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A Study of Filter Drain Performance for the Pollution Control of Urban Runoff

دراسة أداء مرشحات الصرف للتحكم فى ملوثات السريان السطحى

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الخلاصة

الملوثات الناتجة من إنشاء و صيانة الطرق و مرور السيارات و مع سقوط الأمطار تعمل على غسيل أسطح هذه الطرق و بها هذه الملوثات المتراكمة و تسرب مياه الأمطار بالملوثات خلال الطبقات السطحية و الغير سطحية. هذا البحث يدرس تقييم أداء مرشحات الصرف (**filter drain**) المنشأة كأحد أنظمة الصرف المستدامة (Sustainable Urban Drainage Systems, SUDS) فى إزالة المواد العالقة الصلبة و المواد الهيدروكربونية البترولية و المتطايرة و معادن مثل الزنك و النحاس و التى تنتج من الطرق و مع سقوط الأمطار. ونجح هذا النظام (**filter drain**) فى التحكم فى الملوثات الناتجة من سريان مياه الأمطار و معالجتها. تم إجراء عدد (٨) اختبارات وكانت كفاءة إزالة (**SS**) ٩٧% و (petroleum hydrocarbon) ٩٧,٨ % و النحاس ٨٢% و الزنك ٩٢% و (polycyclic aromatic hydrocarbons) أكبر من ٩٩%.

Abstract:

Construction, vehicular traffic and maintenance of highway surfaces are sources of pollutants, which accumulate on highway surfaces and other roadside areas. During rainfall-runoff events these pollutants are washed from these surfaces and flow to surface and subsurface waters. This research is a study to assess the ability of a constructed filter drain as one of Sustainable Urban Drainage Systems (SUDS) in removing suspended solids, petroleum hydrocarbons, metals in the form of Copper and Zinc and polycyclic aromatic hydrocarbons were used for the present study from urban runoff. The constructed filter drain was successful in controlling, attenuating and treating runoff containing pollutant loadings of (sediments, petroleum hydrocarbons, metals and polycyclic aromatic hydrocarbons). For the eight stimulated test runs, the average removal rate of the builder's sand as sediments was 97%. The average total petroleum hydrocarbon removing rate was 97.8%. The mean copper (Cu) and zinc (Zn) removing rate was 82% and 92% respectively. The average removing rate of polycyclic aromatic hydrocarbons was greater than 99%.

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Key Words

Sustainable Urban Drainage Systems, sediments, petroleum hydrocarbons, metals and polycyclic aromatic hydrocarbons.

1.Introduction:

Because pollutants from urban areas are washed into watercourses or ground water, water quality become an important issue. It is difficult for traditional drainage systems to remove pollutants and to control poor runoff quality. Current drainage systems are not designed for the amenity aspects which include all environmental and community issues, such as water resources, community facilities, landscaping potential and provision of varied wildlife habitats. Particularly in urban areas, runoff from impervious surfaces, such as roads and parking lots, contributes significant quantities of pollutants to surrounding surface water bodies (Drapper et al., 2000; Krein and Schorer, 2000; Smith et al., 2000).

Storm water runoff can contain high levels of anthropogenic contaminants, including polycyclic aromatic hydrocarbons (PAH) and heavy metals (US EPA, 1983; Pitt et al., 2004; Mahler et al., 2005). A report on the state of the environment in Scotland (SEPA, 1996) found that 20% of poor river quality resulted from runoff from urban areas. Upon entering the water, organic and inorganic contaminants can remain in the environment for long periods (Sanders *et al*., 1993), posing a threat to human health and the environment (Tuhackova *et al*., 2001; Grynkiewicz et al., 2002).

Approximately one-third of the world's people currently live in countries with at least moderate water stress, and every year more than five million people die on account of poor water quality (DEH,2004). Given current trends, by 2050 at least 25% of the world's population is likely to face freshwater scarcity (UNESCO, 2003). Further, it is predicted that 60% of the world's population will be urban by 2020, making the improvement of urban water infrastructure a particularly pressing issue (UNESCO, 2003).

Roads represent approximately 20% of urban catchments areas, but their drainage water can contribute 50% of the total suspended solids and 30% of total hydrocarbons discharged directly to receiving streams (Ellis *et al*., 1987). In urban receiving waters, the principal pollutants are suspended solids, heavy metals, hydrocarbons and deicing salts with the major sources of highway pollution arising from road and vehicle wear (Mungur *et al*., 1995).

In-ground SUDS are often the developers preferred choice in urban areas in Scotland as they require little space, are inexpensive and include environmental issues (schlüter, 2005). It is estimated that filter drains are used to collect surface waters from about 25% of all major roads in Great Britain (CIRIA, 1999). But until this time, there has been limited examination of there performance (warnaars *et al*., 1999).

Filter drain is one of In-ground SUDS, and this paper is a study of its performance in the control of urban runoff from both quantity and quality aspects. The main objectives of this study to investigate the performance of the constructed filter drain in terms of treatment efficiency for removal of sediments, total hydrocarbon (TPH), polycyclic aromatic hydrocarbons (PAHs) and metals such as zinc and copper from stimulated rainfall events.

2. Materials and methods:

2.1 Location of Study Site:

The study was carried out at a secure outdoor site located on Scottish water-owned land at riverside drive at Dundee airport, Dundee, Scotland.

2.2 Construction of the Filter Drain:

The filter drain was constructed as a 10m long trench, situated alongside paving slabs and filled with crushed stone ranging from (40-60)mm diameter, with two 150mm diameter perforated pipes. The stimulated runoff flows over the pavement slabs and directed through the granular material, trapping pollutants and providing attenuation. Flow is then directed to a perforated pipe. The drain is lined with an impermeable geotextile membrane to prevent ingress of soil and other materials into the structure. The geotextile warp is although not sealed at the manholes and may have inflows/outflows at the end.

The lower perforated pipe serves in conveying water to the outlet manhole. The upper pipe serves as an overflow pipe when clogging occurs in the system. Adjacent paving slabs represent the road from which the water flow sheet will flow into the drain. To measure the effluent flow rate a V-notch weir was installed at the end of the lower perforated pipe (outlet pipe). Fig. 1 shows a cross and longitudinal sections in the constructed filter drain.

Plates from plate (1) to plate (5) show the steps of constructing the filter drain and table (1) shows a summary of events during the eight test runs. At the first run test no pollutants was added and the clean water only was applied to the system for the purpose of hydraulic test. Then seven test runs were done with applying pollutants and collecting samples from the effluent water.

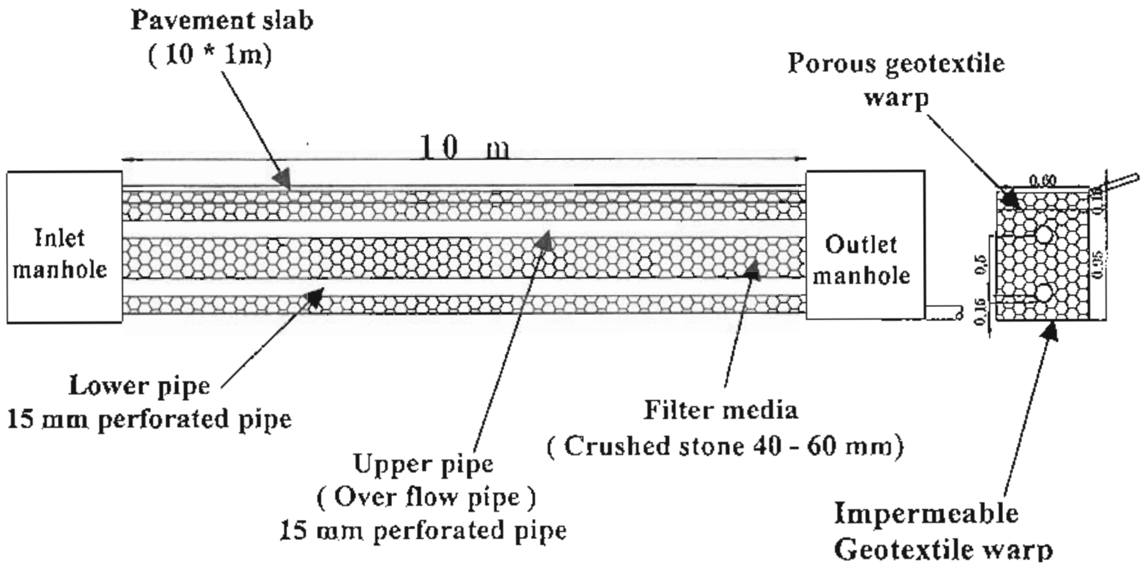

Fig. 1 Longitudinal and cross sections in the filter drain, the flow is from left to right.

Plate (1) the filter is excavated and lined with an impermeable geotextile warp

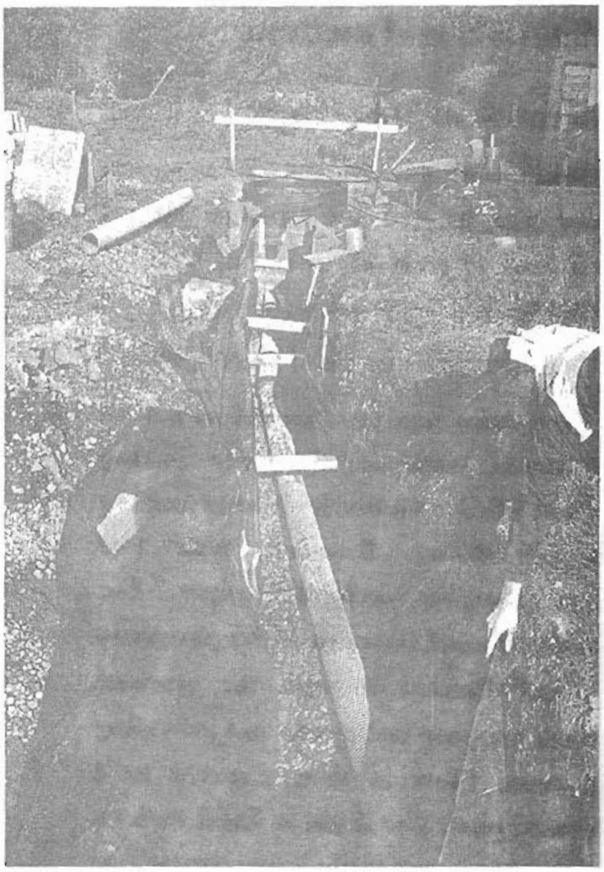

Plate (2) the filter during the fixation of the lower pipe (conveyance pipe).

Plate (3) the filter drain during the fixation of the upper pipe (overflow pipe).

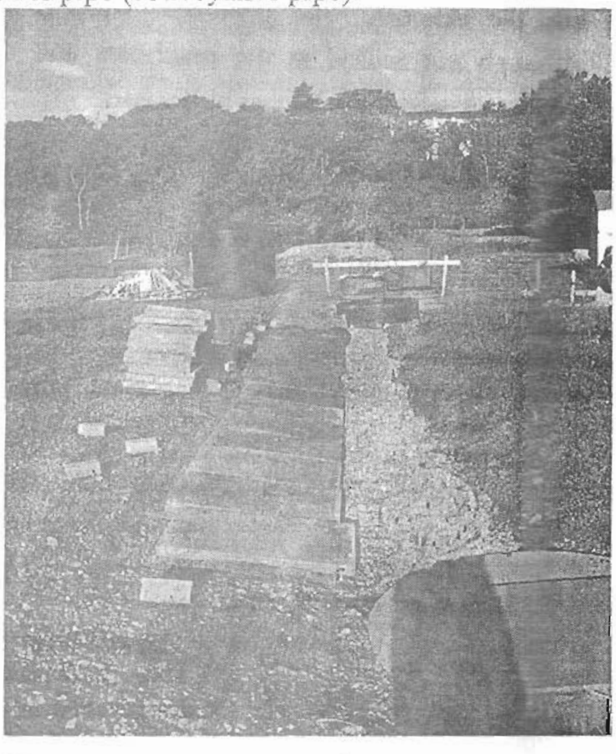

Plate (4) the filter during the construction of side paving slabs.

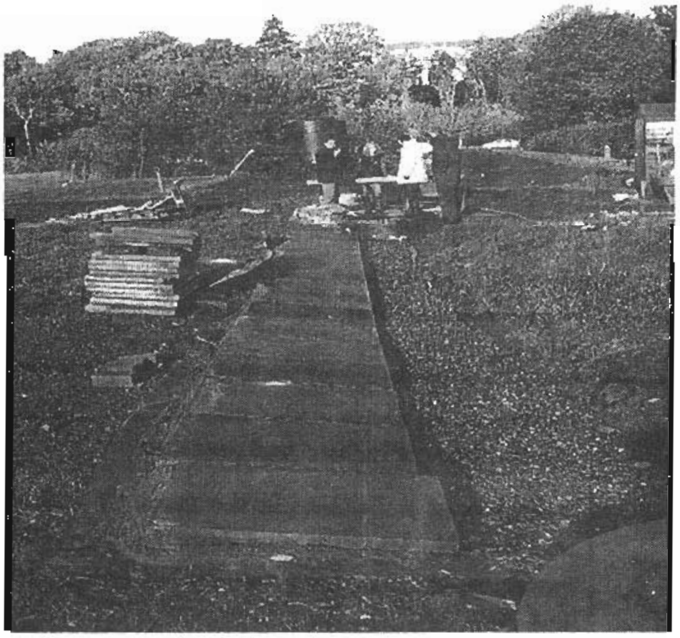

Plate (5) the filter drain after finishing its construction

According to CIRIA 521, (2000) filter drains are designed to store 10mm of rainfall from the contributing area (road area). The Building Regulation Part H recommends a rainfall intensity of 50mm/hr be used for design purposes; therefore the stimulated storm loading used this as the maximum flow rate. Rainfall depths range from 10-30mm, but 10mm was used for the purpose of this study. The maximum total volume of water used for each test run was about 1000liters, so the filter was assumed to serve about $100m^2$.

A rectangular tank at the test site with volume of about 1000 liters was filled with water for each test run. Builder's sand was used as sediment loading and was applied directly onto the paving slabs adjacent the filter drain. Engine oil was used as hydrocarbon loading and was dripped directly on the filter media not on the paving slabs to ensure that no hydrocarbons will remain on the paving slabs surface. Also a solution containing a known concentration of poly cyclic aromatic hydrocarbon (PAHs) was sprinkled directly on the filter media. Solution containing a known concentration of metals such zinc and copper was added to the water in the rectangular tank and applied with water onto the paving slabs. Water from the tank was applied via a hose pipe onto the paving slabs (road) and then directed to the filter media washing builder's sand in its way to the filter.

2.3 Analytical methods

In order to investigate the performance of the constructed filter drain during its operation, analyzing different parameters was carried out in this study.

2.3.1 Flow measurements

Flow measurement was carried out to support the analysis of filter drain hydraulic performance and to calculate the water volume and flow rate through effluent pipe a V-notch weir and a Bühler Montec Flow logger were installed at the end of the outlet perforated pipe. The flow logger was used to measure the depth of the effluent flow

2.3.2 Total suspended solids

Determination of the total suspended solids was carried out as recommended by standard methods (APHA, 1992).

2.3.3 Total petroleum hydrocarbons, metals and PAHs

The analyzing of samples for TPHs, Cu, Zn, and PAHs was carried out by Environmental Services Group Limited with a trade name (TES Bretby), registered office: Askern Road, Carcroft, Doncaster, South Yorkshire DN6 8DG and registered No: 2880501

Table 1: Summary of events for the eight runs

Test run	Date	Events
Test run 1	20-Nov-2006	Additions of clean water into the filter drain as a hydraulic test for the system inflow and outflow.
Test run 2	23-Nov-2006	Addition of pollutants in the form of builder's sand, engine oil and metals. Analysis was done for the effluent samples to find concentrations of total suspended solids, hydrocarbons, copper and zinc.
Test run 3 to Test run 8	29-Nov-2006 to 11 Dec-2006	Addition of pollutants in the form of builder's sand, engine oil, metals and polycyclic aromatic hydrocarbons (PAHs). Analysis was done for the effluent samples to find concentrations of total suspended solids, hydrocarbons, copper, zinc and total poly cyclic aromatic hydrocarbons (PAHs).

3. Results and Discussions

3.1 Water flow results

In the 1st test run no pollutants was added, only clean water with an approximate volume 1000 liters was applied to the system. The inflow and out flow hydraulic results was used to support analysis. The estimated volume of water applied was 1000 liter, but the results show an effluent volume of about 44.55 liters. This volume is about 4.455% of the total applied volume. This low volume of the effluent water could be attributed to the storage and retention in the system and side leakages occurring at the end of the system near the manhole. The storage volume in the system is estimated to be 1.8 m³, as the volume of the filter media is about 6 m³ and the assumed voids ratio is 30%. Inflow water measurements are shown in Fig.2. Outflow water measurements are shown in Fig. 3.

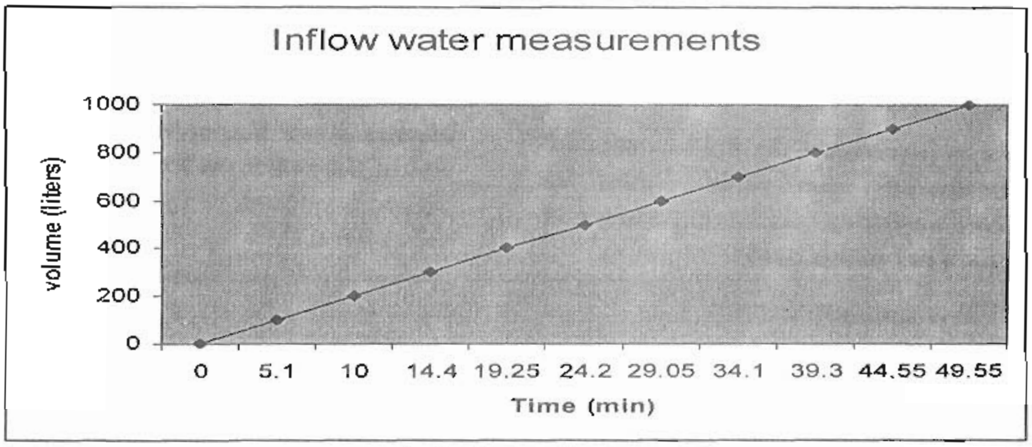

Fig. 2 The inflow water measurements

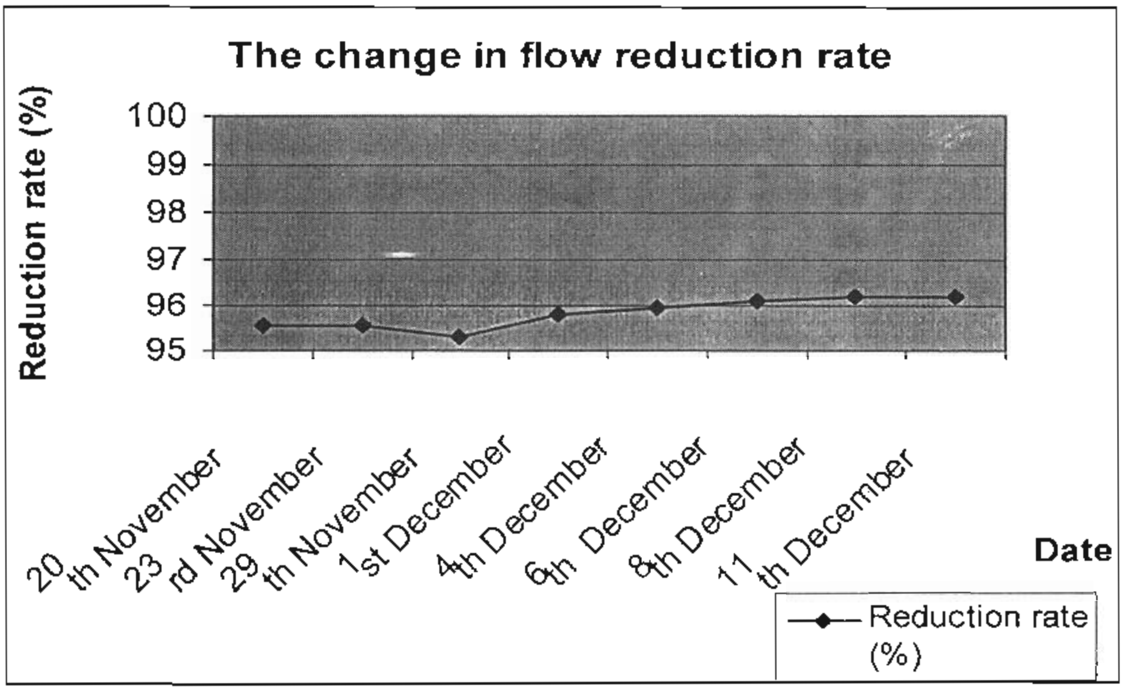

Fig. 3 The change in the flow reduction rate.

3.2 Suspended Solids Results

Table 2 shows the results. The total suspended solids mean concentration in the effluent water was 63.67 mg/l and the mean influent concentration of sediment was 2600mg/l, in the test run 5, the system gave an average removal rate of about 97.55%.

Table 2 TSS Influent and Effluent concentrations and removal rates for test runs from test run 2 to test run 8

Date	Test run	Influent conc. (mg/l)	Effluent mean conc. (mg/l)	Removal rate (%)
23rd November 06	Test run 2	2600	62.67	97.58
29th November 06	Test run 3	2600	87.33	96.64
1st December 06	Test run 4	2600	83.67	96.78
4th December 06	Test run 5	2600	63.67	97.55
6th December 06	Test run 6	2600	76.67	97.05
8th December 06	Test run 7	2600	63	97.57
11th December 06	Test run 8	2600	66	97.46

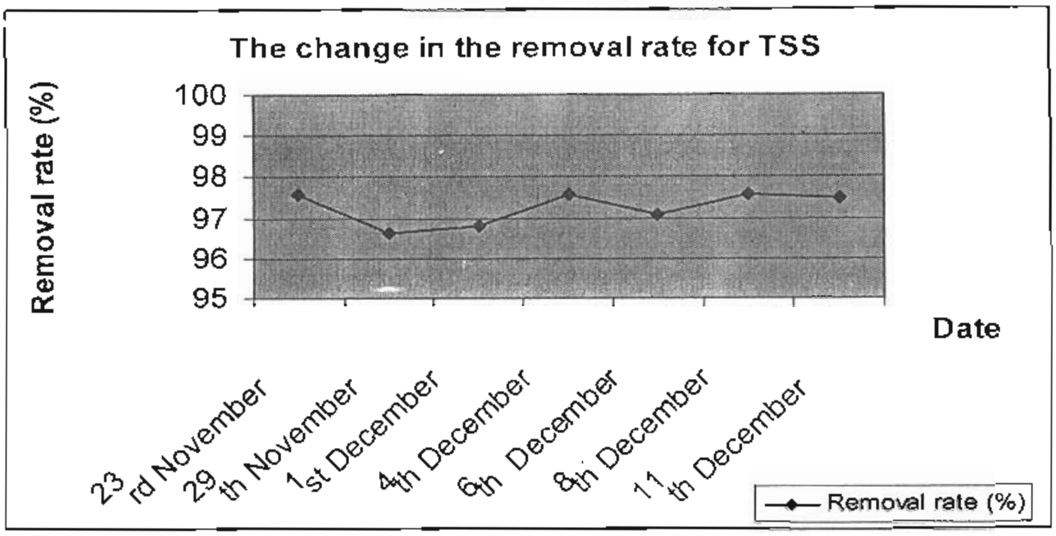

Fig.4 : The change in the removal rates for TSS

3.3 Metals results

Copper and Zinc influent and effluent concentrations are shown in Table 3 and Fig. 5.The effluent mean concentration of total copper was 0.016 mg/l and the effluent mean concentration of total zinc was 0.0745mg/l. The influent mean concentration for copper and zinc was 72.8 µg/l and 1.28 mg/l respectively. Removal rate in the test run 5 for copper was 78.02% and for zinc was 94.17%.

Table 3 Cu and Zn Influent and Effluent concentrations and removal rates for test runs from test run 2 to test run 8

Date	Test run	Influent conc. (mg/l)		Effluent mean conc. (mg/l)		Removal rate (%)	
		Cu	Zn	Cu	Zn	Cu	Zn
23rd November 06	Test run 2	0.0728	1.28	0.0136	0.1326	81.22	89.64
29th November 06	Test run 3	0.0728	1.28	0.0135	0.0615	81.45	95.19
1st December 06	Test run 4	0.0728	1.28	0.0155	0.1040	78.70	91.87
4th December 06	Test run 5	0.0728	1.28	0.0160	0.0745	78.02	94.17
6th December 06	Test run 6	0.0728	1.28	0.0140	0.1245	80.76	90.27
8th December 06	Test run 7	0.0728	1.28	0.0085	0.0735	88.32	94.25
11th December 06	Test run 8	0.0728	1.28	0.0105	0.1055	85.57	91.75

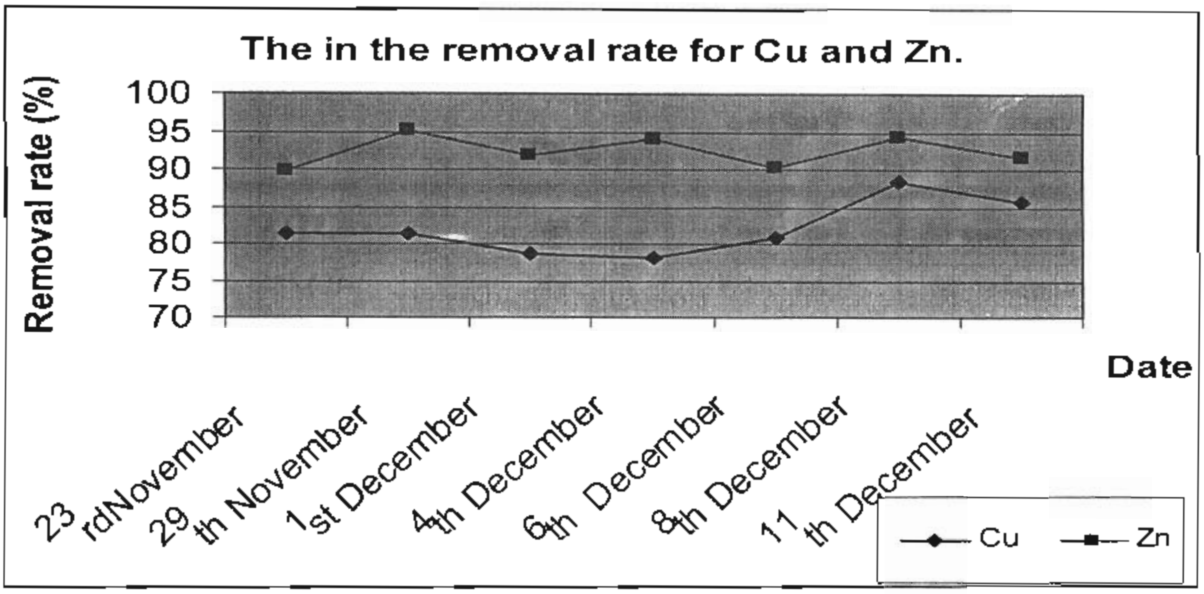

Fig. 5 The change in the removal rate for both Cu and Zn

3.4 Total Hydrocarbons Results

The mean effluent TPH concentration was 0.2 mg/l and the mean influent TPH concentration was 23.14 mg/l, so the removal rate of total petroleum hydrocarbons was 99.13%(run 5). Table 4 shows the results for TPHs.

Table 4 TPH Influent and Effluent concentrations and removal rates for test runs from test run 2 to test run 8

Date	Test run	Influent conc. (mg/l)	Effluent mean conc. (mg/l)	Removal rate (%)
23rd November 06	Test run 2	23.14	0.1	99.56
29th November 06	Test run 3	23.14	0.25	98.91
1st December 06	Test run 4	23.14	0.25	98.91
4th December 06	Test run 5	23.14	0.2	99.13
6th December 06	Test run 6	23.14	0.35	98.48
8th December 06	Test run 7	23.14	2.05	91.14
11th December 06	Test run 8	23.14	0.35	98.48

3.5 Total Polycyclic Aromatic Hydrocarbons Results

The effluent collected samples were analyzed for Total Polycyclic Aromatic Hydrocarbons (PAHs). The influent mean concentration of total petroleum hydrocarbons was 56μg/l. The removal rate was >99% for all runs. Table 5 shows the results for PAHs.

Table 5 PAHs Influent and Effluent concentrations and removal rates for test runs from test run 2 to test run 8

Date	Test run	Influent conc. (μg/l)	Effluent mean conc. (μg /l)	Removal rate (%)
29th November 06	Test run 3	56	<0.5515	>99
1st December 06	Test run 4	56	<0.171	>99
4th December 06	Test run 5	56	<0.5225	>99
6th December 06	Test run 6	56	<0.460	>99
8th December 06	Test run 7	56	<0.8705	>99
11th December 06	Test run 8	56	<0.4065	>99

It has been reported that filter drains can remove 95% of total suspended solids, 99% of total petroleum hydrocarbons, 84% of copper, 91% of zinc and reduction in flow rate of about 83% (Taye S. Akinrelere, 2005). From the results obtained from this study, the filter drain performed better at TSS removing, zinc retaining and flow rate reduction and less at copper retaining and TPHs removing. This may be due to the using of greater concentrations of pollutants than the used by Taye S. Akinrelere, (2005).

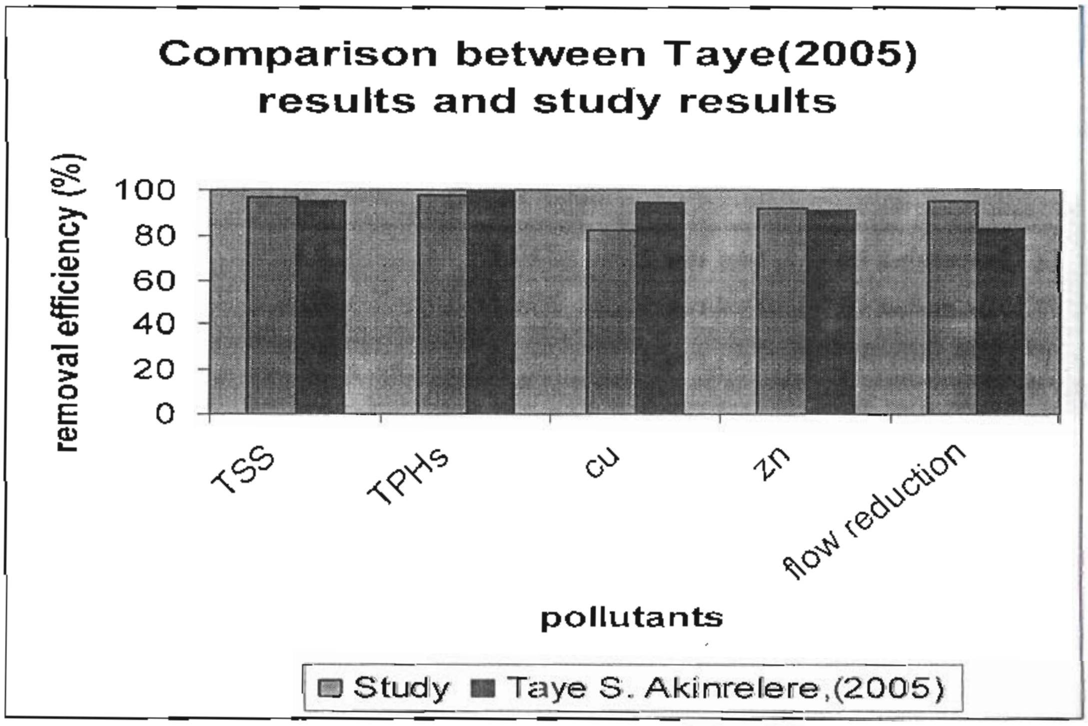

Fig. 6 A comparison between the results from the two studies

Water treatment efficiency may be sensitive to the change in pollutant concentrations, but it is not conclusive and further studies can be made to verify this observation. Fig. 6 shows a comparison between the results from the two studies

3.6 Discussions

The removal rates for the constructed filter drain were due to the use of removal mechanisms such as detention/attenuation, sedimentation, filtration, and adsorption as follow:-

- **Detention / attenuation:**

Detention or attenuation is the slowing down of surface flows prior to their transfer downstream. This is achieved through the use of a storage volume with the filter media.

- **Sedimentation:**

Sedimentation is one of the primary removal mechanisms that is used by the constructed filter drain. Most pollution in runoff is attached to sediment particles and therefore removal of sediment results in a significant reduction in pollutant loads.

- **Filtration:**

Pollutants that are conveyed in association with sediment may be filtered from the percolating waters. This may occur through trapping within the aggregate matrix or on geotextile layers within the construction..

- **Adsorption:**

Adsorption occurs when pollutants attach or bind to the aggregate particles. The actual process is complex but tends to be a combination of surface reactions grouped as sorption processes:-

· Adsorption: Pollutants bind to surface of soil/aggregate.

· Cation Exchange: Attraction between cations and clay minerals.

· Chemisorption: Solute is incorporated in the structure of a soil/aggregate.

· Absorption: the solute diffuses into the soil/aggregate/organic matter.

. The results obtained from the suggested filter drain are very effective for removing total suspended solids (TSS) and also effective to retaining petroleum hydrocarbons, metals (copper and zinc) and polycyclic aromatic hydrocarbons.

4. Conclusions

Investigations carried out in this research are for studying the performance of the constructed filter drain for the control of urban runoff. This study was seeking to determine the effectiveness of the filter drain in terms of water quality perspective; it aimed to address the ability of the filter drain to remove copper and zinc from the drainage route. Also determining its effectiveness in attenuating water flow.

The obtained results presented in this research suggest the filter drain to be effective at removing total suspended solids (TSS) and also effective at retaining petroleum hydrocarbons, metals (copper and zinc) and polycyclic aromatic hydrocarbons. During the stimulated test runs the filter drain was:

- Very effective in attenuating water flow with a mean reduction efficiency of about 95% in flow rate.
- Very effective in removing total suspended solids with a mean removal efficiency of approximately 97%.
- Very effective in retaining petroleum hydrocarbons with a mean removal efficiency of about 97.8%;
- Very effective in retaining Cu and Zn with a mean removal efficiency of about 82% for Cu and 92% for Zn;
- Excellent in retaining PAHs with mean removal efficiency greater than 99%.

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