and mesocarp fibre (MF) [69], at 23%, 5%, and 12% respectively, whereas the remaining 60% becomes palm oil mill effluent (POME). Figure 2 shows the segments from the palm oil trees.

**Figure 2** Segments from palm oil trees

The work on local palm oil wastes as filter media has been extensively researched. A study on utilizing fibrous OPEFB [70] and granular burnt oil palm shells (BOPS) as single or dual media in a deep bed column experiment for raw water [71-75] has been conducted to explain the relationship between grain effective size, hydraulic loading rate, filter running time, and head loss. For head loss determination, the modified non-spheres equation, such as Ergun and Carmen-Kozeny, shows good agreement near experimental value [76].

Materials such as POKS have high lignocellulosic contents, low ash with high carbon and volatile matters [77], thus favourable in producing AC. It was highlighted that harvesting heat is sustainable to produce AC from POKS [77] and OPEFB [78, 79]. Another study demonstrated the steam effect on the AC derived from OPEFB, which yields higher cellulose and lesser lignin content [48]. Similarly, adsorption for AC from POKS with different activation temperatures [80, 81], optimizing media thickness [82], and also modelling [83] have been investigated. The properties of AC at various activation temperature changes with the decomposition of cellulose, hemicellulose, and lignin due to heat. Higher temperature increases the fixed carbon. However, it consumes more energy, and any additional pretreatment process would have a cost implication. This needs to be considered in future studies. In other applications, activated palm oil sludge biochar and AC from POKS has experimented successfully for sulphur dioxide removal [84], and that bio-oil can be produced from EFB through pyrolysis [85].

Coconut

Malaysia is among the world's top coconut producers. Although it received competition from neighbouring countries and decreased production from 2014 to 2016, coconut is currently one of the major economic contributors, with an estimated production of 530,000 tonnes across the nation. Currently, the total acreage of coconut plantations in Malaysia is 85,000 ha, with an annual import of up to 220 million coconuts [67]. Usually, only the oil and water are consumed, whereas the remaining 70% of the coconut is disposed of as wastes, with 15% from the de-husked coconut is the remaining coconut shell [86]. Figure 3 shows the segments from the coconut trees.



Figure 3 Segments from coconut trees



Figure 4 Segments from durian trees

A pilot-scale study on AC derived from coconut shell show that deeper thickness of AC has a pronounced effect in COD and BOD reduction from raw water, but no further improvement to iron and turbidity [87]. A comparison between the use of AC from coconut shell and POKS pointed that the passing water velocity relates inversely to the thickness of the filter bed [82], as the longer contact time between feed water and the filter bed improves the pollutant removal. Though, it was found that the sorption for magnetized and non-magnetized AC can be comparable due to the greater attenuation effect by colloidal matter [88]. A comparison between raw coconut shell with stone chips, brick khoa, and sand under anaerobic conditions has also been investigated [6].

AC can be efficient through an activation with acid or heat control [89], affecting the lignin content and pore volume at a specific temperature [47]. Interestingly, a coconut shell with high SSA processed using only one-step low-temperature carbonization without activation was successfully experimented [90]. Another study demonstrated that biochar and activated biochar from coconut fibre is highly porous with micropores that aid the adsorbent [91]. Nonetheless, the size and depth of media are essential for a good filter media that needs to be considered in the configuration design and optimize the performance.

Durian

Durian is a famous seasonal tropical fruit and is attracting investors for international export. The production of durian amounted to 210,874 tonnes in the year 2017. However, only less than half of the durian is consumable. The seeds (20-25%) are either replanted or disposed of together with the peels (55-60%), which are commonly done. Thus, it causes issues such as odour and aesthetical problems, particularly in the residential areas. Figure 4 shows the segments from durian wastes. Generally, there consists of inner and thorny outer husk, its peduncle, and seeds.

A study on the composition of durian husk is varied in each segment where the green and thorny outer husk has the highest dry matter content of 30.47%, the thick bottom inner husk has the highest moisture of 81.83%, and ash of 6.95%, and a combination of all segments produces the highest crude fibre content of 14.66% [92]. Due to its diverse composition, the selection of parts from the durian segment could produce varied effectiveness in water treatment applications. There are also kinetics and equilibrium sorption studies for AC derived from durian shell [93], where there is an increase in the uptake with the increase in initial dye concentration. As the concentrations of the initial dye increased, the maximum adsorption increases. At lower pH also has higher uptakes, whereas an increase in temperature reduces the adsorption uptakes.

In other applications, the reduction of toluene vapours is achieved using impregnated durian peel with a 30% concentration of phosphoric acid, which led to pore enlargement [50]. It is shown from the statistical analysis that the contact time has more effect on the pollutant removal compared to the varied concentrations of toluene, as the toluene molecules continuously adsorbed even when a higher toluene concentration is introduced. With the increased concentration, there are possible interactions between the interlayer and intralayer of the carbon and that the toluene molecules branched to nearby molecules, thus allowing adsorption to continue.

Pineapple

Pineapple crops in Malaysia had increased between 3-5% annually. With such prospects, it is still insufficient to meet the local and foreign demand. Currently, the area used for pineapple cultivation is approximately 16,500 ha, with a production of 340,721 tonnes in the year 2019. However, only half of the pineapple fruit is edible, whereas its core and crown are discarded together with the pineapple leaves and peels (50%). Figure 5 shows the segments from the pineapple fruit. Generally, it contains the crown, leaves, and also peels.



Figure 5 Segments from pineapple plants

Like other plant fibres, the decomposition of cellulose, hemicelluloses, and lignin increases fixed carbon [80]. The biochar prepared from the pineapple peel using slow pyrolysis [94] shows that the surface area does not mainly contribute to the Cr(VI) adsorption. From the previous study mentioned that the surface area of the media, average pore size and percentage of the micropores increase as the activation temperature increased. Also, the adsorption rate increases with a decrease in dye concentration and ionic strength, and it is favourable at higher pH and lower temperatures. However, the pre-carbonized AC from pineapple leaves activated with phosphoric acid has a larger surface area than the materials prepared without them [95] at a similar temperature. Nevertheless, chemical activation may as well offer effectiveness in porosity improvement, which increases the adsorption capability. Still, it is less preferred to the authors' view (for stormwater filtration) as it would be costly in an extensive scale application.

Sugarcane

Sugarcane plantations have a limitation on the type of suitable local soil for their cultivation. The sugarcane production is concentrated in Peninsular Malaysia, with approximately 1,668 ha used for their harvesting activities. In general, these sugarcane contains leaves, stalk and bagasse after processed. The stalk is commonly utilized for crafts and juice extraction, leaving the fibrous sugarcane bagasse as the waste. Figure 6 shows the segments from the sugarcane.

Sugarcane bagasse has a fibrous structure and low ash content, ideal for creating highly porous structures [96]. In previous studies, the AC from sugarcane bagasse carbonized at 400, 600, and 800°C shows that higher temperature produces higher surface area and pore development [96], which significantly affects the carbonization time [49]. An increase in the temperature caused more volatiles to be released and enhance pore development. However, not all agro-wastes can be used for AC production as a further increase in the temperature could reduce the average pore

diameter [97]. Then, another study demonstrated that sugarcane bagasse is a better adsorbent for methylene blue than cassava residue [98]. However, both can be used as sorbents without being transformed into ashes. Thus, the ashes did not justify their production.

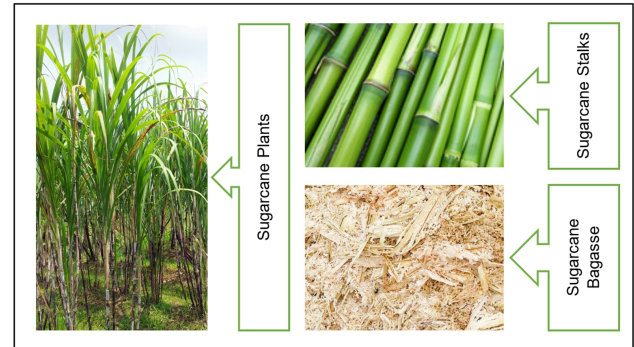


Figure 6 Segments from sugarcane plants

In other applications, the rise in temperature increases the yields of liquids and gaseous while decreasing the remaining solids, showing that the decomposition of these volatile compounds is more significant at high temperatures [99]. Therefore, the production must be optimized based on their applications of interest, either as AC or bio-oil. The utilization of sugarcane bagasse would benefit in terms of waste disposal. However, further studies are still required in characterizing the material when used as a filter media.

3.3.2 The Criterion for Optimizing Filter Media

The understanding of particle removal from water suspension varies due to the diverse water characteristics and the design setup for the filtration system. Hence, it is essential to understand the criteria affecting the performances of the filtration system, which can be categorized into media characterization and its configuration. The media's characterization is typically used to view different perspectives to understand the impact of different materials with various properties and behaviours. It is often assumed that particles and filter grains are spherical, although there are sharp and angular shapes. However, it has been demonstrated [40, 100] that the shape and smoothness of granular media have minor implications toward removing sediment that may affect the clogging.

The most important characteristic of the granular filter media is the grain sizes or the effective size of the media. This can be obtained from the sieving apparatus. The sieve shakers may also be used for ball-pan hardness as higher hardness suggests stronger resistance to mechanical abrasion [101], which will increase its commercialization value. In general, the fine-grained media filtrate better than the coarse-grained media [72]. Whereas, the

hydraulic performance of the finest media has a significant role in controlling the overall performance of a multi-media filter [102]. With sand media, the filter has a short running time with a deficiency in total capacity to retain SS. However, larger sizes resulted in a greater optimum filter bed depth, in which the SS could penetrate deeper, and the filter could retain a higher quantity of solids. This would allow for fewer backwash and reduce operating costs. Besides, ripening after backwash increases solids' removal efficiency and decreases the effluent concentration [103]. Maintenance periodically is important to maintain high permeability [56].

Similarly, the specific surface area (SSA) of the grains is essential in determining filter efficiencies. SSA is the total surface area of a material per unit of mass (m^2/g) or bulk volume (m^2/m^3). Larger media sizes are more porous and have higher permeability but consist of a lower SSA that decreases biological and physical action [104]. For filter media preparation, a higher activation temperature produces a larger surface area, carbon porosity, and total micropore volume by creating and enlarging the pores [95, 96, 99]. However, any further increases in activation temperature may lower the total AC yield [48, 94, 96, 99] and the porous diameter due to the formation of new pores, as it produces ashes, enhances the evaporation of volatile compounds, and reduce surface area [81, 97]. Other than temperature, the duration of carbonization also has a role [48] whereby the longer heating time, although at a lower temperature, significantly lower the lignin content and increases the pore volume [47].

Optimizing filter bed depth is straightforward, but it is essential because utilizing unnecessary thick filter beds would lead to the undesired rapid development of negative pressure (head loss), which increases the operational cost. Increasing the depth of media increases removal efficiencies as the media's total surface area also increases due to the longer contact time between the feed water with the filter media. In contrast, smaller media sizes comprise large SSA and a lower void ratio, which gives better removal efficiency [87, 104] as it has a higher total surface area and more contact time. Thus, media with higher SSA is more effective. However, selecting the deepest bed depth is unnecessary as shallower depth could be more cost-effective. The thickness of the filter bed is also proportionate to the water pressure, whereby an increase in filter bed depth increases the flow pressure. Also, a higher hydraulic rate may decrease its removal efficiency due to shorter contact time made between the suspended particles and the filter bed.

The removal of suspended solids is a function of particle distribution and concentration. The hydraulic conductivity decrease with an increase in sediment size as a large suspended particle can easily seal the void in media [57]. Then, a higher loading rate removes the particle mass entrapped at the top layer, leading to particle deposition in a deeper

section of the media. From Darcy's law, the superficial flow velocity through the porous media relates inversely to the thickness of the bed depth. Thus, the water flow velocity can be increased using shallower filter bed thickness. However, reducing media thickness could reduce quality performance as the high velocity may force the micropores to open and allow the smaller particles to pass through the media [82]. The increase of hydraulic loading rate reduces the straining and attachment process, which decreases the removal performance [74], as a higher flowrate means shorter contact time between flow and the media, which subsequently resulted in lower filtration performance. Simultaneously, an increase in hydraulic load resulted in the reduction of free void area as the particles accumulate in the bed cause an increase in resistance to the water flow through the filters [73]. A regular check is required to ensure the media is not saturated with contaminants reaching its capacity. Otherwise, these contaminants may not be adsorbed and move back from the media into the water [82].

The multilayered reactive barrier has longer effective heavy metals removal [22]. However, both metals and nutrients have a minor impact on hydraulic performance [100]. Pollutant removal depends largely on the size of the media grains, concentration and size of TSS from the pollutant loadings, and hydraulic loading rate, more than the other factors such as catchment type, storm events, the objectives of its treatment, groundwater level, imperviousness, and type of the receiving water bodies [100, 105, 106]. Otherwise, factors such as cost-effectiveness, adsorption and desorption rate, infiltration, lifespan, retention capacity, and also availability could be considered [107]. Optimization of the filter media design utilizing the agro-industrial waste is suggested in this review to be further explored for stormwater application, assessing the filter performance in terms of pollutants removal effectiveness and filter running time.

3.4 Future Perspectives

Despite global challenges such as climate change, a growing population density, and the scarcity of resources, the agriculture industry in Malaysia has shown progress, recording approximately RM99.5 billion or 7.3% contribution to the national Gross Domestic Product (GDP) the year 2018. Then, 8% of GDP was recorded in the third quarter of the year 2019, as shown in Figure 7. Malaysia produces millions of tonnes of the country and industry supply of various agricultural products. Oil palm remains as the major contributor with 37.9%. This is followed by other agriculture at 25.1%, livestock at 14.9%, fishing at 12.5%, forestry and logging activity at 6.9%, and rubber at 2.8% [65].

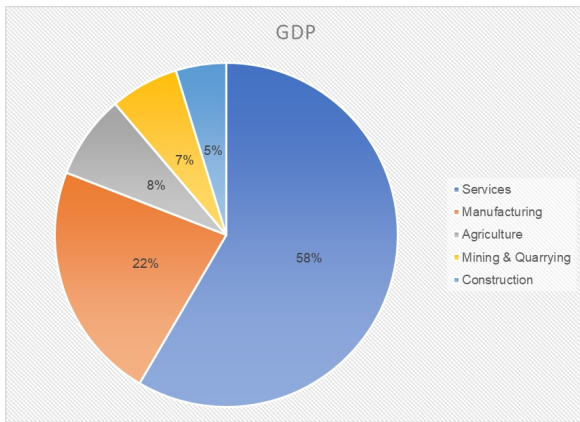


Figure 7 Malaysia GDP for the third quarter in the year 2019

The growth in agriculture productions subsequently leads to the underutilized agro-industrial wastes disposed of continuously [108], causing significant environmental problems. They are often discarded as wastes due to the apparent cost for storage, collection, handling, and processing. However, these agro-industrial wastes contain carbon components [85], which are valuable for applying filtration in water quality improvement. Investing in technologies that would transform these wastes into a cost-efficient material for filter media would complement the existing filtration practices, particularly for developing countries such as Malaysia or other underdeveloped nations. Hence, there is a need to reduce wastes from the agricultural industries [109] while fulfilling the need to incorporate low-cost alternative filter media [110] in stormwater treatment.

The challenge in handling stormwater quality does not require advanced filtration technology compared to wastewater. Instead, it is the cost-effectiveness and reliability of the treatment and management system that is important. GMF is an established purification technique with benefits such as requires less energy, minimal supervision, low maintenance costs, and proven reliability when optimized. The performance effectiveness of the GMF is determined by solids concentration to be removed from the stormwater and filter design, which includes material for media and its configuration. Then competitive adsorption is less of a concern for real application [52] than the clogging issue. It affects the infiltration rate [40], making maintaining long-term performance interesting to be further explored. Although experimenting with actual stormwater particle distributions and fulfilling the on-field condition may become limitations [20], clogging of media can be simulated in the laboratory.

There are limited studies on the influence of the stormwater treatment system design, configuration, and continuous performance [51], which become a barrier to their extensive applications. The response of GAC on the field is likely to be different from the lab due to media clogging [57], biological activity, and

actual stormwater quality parameters, in which it depends on landuse, rainfall characteristics, surface imperviousness, and stormwater management. Rainfall intensity led to decreased contact time between feed water and media, thus reducing performance [20]. TSS would also discharge better when stagnant water was drained before the backwash [17]. There is infiltration rate recovery following an extended dry period as potentially drying reduces interstitial clogging and pores through surface sediment layer cracking, which causes faster infiltration [28]. Thus dry period affects the filter performance.

Nonetheless, the filter design will affect both initial and operational costs. Caution must be exercised in drawing firm conclusions from the results. For instance, if AC production is not economically viable, it is recommended not to be used. Also, variations in stormwater quality should be considered when applying these data to other locations is planned. Synthetic stormwater can be used [51] as it is impossible to maintain pollutant concentration in testing due to the first flush phenomenon. The preparation of the filter media should be based on the pilot study to obtain the desired result. When stormwater is adequately treated, this could benefit less bank erosion, less demand on the aquifer, and reduce pollution in waterways. This proposition will also align with the government policy to promote sustainable development [111, 112] in our industry.

4.0 CONCLUSION

Managing agro-industrial wastes is challenging, but they have shown potential performance in pollutant removal efficiency. The paper aims to overview the recent utilization of agro-industrial wastes as granular filter media and the potential preparation aspects for its application in stormwater quality improvement. Hence, the criteria affecting the performances of the filtration system, which includes the grain sizes of the media, filter bed configuration, the hydraulic loading rate, and the suspended solids concentration, are highlighted. Theoretically, a single filter media in the GMF application provides high SSA, but dual- and multi-media performance is considerably efficient. There are varieties of agro-industrial wastes locally available that can be considered, particularly in developing countries like Malaysia, to achieve economic cost savings. The large size of granular media from agro-based material provides porosity with a higher void than conventional sand. However, despite retaining a higher capacity of solids and having extended filtration running time that allows for a higher loading rate, the use of large granular size media solely produces lower performance. Thus, solids removal is inversely proportionate to media size. Although they have a longer filter running time, unwanted negative pressure or head loss is still expected. Different material for filter media shows

dissimilar filtration performance. Thus, a combination of filler materials can enhance its potentiality. Finally, the study on criteria affecting filter media performances, including the grain sizes of the media, hydraulic loading rate, media bed configuration, and the suspended solids concentration, can improve the stormwater filtration by utilizing agro-based media.

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