COMPARATIVE ANALYSIS OF THE FILTRATION POTENTIAL OF LIGHT GREYWATER THROUGH VARIOUS MEDIA

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ABSTRACT Water scarcity is an emerging problem across the globe and therefore planners have started promoting the concept of reuse in sustainable planning for conserving water resources. The centralized reuse of treated wastewater is an expensive option and hence decentralized reuse of treated greywater (light and dark) needs to be popularized through simple inexpensive methods like filtration and adsorption. Greywater recycling extends a sustainable pathway in which freshwater resource is conserved and wastewater generation is minimized. Moreover, light greywater can be successfully treated through low-tech filters owing to its weaker strength. In this study, the potential of using low cost waste material as filtering media for treating light greywater was analyzed and possibility of providing prior preliminary treatment to light greywater entering media was assessed using geotextile. The experimental results showed that geotextile used in the study was efficient enough in removing considerable amount of TSS. The study investigates that the low-cost media like Rice - husk, Rice husk ash, Sugarcane bagasse, Sugarcane bagasse ash used in treating light greywater could remove BOD, COD, TSS, NO_3 and PO_4 partially while crushed glass could remove considerable amount of BOD, COD and TSS.

Keywords: Light greywater, Filtration, Adsorption, Rice husk ash, Sugarcane bagasse ash, Treatment

1. INTRODUCTION

Water scarcity was always looked as a problem of arid and semi-arid areas until now when this has been widely accepted as an emerging challenge across the globe due to the increased stress on the existing resources imposed by the increasing population and rapid urbanization (Hagström et al., 2016). This has lead planners and policy makers to consider reuse of treated wastewater as an essential component in sustainable planning of water resources. Several wastewater streams have been considered for reuse after treatment, other than domestic sewage, most of which are limited by their seasonal availability and varying quantity of supply (Schuetze & Chelleri, 2013; Furumai, 2008). Domestic Sewage is often treated in the centralized treatment facilities owned and operated by urban local bodies. These treatment facilities have at least secondary level of treatment, though for reuse often advance treatment mechanisms is required to eliminate the risk of pathogenic exposure. Reuse from such centralized treatment facilities is also limited by factors like the location, availability of space, topography of site, capex and opex of reuse infrastructure, level of treatment for specific reuse etc. (Singh et. al. 2018) resulting in high cost in addition to lack of public acceptance of treated sewage in reuse (Al-Mashaqbeh, 2012). This compels to advocate the decentralized reuse of domestic wastewater by bifurcating it into black and grey. Greywater (GW) is the waste stream excluding flushing wastewater and it constitutes about 60-70% of domestic wastewater while remaining 30-40% (Singh et al., 2018; Tony et al., 2016; Kujawa-Roeleveld et al., 2006) generated from flushing makes Blackwater (BW). GW has been treated through several methods like Activated Sludge Process (ASP), Extended Aeration Process and Sequential Batch Reactor (SBR) etc. However, these methods are expensive and require higher level of expertise. Therefore, attempts have been made to treat wastewater through low cost treatment technologies like filtration and adsorption.

The major cost of treatment through filtration and adsorption is of media used in the process and its regeneration when the adsorbent media gets saturated. To overcome this several studies have been taken up on identification and development of low-cost adsorbent and filtering media from waste materials for treating wastewater (Gupta et al., 2018; Gupta et al., 2009; Kumar, 2006). These materials include natural substances like chitosan, zeolite, clay minerals (Yu and Han, 2015); agricultural by products and agricultural residues (Kyzas and Kostoglou, 2014) like jute and coconut fiber (Phan et al., 2016), sugarcane bagasse (Tao et al., 2015; Homagai, et al., 2010), rice husk ash (Dada et al., 2012; Kumar & Bandyopadhyay, 2006), walnut shell (Ding et al., 2013; Zabihi et al., 2010), groundnut shell (Babarinde & Onyiaocha, 2016; Alagumuthu & Rajan, 2010), cacao shell and corncob (Hale et al., 2013), sawdust and neem bark (Naiya et al., 2009) etc.

Attempts have also been made to treat GW using low-cost filtering media. Dalalmeh et al. (2014) treated GW through three different filters (bark, charcoal, and sand) and compared the treatment results using flow rate of 0.032 m/day and organic loading rate of 14 g BOD/m^2 /day. They found that BOD removal efficiency of sand filter was less (75% vs. 97%–98%) compared to other filters and only charcoal filter could remove total nitrogen. Abdel-Shafy et al. (2014) have reported to treat settled GW using gravel filter followed by sand filter to meet local reuse standards for irrigation in terms of BOD, COD and TSS removals. Katukiza et al. (2014) compared the performance of two filters (lava rock with sand and crushed lava rock) for treating household GW from bathroom, laundry and kitchen wastewater at hydraulic loading rate (HLR) of 0.2 and 0.4 m/day. Performances of both the filters were similar in BOD, COD, NH_3-N and NO_3-N removals. They also found that these filters operating in series showed better removal efficiency for analyzed parameters and that double filtration using coarse and fine media could reduce about 60% of pollution load from domestic wastewater.

Thompson et al. (2017) compared the performance of five biochar and activated carbon for removal of dissolved organic carbon (DOC) in GW and found that biochar could be effectively used in 70% or 80% of DOC removal from both real and synthetic GW against 1-10% of DOC removal by activated carbon.

Noutsopoulos et al. (2018) reported that when sand filtration and GAC filtration followed by coagulation-sedimentation it could help treating GW to achieve TSS < 2 mg/L, turbidity < 2 NTU, BOD5 < 10 mg/L.

Samayamanthula et al. (2019) passed GW from kitchen sink, shower and laundry through a column filled with activated carbon, sand and gravel to achieve pH, color, TDS, turbidity, total coliform and E. coli removal of 23%, 95%, 52%, 88%, 100% and 100% respectively.

The Light Greywater (LGW) from shower, wash basin, washing machine (Penn et al. 2012) successfully treated through these low-tech filters using locally available filtering media. When these locally available media are waste material or by-products of other system, using them also helps in their efficient management.

Asia generates about 4.4 billion tonnes of solid wastes annually while India alone generates about 600 million tonnes of agricultural waste in the form of biomass (Katare & Madurwar., 2017). Disposal of these waste materials without effective treatment may cause serious environmental issues (Anastopoulos et al., 2017). However, most of the treatment methods for managing such wastes are expensive, complex and lead to generation of secondary pollution (Mo et al., 2018). Examples of such wastes leading to generation of secondary waste are bagasse and rice husk which when burned generate ash. About 43.845 Metric Tons of sugarcane bagasse (Dotaniya et al., 2016); 44,000 tonnes of sugarcane bagasse ash (Katare and Madurwar., 2017); 31.68 Metric tons of rice husk and 5.70 Metric tons of rice husk ash (Thomas, 2018) is reported to be generated annually in India.

The other category of waste generated is the waste which can neither be decomposed nor incinerated like automobile windshield glass. Annually, about 65, 68, 63, 170 kg of waste glass is generated by assuming weight of one vehicle is 1000 kg and 3% of its mass is glass and it is expensive to recycle these glasses unlike other glass owing to their complex structure (Farzana & Sahajwalla, 2015).

These waste materials could however be transformed into reusable materials to reduce the pollution problem caused by them (Li et al., 2018). In this study, an attempt has been made to use locally available low-cost waste biomass materials - rice husk (RH), rice husk ash (RHA), sugarcane bagasse (SB) and sugar cane bagasse ash (SBA) as potential adsorbents along with crushed windshield waste glass beads as physical filtering media in treatment of GW.

During use, filters media often gets clogged due to entrapment of solid particles within the media pores leading to frequent replacement. The frequency of media replacement can be reduced by providing preliminary treatment to capture some of the solid particles before entering the media. This preliminary treatment can be provided by filtration through geotextile membrane which is being frequently used in infrastructure projects to capture solid particles (Miszkowska et al., 2017; Yaman et al., 2006).

Therefore, in this paper the potential of using low cost waste material as adsorbing and filtering media for treating GW was analyzed. The study also assesses the possibility of providing prior preliminary treatment to GW using geotextile.

2. MATERIAL AND METHODOLOGY

2.1 Sample Collection and Preparation

For this study, raw LGW was collected by diverting wastewater flow from drainage pipe receiving wastewater from shower, washbasin and washing machines area of a multistoried residential building. The raw LGW collection arrangement is shown in Figure 1.

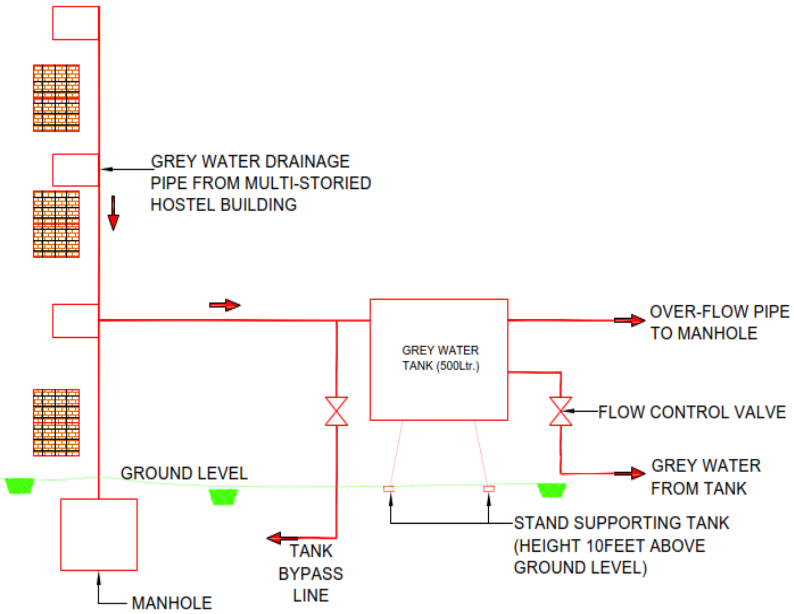

Figure 1. Schematic of GW Collection Arrangement

2.2. Preliminary Treatment

The geotextile used in preliminary treatment was non-woven with apparent opening size (AOS) 125 micron, thickness 2.1 mm, mass 300 g/m^2 and permeability 0.052 cm/s. A single layer of geotextile was placed in a strainer of 6 cm inner diameter. A slotted ring of 6 cm outer diameter was then placed on the strainer to hold the geotextile in place. Raw LGW was then passed from the top of the strainer at 10 l/hr and the filtrate was analyzed to evaluate the preliminary treatment capability of geotextile.

2.3 Media Preparation

The media used in this namely RH, RHA, SB and SBA which were sourced from a local dealer based in Kanpur India. RH and SB were washed using distilled water and dried in hot air oven at 60°C temperature for 24 hrs and weighed. The process was continued till a constant weight was achieved. Then, these materials were crushed in mixer over low speed and sieved to size of 0.5 mm - 0.7 mm. The SBA and RHA procured from vendor were in powder form and hence were washed in a cloth using distilled water. It was then transferred to a wide tray, spread in a thin layer and dried in a hot air oven at 60°C temperature for 24 hrs.

The physical filtering media used in this study was crushed glass bought from vehicle windscreen recyclers. It was washed and sieved to 0.5 mm-0.7 mm sizes. It was washed with distilled water and dried in hot air oven at 60°C temperature for 24 hrs.

2.4 Experimental Set Up

The study was carried out in a

glass column of 40 mm diameter and 60 cm height with a tapering nozzle at the bottom. At the bottom of the column just above the nozzle a plastic net with some glass fiber was placed. Upon it, media was dropped from the top to a height of 14.7 cm. The experimental setup is presented in the Figure 2. Column was tapped thrice and then the height of the media was readjusted to 14.7 if needed. The top of the media was again packed with plastic net and some glass fiber.

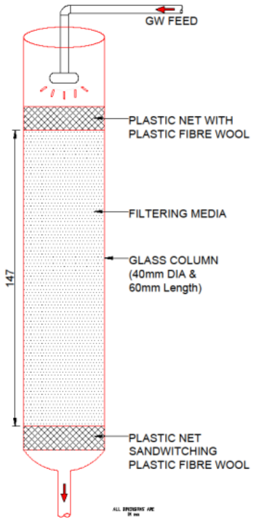

Figure 2. Experimental Setup

Raw LGW was then passed through the filtering media from the top at 10 l/hr rate and filtrate samples were collected from the bottom and analyzed to evaluate and compare GW treatment potential. All experiments were carried out at room temperature.

2.5 Samples Analysis

All the samples collected were analyzed using respective India Standard Codes within 24 hrs of collection.

3. RESULTS

Table 1 shows the preliminary treatment potential of geotextile in terms of removal of Total Suspended Solids (TSS), BOD and COD from the raw LGW. TSS removal achieved by passing raw LGW through geotextile is 26.47%. The reduction in TSS is because the complex pore in the non-woven geotextile entraps the suspended solid particles of relatively bigger size particles in LGW. Overall BOD and COD removal achieved is 2.28% and 4.65% respectively. The BOD and COD in the LGW have both soluble and particulate fraction. Therefore, BOD and COD removal is associated with particulate fraction removal and is therefore proportional to TSS removal. Other parameters analyzed in GW were NO_3, SO_4, PO_4 and Chloride however, no removal was observed as they are contributed by the soluble portions.

Geotextile used in this study can remove coarse solids and other large particles found in raw LGW. This means that the clogging time for filtering media may be extended considerably and thereby filter backwashing may be delayed and power consumption may be reduced. Using geotextile in preliminary treatment, prior to filtration, becomes more helpful knowing the particulate matter in LGW is less predictable and sticky than water plant solids making filter backwashing more expensive and difficult (Latrach et al., 2016; Hamoda et al., 2004). It may be noted here that, geotextile used is the study has almost negligible cost when compared to other preliminary treatment schemes.

Table 1. Percentage removal of BOD, COD and TSS by geotextile membrane

Parameter	Unit	Set 1			Set 2			Average Removal
		Raw LGW	Treated LGW	% Removal	Raw LGW	Treated LGW	% Removal	
BOD	mg/l	18.82	18.39	2.31	18.60	18.18	2.24	2.28%
COD	mg/l	65.28	62.30	4.56	65.20	62.12	4.73	4.65%
TSS	mg/l	17.00	12.52	26.33	16.80	12.33	26.61	26.47%

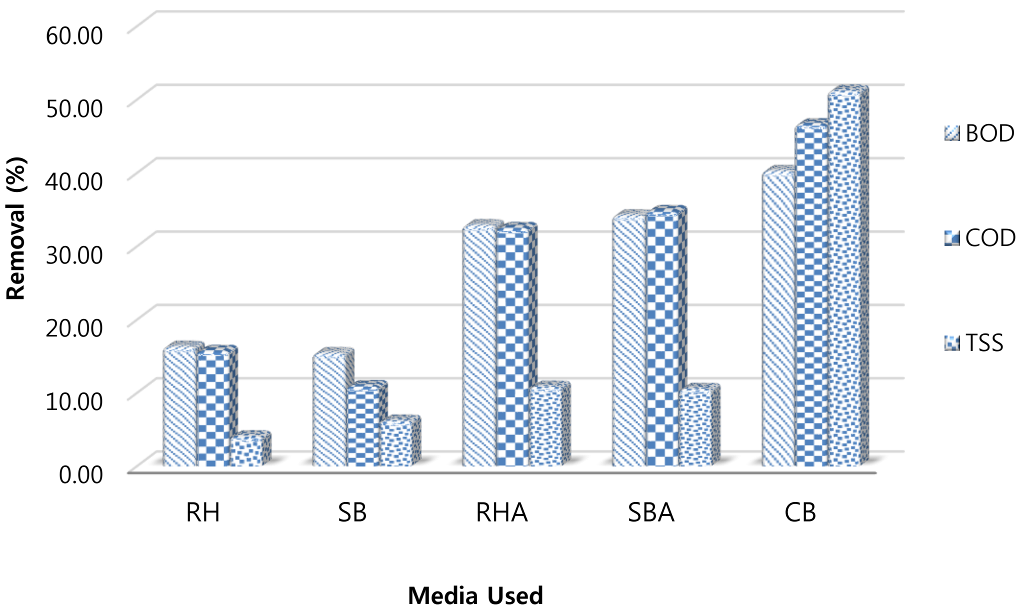

Figure 3. Percentage Removal of BOD, COD & TSS from LGW using low cost filtering media

Plot in the Figure 3 shows the BOD, COD & TSS removal efficiencies of all the materials considered as low-cost filtering media in treating LGW. The selected filtering media works both on the principle of physical filtration and adsorption. However, detail of adsorption mechanism is not in the scope of present study objectives.

It is seen from the plot that BOD removal efficiency of RH is low and is like SB. This may be because the adsorbates size hinders the adsorbate molecules from entering the pore system of adsorbents. It is seen that removal of COD is high using RH compared to using BA which may be because of higher internal surface (increasing micropore volume) of RH.

Further, removal of BOD and COD are higher using RHA and SBA then raw RH and SB. This may be due to the more porous structures of ash compared to their raw forms (Lahti et al., 2017). The better performance of SBA compared to RHA may be contributed to its better adsorption capacity.

The TSS removal efficiencies as seen from the plot are RH<SB<RHA ≈SBA<Glass Beads (CB). It may be mentioned that unlike BOD and COD which are attributed mainly due to dissolved solids, TSS is the measure of suspended solids in LGW. These solids are too big to enter the porous structure of adsorbents and are therefore, removed when captured in the pores formed by the media particles and thus the more the TSS removal, the smaller is the interstitial space between the media particles.

It is clearly seen from the plot that CB, which remove BOD, COD and TSS from LGW based only on the physical process of filtration, are more efficient in removing BOD, COD and TSS from LGW compared to other filtering media-based working on the principle of adsorption.

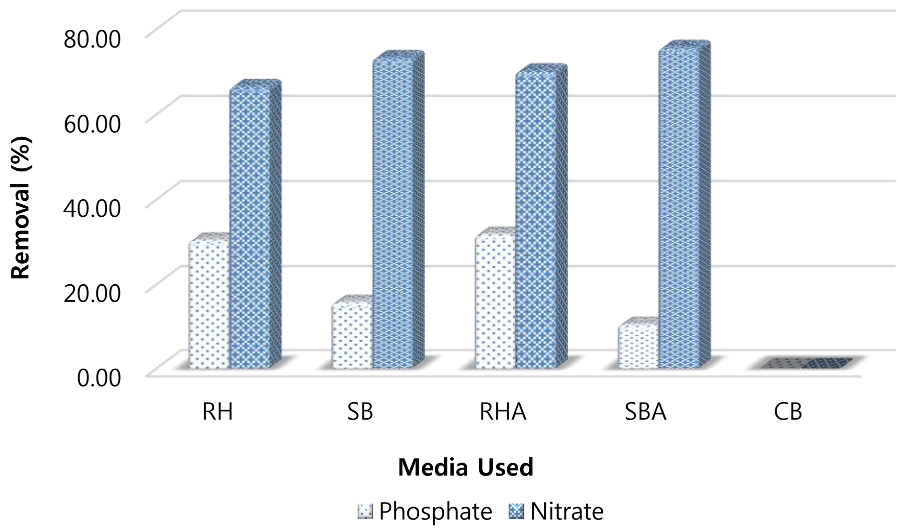

Figure 4. Percentage Removal of PO_4 and NO_3 from GW using low cost filtering media

Plot in the Figure 4 shows PO_4 and NO_3 removal efficiencies of all the low-cost filtering media considered in this study. It is seen that removal of PO_4 is lower compared to NO_3 indicating better removal efficiency of NO_3 compared to PO_4. This may be because PO_4 ions compete very poorly with NO_3 ions during adsorption (Namasivayam & Sangeetha, 2005) which may in turn be because size exclusion hinders the adsorbate molecules from entering the pore system (Loganathan et al., 2013).

Adsorption of NO_3 on RH, RHA, SB, SBA are high and are almost similar indicating no major role of surface area in adsorption. In a similar study carried out by Mathurasa & Damrangsiri (2018) to remove NO_3, it is reported that adsorption by RH and its char is due to surface charge and is not much affected by surface area. It has been reported that lignin in RH acts asan exchanger and is the dominant reactive component responsible for adsorption of NO_3 and therefore, RH could be developed into an effective low-cost adsorbent for NO_3 (Ahmaruzzaman and Gupta, 2011; Orlando et al., 2003). However, the slightly higher removal NO_3 by SB and SBA compared to RH and RHA may be attributed to the higher percentage of lignin presence in the earlier compared to the later. (Su et al., 2015; Ngia et al., 2019).

The adsorption of PO_4 on RH and SB are only marginally higher than their ashes indicating that adsorption of PO_4 is also independent of surface area and is ionic in nature (Wang et al., 2016, Yadav et al., 2015; Hong et al., 2014). Adsorption of PO_4 on SB can be attributed to presence of amino groups which are used as adsorption sites for phosphate removal (Hena et al., 2015; Gao et al., 2009). Higher removal of PO_4 by RH & RHA as compared to SB and SBA may be attributed to presence of higher percentage of amino groups in it compared to the other (Deokar and Mandavgane, 2015; De Moraes et al., 2015).

None of the media, based on the principle of adsorption or physical filtration used in the present study could remove SO_4 and chloride. This may be attributed to less likely availability of active binding sites on the adsorbent surface for SO_4 and chloride.

No removal of PO_4, NO_3, SO_4 and chloride was observed by using crushed glass as filtering media because these pollutants are in dissolved form and the crushed glass media working on the principle of physical filtration is unable to trap the dissolved solid particles in its media spacing.

Figure 5 shows the various combinations of simple filtration schemes that can be developed using the results from this study. Such schemes can provide a sustainable solution for GW treatment and reuse in developing countries like India where centralized Sewage Treatment Plants suffer low efficiency due to unskilled operations, interrupted power supply, weaker capacity augmentation possibilities with increasing flow etc. (Chatterjee, 2016). These treatment schemes may either have adsorption or filtration or both depending on the quality of treated LGW desired. Schemes based only on filtration may be helpful in promoting aesthetics of treated LGW without reducing the nutrients in it. Such schemes may be helpful when the objective of treatment is agricultural or landscaping reuse of treated effluent. Combined adsorption and filtration schemes may be adopted where objective of treatment is environmental reuse or development of restricted impoundment is desired using treated LGW. Such schemes may also be used in polishing secondary effluent especially when the fraction of particles > 20µm size (Healy et al., 2010; Young, 1985) is high.

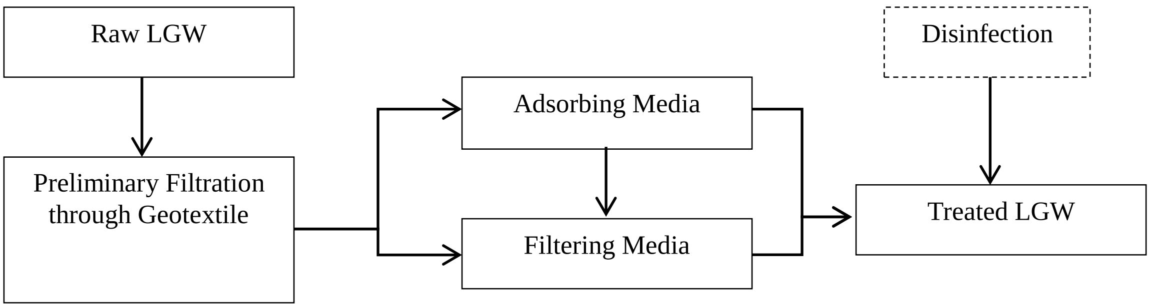

Figure 5. Proposed Treatment Schemes for LGW

The un-stratified bed filters require air-water and specially designed backwash troughs to avoid media loss during backwash. Therefore, to eliminate process of frequent backwashing and adsorbent regeneration, it is suggest to use geotextile in preliminary treatment and to replace the inexpensive media when it gets clogged/exhausted. However, in that case disposal of media may be done as indicated in Figure 6. Disinfection of treated LGW is kept optional and would depend on the microbial content of LGW.

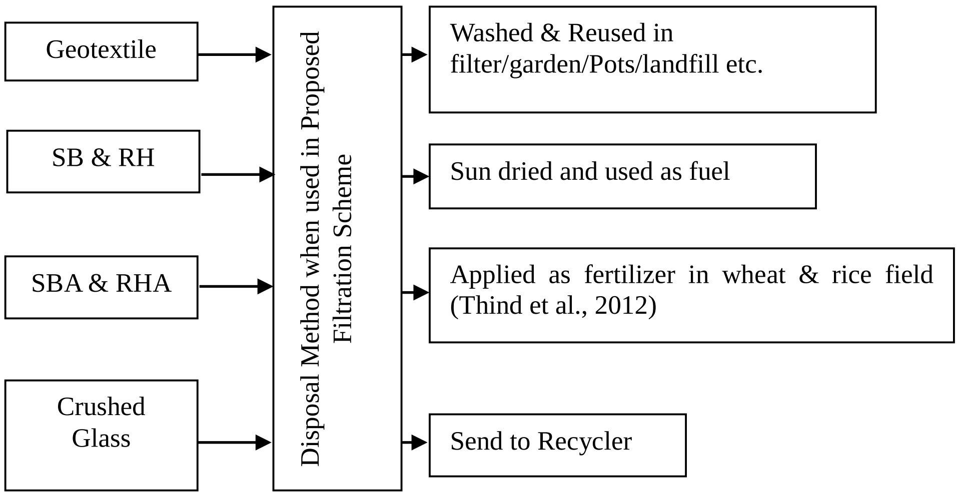

Figure 6. Proposed disposal of filtering media used in the study

The cost for treatment technologies of wastewater including LGW range between 23 - 300 lakhs/MLD while the cost of using proposed filtration and adsorption system would be negligible. Therefore, proposed treatment method may be called as the best treatment method for LGW due to its ease of construction and operation. The proposed scheme is simplistic and would require just a filter case wherein the media need not be regenerated or backwashed but may be replaced owing to its inexpensiveness. This implies the power cost and cost of consumables is reduced considerably leading to minimal operational cost. Additionally, such application of waste material as filtering and adsorbing media helps in better waste management by enabling efficient waste minimization, recovery and reuse (Ali et al, 2012; Patterson, 1989).

4. CONCLUSION & RECOMMENDATION

Geotextile can be successfully used in removing suspended solids and other large particles found in raw LGW and therefore could remove some amount of BOD and COD in addition to TSS. However, it cannot remove dissolved pollutants like NO_3, SO_4 etc.

In this study, RH, RHA, SB, SBA and crushed glass were successfully used as low cost filtering media in treating LGW generated from a high-rise building using adsorption and physical filtration principle. The study shows that filtering media based on the principle of physical filtration out-performed adsorbing media in removing BOD, COD and TSS while the later removed some amount of NO_3 and PO_4 which the former could not remove.

The basic filtration scheme proposed in this paper is cost effective and suitable for decentralized application owing to its simplicity and inexpensiveness. It not only projects simple treatment scheme for reuse of LGW in landscaping, environmental reuse etc. but also provides a channel for waste minimization and recycle. However, further detailed studies like pilot plant study, optimization study etc. may be required before finally adopting the proposed treatment scheme.

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