TECHNICAL NOTE

JOURNAL OF THE SOUTH AFRICAN INSTITUTION OF CIVIL ENGINEERING
ISSN 1021-2019
Vol 63 No 1, March 2021, Pages 61–66, Technical Note 1158

Design and construction of laboratory-scale activated carbon, gravel and rice husk filter columns for the treatment of stormwater runoff from automobile workshops

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The design and construction of low-cost laboratory-scale filter columns using locally available Nigerian filter materials – granular activated carbon (GAC), gravel (GR) and rice husk (RH) – were carried out and reported. The filter materials and columns were designed, constructed and used for the treatment of stormwater runoff from selected automobile workshops in Nigeria over a period of three rainy months. The combined granular activated carbon and rice husk filter systems performed best with pollutant removal efficiency of 58%. It was shown that the materials, considered as waste, could be recycled and used as filter materials in the treatment of stormwater from automobile workshops. This low-cost technology for stormwater runoff treatment, especially for automobile workshops at large scale and in-situ, can be further explored.

INTRODUCTION

Stormwater runoff from automobile workshops washes debris, waste, oil combinations, grease, etc, through the drainage infrastructure within the urban catchment and discharges into receiving water bodies. This has resulted in a high degree of water pollution in Nigeria (Idu 2015; Ekiye & Zejiao 2010).

Studies have shown that land use plays a critical role in the concentration and composition of pollutants that are discharged into receiving water bodies (Khatun *et al* 2014; Shrestha 2017; Wang *et al* 2013). In a study carried out by Pitt *et al* (1995), it was reported that stormwater runoff from vehicle service and parking lots was found to have the highest levels of metals, petroleum hydrocarbon compounds and organics pollutants when compared with other urban land uses.

Conventional wastewater/stormwater treatment methods, such as reverse osmosis, chemical precipitation, electrodialysis, ion exchange, ultrafiltration, etc, have been reported to be unsuitable for adoption in developing countries due to high operating costs, high energy requirement and non-availability of appropriate labour to operate the technologies (Bahgat *et al* 1999). These challenges have created opportunities for the exploration of locally available materials/technologies.

In this research, the potential of combined (a) gravel – activated carbon, (b) activated carbon – rice husk, and (c) single rice husk as filter materials in the treatment of selected automobile workshop stormwater runoff was investigated. These materials are readily available and affordable in Nigeria. Five automobile workshops were selected from the two study towns of Idah and Lokoja in Nigeria for this stormwater sampling and treatment. These selected workshops were named Automobile Workshops 1–5.

This technical note reports the design, construction and preliminary use of the combined (a) gravel – granular activated carbon, (b) granular activated carbon – rice husk, and (c) single rice husk filter materials as vertical columns for the treatment of automobile workshop stormwater runoff. Results of the laboratory investigation of the pre-treatment and post-treatment quality of the stormwater samples collected

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Keywords: automobile workshop, filter media, pollution, stormwater runoff, treatment

Ataguba CO, Brink I. Design and construction of laboratory-scale activated carbon, gravel and rice husk filter columns for the treatment of stormwater runoff from automobile workshops. J. S. Afr. Inst. Civ. Eng. 2021:63(1), Art. #1158, 6 pages. http://dx.doi.org/10.17159/2309-8775/2021/v63n1a6

Figure 1 Filter materials: (a) granular activated carbon, (b) gravel, (c) rice husk

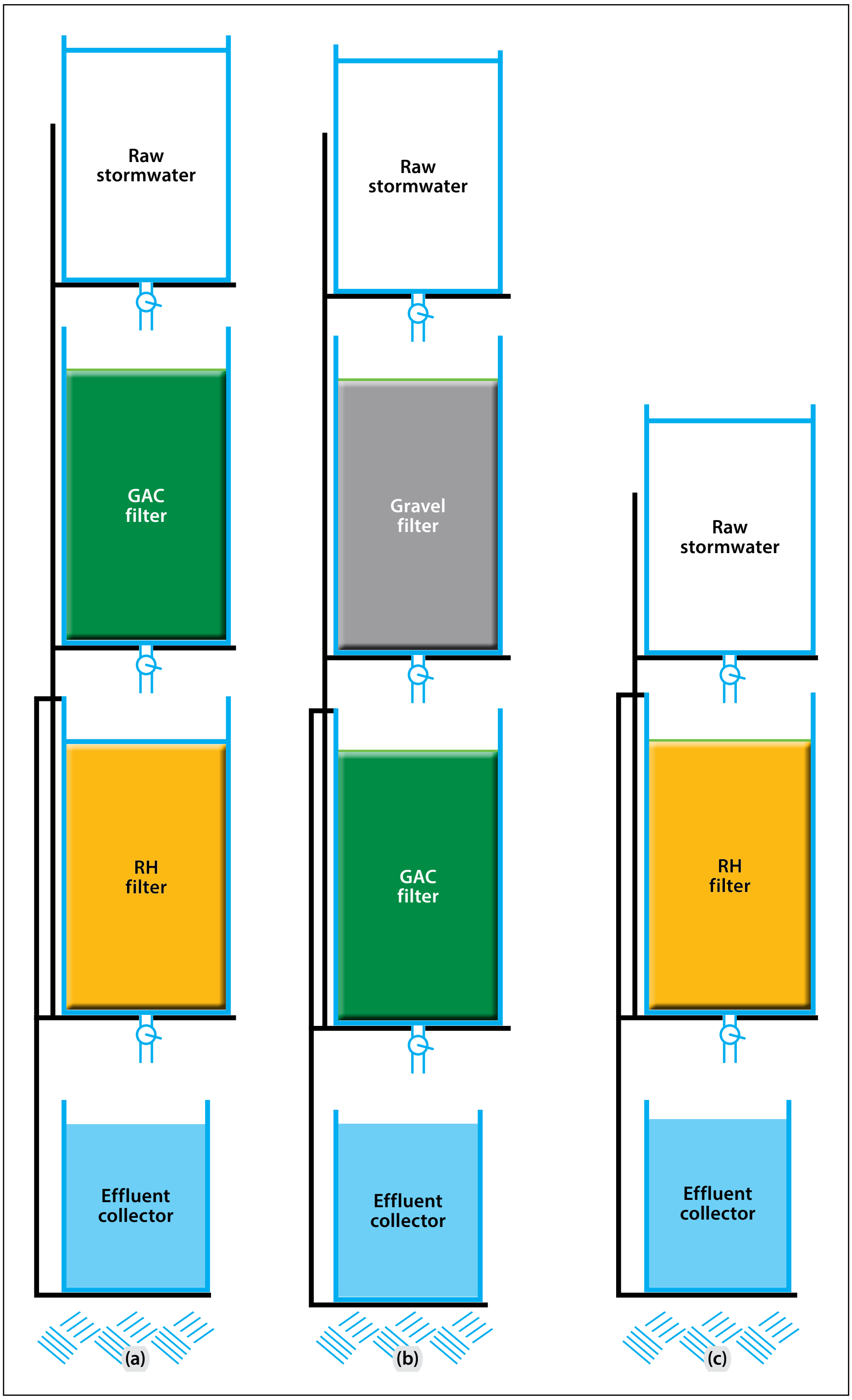

Figure 2 Schematic representation of the filter media setups for the automobile stormwater runoff treatment: (a) GAC – RH filter setup, (b) GR – GAC filter setup, (c) RH filter setup

over the period of nine weeks of a rainy season in Nigeria have also been reported.

The use of these filter materials in water treatment is not a novel concept, as their uses, as documented by Halli *et al* (2018), Maebh (2016) and Lakhote *et al* (2016), have proved that they are good low-cost water treatment materials. These filter materials are ecologically safe, and need little or no regeneration due to their local availability and low production costs (Cecen & Aktas 2011; Baker *et al* 1992; Andersen 2016; Sukia 2020; Nurul Amin *et al* 2006; Zunaira & Zhi, 2017; Xu *et al* 2013; Chukwudebelu *et al* 2015).

MATERIALS AND METHODOLOGY

Figures 1(a – c) show the different filter materials adopted for this research. Similarly, Figure 2 is a schematic representation of the different filter media setups for the filtration process. These configurations/order of arrangement of the filter columns in Figure 2 were basically the choice of the researchers. The denser filter materials were placed above the less dense ones. However, further research work may consider changing the configurations of the filter columns in order to study the quality of the effluents for comparison with these results.

The smooth surface gravel was obtained at minimal cost from the gravel mining site at the bank of the River Niger in Idah, Nigeria. Raw carbon was obtained from local dealers of carbon. The raw carbon was converted to granular activated carbon using thermal activation (pyrolysis) as described in McDougall (1991). Rice husk used for this research was obtained from the rice mill in Idah, Nigeria. Commercially available 100 mm diameter polyvinyl chloride (PVC) pipes were sourced from the local market and used to fabricate the filter columns. Other materials that were obtained and used for the construction

Table 1 Details of design equations, data and references for the filter designs

Filter	Design equation	Design data	Reference
GR filter design	$V_f\left(\frac{m}{h}\right) = \frac{Q}{A} = \mathrm{Q} \div \frac{\pi D^2}{4}$ $Density\ \rho = \frac{Mass\ (m)}{Volume\ (v)}$	Depth of column H = 0.40 m Height of filter L = 0.3 m Freeboard t = 0.10 m Diameter of column D = 0.10 m Volume of gravel V_G = 0.0024 m^3 Density of gravel ρ_G = 1 400 kg/m^3 Mass of gravel M_G = 3.4 kg Filtration rate V_f = 1.0 m/h Flow rate Q = 0.008 m^3/h	Wegelin (1996); Density-Mass-Volume Relation
GAC filter design	$EBCT = \frac{V}{Q} = \frac{A \times L}{Q}$ $Density\ \rho = \frac{Mass\ (m)}{Volume\ (v)}$	Depth of column H = 0.40 m Height of column L = 0.30 m Freeboard t = 0.10 m Diameter of column D = 0.10 m Volume of GAC V_{GAC} = 0.0024 m^3 Density of GAC ρ_{GAC} = 650 kg/m^3 Mass of GAC M_{GAC} = 1.56 kg Empty Bed Contact Time (EBCT) = 18 mins	USACE (2001); Density-Mass-Volume Relation
RH filter design	$Density\ \rho = \frac{Mass\ (m)}{Volume\ (v)}$	Depth of column H = 0.40 m Height of filter L = 0.30 m Freeboard t = 0.10 m Diameter of column D = 0.10 m Volume of RH V_{RH} = 0.0024 m^3 Density of RH ρ_{RH} = 100 kg/m^3 Mass of RH M_{RH} = 0.24 kg	Density-Mass-Volume Relation

of the filter columns were PVC filter mesh, Araldyte (sealant), flow regulator and discharge hose. The arrangements of these materials is schematically shown in Figure 3. Filter column stands were also fabricated to hold the individual columns as shown in Figures 2, 3 and 5.

Design and construction of granular activated carbon, gravel and rice husk filter columns

The vertical downflow bed filter system has been adopted from Wegelin (1996). This design concept is based on its ease of use of gravity flow in underdeveloped areas (Diaper 1965; Pratap *et al* 2007).

The details of the design equations, data and the relevant references used in the design of the filters are presented in Table 1 with the design equations from the references, while the dimensions are the authors' work. The design data in Table 1 was used to construct the columns and the setup for the entire filter systems as shown in Figures 3 and 4.

The PVC mesh was introduced in the setup as shown in Figure 3 to retain and hold back particles from the stormwater runoff that might cause blockage of the flow regulator. The PVC caps covering the PVC mesh at the bottom of the columns were sealed to the column using a commonly available water tight sealant called Araldyte to eliminate leakages in the system.

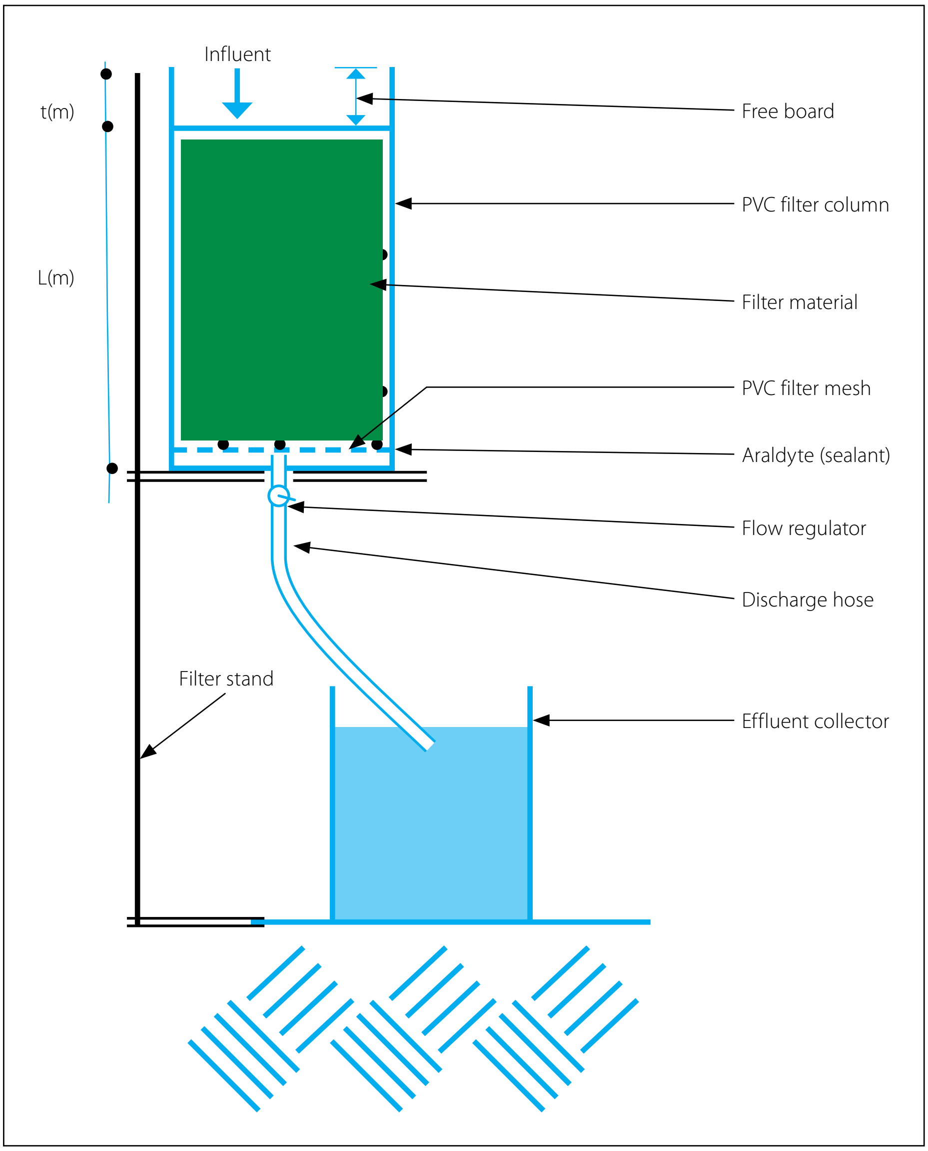

Figure 3 Cross-section of filter system showing the different components

Table 2 Pollutant removal efficiency of the filters for Automobile Workshop 4 at week 1

Test parameters	GAC-RH	*Te* (GAC-RH) %	GR-GAC	*Te* (GR-GAC) %	RH	*Te* (RH) %	Untreated sample
PH	8.24	35.875	10.46	18.599	9.95	22.568	12.85
Conductivity (µS/cm)	823.1	71.417	1 784.34	38.038	898.15	68.811	2 879.73
Turbidity (NTU)	101	63.139	266	2.920	114	58.394	274
Dissolved oxygen, DO (mg/L)	4.62	36.712	5.66	22.466	6.13	16.027	7.3
Total dissolved solids, TDS (mg/L)	604.08	68.776	1 181.01	38.956	646.56	66.581	1 934.69
Total solids, TS (mg/L)	786.08	82.162	1 297.01	70.567	787.56	82.128	4 406.69
Total suspended solids, TSS (mg/L)	182	92.638	116	95.307	141	94.296	2472
Oil and grease, O&G (mg/L)	3.43	46.238	4.88	23.511	4.24	33.542	6.38
Cadmium, Cd (mg/L)	0.012	47.826	0.014	39.130	0.017	26.087	0.023
Copper, Cu (mg/L)	0.016	46.667	0.018	40.000	0.016	46.667	0.03
Lead, Pb (mg/L)	1	41.860	1.22	29.070	1.35	21.512	1.72
Iron, Fe (mg/L)	20.5	45.767	28.65	24.206	32.35	14.418	37.8
Average pollutant removal efficiency (%)		**56.590**		**36.898**		**50.343**	

Filter system setups, stormwater sampling, treatment and laboratory analyses

The different filter materials designed in Table 1 were placed in the different filter columns and fastened to the fabricated stand as shown in Figure 4(b).

Stormwater sampling from each automobile workshop spanning a period of nine weeks during the rainy season was carried out according to Lowe *et al* (2018). The influents and effluents from the different filter setups were analysed for quality before (raw stormwater) and after treatment with the filter media (filtered effluents). Replacement of filter material was chosen over regeneration for this study, as it is economical, and materials are locally available at little or no cost. The parameters analysed included: pH, conductivity, turbidity, oil and grease (O&G), dissolved oxygen (DO), total dissolved solids (TDS), total solids (TS), total suspended solids (TSS), cadmium (Cd), copper (Cu), lead (Pb) and iron (Fe). These parameters were selected based on the characteristic pollutants associated with this land use (Pitt *et al* 1995). The parameters were analysed in accordance with APHA (2017) at the Water Quality Control Laboratory at the National Geosciences Research Laboratories in Kaduna, Nigeria. The efficiency of pollutant removal of each filter system was computed, as presented in Tables 2, 3 and 4.

The pollutant removal efficiency T_e of a particular filter system with respect to any particular parameter is given as:

$$T_e(x)\% = \frac{C_d - C_x}{C_d} \times 100$$

Where:

C_d = concentration of a particular parameter from its untreated sample

$\boldsymbol{C_x}$ = concentration of the same parameter from the filtered sample x

(for x = filter systems GAC-RH, GR-GAC or RH).

Table 3 Pollutant removal efficiency of the filters for Automobile Workshop 4 at week 2

Test parameters	GAC-RH	*Te* (GAC-RH) %	GR-GAC	*Te* (GR-GAC) %	RH	*Te* (RH) %	Untreated sample
PH	8.91	33.108	10.8	18.919	10.23	23.198	13.32
Conductivity (µS/cm)	886	70.328	1 843	38.279	1 024	65.707	2 986
Turbidity (NTU)	98	63.838	192	29.151	106	60.886	271
Dissolved oxygen, DO (mg/L)	4.28	45.408	5.1	34.949	5.88	25.000	7.84
Total dissolved solids, TDS (mg/L)	641.46	68.547	1 164.78	42.887	770.05	62.242	2 039.44
Total solids, TS (mg/L)	854.46	80.200	1 357.78	68.537	971.05	77.498	4 315.44
Total suspended solids, TSS (mg/L)	213	90.641	193	91.520	201	91.169	2 276
Oil and grease, O&G (mg/L)	3.73	43.910	5.12	23.008	4.81	27.669	6.65
Cadmium, Cd (mg/L)	0.014	48.148	0.015	44.444	0.017	37.037	0.027
Copper, Cu (mg/L)	0.015	50.000	0.017	43.333	0.017	43.333	0.03
Lead, Pb (mg/L)	1.1	42.408	1.45	24.084	1.64	14.136	1.91
Iron, Fe (mg/L)	17.52	46.125	23.6	27.429	27.85	14.360	32.52
Average pollutant removal efficiency (%)		**56.889**		**40.545**		**49.106**	

Table 4 Pollutant removal efficiency of the filters for Automobile Workshop 4 at week 3

Test parameters	GAC-RH	*Te* (GAC-RH) %	GR-GAC	*Te* (GR-GAC) %	RH	*Te* (RH) %	Untreated sample
PH	9.82	24.287	11.15	14.032	10.72	17.348	12.97
Conductivity (µS/cm)	916.27	69.561	1 973.02	34.456	1 011.11	66.411	3 010.2
Turbidity (NTU)	104	63.380	198	30.282	143	49.648	284
Dissolved oxygen, DO (mg/L)	4.11	47.975	5.65	28.481	6.4	18.987	7.9
Total dissolved solids, TDS (mg/L)	642.26	66.919	1 302.18	32.927	768.36	60.423	1 941.45
Total solids, TS (mg/L)	849.26	79.602	1 477.18	64.520	949.36	77.198	4 163.45
Total suspended solids, TSS (mg/L)	207	90.684	175	92.124	181	91.854	2 222
Oil and grease, O&G (mg/L)	3.3	48.031	4.92	22.520	4.76	25.039	6.35
Cadmium, Cd (mg/L)	0.012	62.500	0.016	50.000	0.015	53.125	0.032
Copper, Cu (mg/L)	0.013	56.667	0.017	43.333	0.019	36.667	0.03
Lead, Pb (mg/L)	0.7	57.576	0.85	48.485	1.2	27.273	1.65
Iron, Fe (mg/L)	15.2	58.402	22.42	38.643	24.6	32.677	36.54
Average pollutant removal efficiency (%)		**60.465**		**41.650**		**46.387**	

RESULTS AND BRIEF DISCUSSION

The fabrication of these filter columns shown in Figure 4 was done with ease as the materials (100 mm diameter PVC pipe, stand, flow regulator, flexible hose, etc) were sourced locally in the study areas. A unit of the treatment facility was made up of three filter columns (Figure 4(a)). A total of three units of treatment facilities were constructed for each of the five automobile workshops. The filter stands were constructed with steel rods as shown in Figure 4(b). The pollutant removal efficiencies of the different low-cost filter systems for Automobile Workshop 4 for a preliminary period of three weeks with respect to each parameter are presented in Tables 2–4. It is suggested that spent rice

Figure 4 Constructed / fabricated filter columns: (a) constructed filter column, (b) filter column setup with stands, (c) filter column with different filter materials, from left to right: GAC, RH and gravel

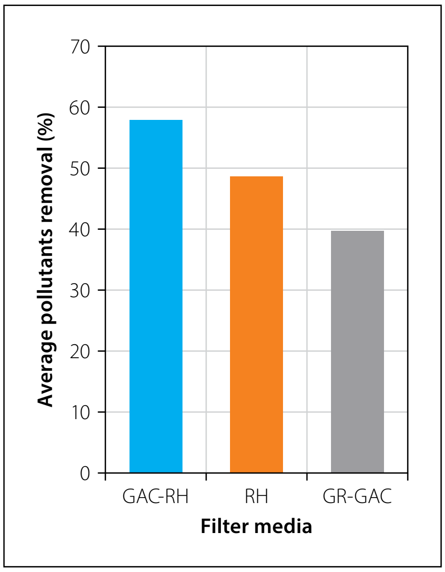

Figure 5 Average pollutant removal efficiencies of the different filter media

husk and GAC can be used as source of heat energy for local industries after sun-drying, while the gravel can be used for concreting. The impact of the filters disposal on the environment will be reduced.

Tables 2, 3, and 4 show the computed average performance of these filter systems in the treatment of the stormwater runoff in terms of pollutant removal efficiency. Figure 5 shows that the combined GAC–RH filter system performed best with average $T_e \approx 58\%$. The RH filter system and the combined Gravel–GAC filter systems followed the combined GAC–RH filter system with average $T_e \approx 49\%$ and average $T_e \approx 40\%$ respectively.

CONCLUSION AND RECOMMENDATION

The results obtained from the use of this technology showed that the combined GAC and RH filter system performed best in the pollutant removal efficiency (58%). The RH filter (49%) and the combined GR and GAC (40%) filter systems respectively followed in pollutant removal efficiency. This technology can be upscaled for use in other environments, with modifications in the available filter materials and the need for sustainable use of the technology. Other cheap locally available agricultural waste materials, such as sugarcane bagasse, groundnut/melon shells, maize cobs, etc, can be explored for use as filter materials. It is highly recommended that other low-cost technology for stormwater runoff treatment, especially for automobile workshops at large scale and in-situ, be explored, researched and prototypes rolled out.

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