Fortification of Sand filters - An alternative technique of enhancing wastewater treatment efficacy

Ezekiel Kholoma[*1], Gunno Renman[1a] and Agnieszka Renman[1b]

* Corresponding author (Email: ezekiel@kth.se)
1 Division of Land and Water Resources Engineering, KTH Royal Institute of Technology, Teknikringen 76, Stockholm, Sweden (a: Email: gunno@kth.se; b: Email: agak@kth.se)

Abstract
Malodourous odour, colour, algae blooms and eutrophication in surface water bodies are caused by presence of dissolved organic carbon and nutrients. Though these constitute wastewater constituents that are usually barely treated by septic systems, they have not been given adequate attention. In the wake of the current global climate change and escalating water demands in various countries, the need to protect available water sources from pollution has necessitated the urge to compel rural communities to comply with federal discharge quality standards. However, the low availability of alternative effective technologies limits their efforts to improve. This study tested the idea of sand filter fortification with biochar as a possible technique to improve septic tank effluent quality. Sand of 0.30 m depth in 0.045 m-diameter columns was topped with 0.20 m layer of biochar and tested on turbidity, DOC and phosphorus removal from wastewater hydraulically loaded at 0.063 L/d. The results showed that all the filters reduced influent turbidity (150 NTU) by up to 99%. The reference-biochar filter was most effective in lowering influent DOC (25.25 mg/L) by >60% than both reference- (51.8%) and fortified (55.2%)-sand. The fortified filter also dominated in influent PO_4^{3-} (6.18 mg/L) reduction achieving >45% whilst the reference-sand only achieved 35.2%. There was a reasonably strong linear correlation between pH and PO_4^{3-} sorption efficiency of biochar ($r = 0.81$) and sand-biochar ($r = 0.83$) but a moderate one for sand ($r = 0.57$). Moreover, regression analysis revealed that 66% and 70% of variation in PO_4^{3-} sorption efficiency was explained by the variation in pH of the B and SaB respectively. Also, student t-test showed that adding biochar to sand significantly improved its efficacy in phosphorus ($p = 0.0001$) and DOC ($p = 0.027$) reduction. Therefore, fortification of sand-filters may be considered a possible measure to improve effluent quality.

Keywords
Fortification; Sand filters; Dissolved organic Carbon; phosphorus; wastewater recycling

INTRODUCTION

On-site wastewater treatment (OWT) facilities are highly-rated worldwide as sources of nutrients and organic compounds contaminating important water sources (Withers et al, 2011). Even though these contaminants are known to be problematic, little has been done to-date to help rural communities improve their removal from wastewater. Instead, the rural communities today are compelled to comply with wastewater discharge limits. Apparently, such standards are stringent in some countries and thus almost impossible to achieve. In Norway (Dawes et al, 2003) and Denmark (Brix and Arias, 2005) for example, they are required to produce effluents with P concentration of ≤1 mg/L. Meanwhile the availability of alternative feasible technologies to use is still generally low worldwide.

Soil- or sand-based infiltration systems (SIS) are commonly used in OWT systems for decontaminating anaerobically pre-settled septic tank effluents (STE). However, these facilities are generally poor in removing dissolved substances (Gill et al, 2009), for instance, dissolved organic carbon (DOC) (Volk et al, 2002), phosphorus (P) (Withers et al., 2011) etc.

Sand that is commonly used in SISs generally lacks the chemical substances such as oxides of calcium (Ca)-, iron (Fe)-, or aluminium (Al)-oxide needed to react with the dissolved substances. Elevated amounts of DOC often imparts malodourous odour to water as it is biologically degraded. It also tends to act as a disinfection by-product precursor as well as a nuisance by fouling membranes used for drinking water production (Kraus et al., 2010). P and N on the other hand nourish aquatic plants. With time, this causes eutrophication and hypoxia condition which often kills aquatic biota (HELCOM, 2009). Therefore, without providing innovative solutions for upgrading septic systems, efforts to abate water pollution might fail.

Today, so-called reactive filter (RF) media, that is, substrates to which contaminants can bind, are increasingly attracting attention as retrofits for sand-based filters. Numerous of these materials are now used in full-scale plants today. See examples in Renman and Renman (2010) and Heistad et al (2006). Those known to be capable of P removal are mostly characterized by high contents of reactive oxides of Ca, Fe, Al or Mg in their lattice structures while those for DOC removal possess high ion exchange capacity and porosity (Bradl, 2004). Apparently, some RF media are versatile in decontaminating water, but their capacity has not been adequately explored. Biochar, that is, a plant-derived pyrolysis product is one such material. In addition to being capable of improving soil water holding, biochar can also immobilize metals (Kołodynska et al, 2012), nutrients (Yao et al, 2012) etc. If synthesized from biomass pyrolyzed at >400 ^{o}C, biochar can remove up to 75% of P from wastewater (Yao et al, 2012). This study was aimed at testing the effectiveness of biochar addition to a sand filter in reducing turbidity and concentrations of DOC and P from a STE.

MATERIALS AND METHODS

Materials

The filter media and wastewater and their sources

These included sand (Sa), biochar (B) and some pebbles. Sa was obtained from Hakungekrossen AB (Sweden) whereas the B was from Skogens kol AB (Sweden). The pebbles were obtained from the same sand after sieving it. The wastewater was a STE obtained from a sedimentation tank serving 4 households in Garns Ösby, a village 35 km NE of Stockholm, Sweden (coordinates: 59.569649, 18.267817).

Pre-experiment physical and chemical analysis of the media

Before the experiment, the particle size (d), pH, bulk density (ρ_b), porosity (ø) and pore volume (V_p), potential discharge (Q), and empty bed contact time ($EBCT$) were measured. The ρ_b was obtained by dividing known mass of a sample by its bulk volume (V_b). The pH of each material was obtained from prepared solutions containing 1:20 material-to-distilled water using a SensIONTM PH31 pH meter (Hach®). The porosity was obtained after mixing known volume of water (V_w) with that of sample (V_s) and subtracting the new volume of the mixture from the theoretical volume (V_w+V_s). Ø was calculated as the ratio of the V_p to V_b. Q was estimated by placing beakers at the outlets of the columns to collect and measure volumes of the effluents in timed intervals until the collected volumes were equal to that for a single run. The EBCT was calculated using relation

$$EBCT = \frac{BV}{Q} \tag{1}$$

where BV and Q were the bed volume (m^3) and discharge (m^3/d). This was All of the data is presented in Table 1.

Table 1: Properties of the filter media prior to the start of the experiment

Material	*pH*	ρ_b (kg/m^3)	*d* (mm)	Ø	*EBCT* (minutes)
Sand	7.43	1.70	0.0 – 4.0	0.46	1 – 1.5
Charcoal	8.01	0.54	0.0 – 4.0	0.53	> 2
Sand-biochar	7.75	-	2.0 – 4.0	0.51	> 2

The experimental set-up and operation

Five PVC columns of 0.7 m height and 0.045 m inner diameter were used to construct the filters. A 0.08 m layer of pebbles overlain with a porous membrane was placed in the bottom of each column to support the tested filter materials. The first and second columns respectively were filled with sand (Sa) and biochar (B) of same particle sizes (table 1) and depths (0.5 m) and used as state-of-the art reference filters. Each of the other three columns was first filled with Sa of 0.30 m depth and subsequently topped with a 0.20 m B layer to serve as biochar-fortified sand (Sa-B) filters. Another porous membrane was placed on top of all the media to facilitate the distribution and further pre-treatment of the influent. A 25 L covered container used for keeping the influent (STE) was kept beside them at an elevated position. Approximately 0.021 L of the wastewater was hydraulically loaded three times per day run for 399 days onto each filter by a timer-regulated pump resulting in a hydraulic loading rate of 40 L/m^2/d (or superficial velocity of 2.8 cm/min). Covered 1 L containers were used to collect the discharge (Figure 1).

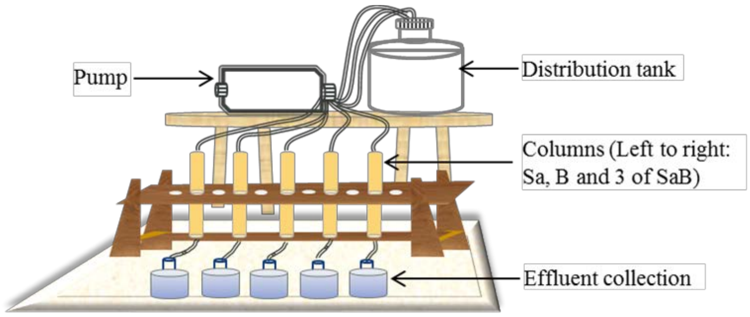

Figure 1: The design and set-up of the filters as they were used for the test

Sampling and analysis

Both the influent and effluents were simultaneously sampled at least once a week for analysis of temperature, pH and turbidity, DOC and PO_4^{3-}. Measurements of pH (with SensIONTH PH31, Hach®), turbidity (with 2100P ISO Turbidity meter, Hach®) and PO_4^{3-} (using the AutoAnalyzer 3 operated using the AACE software, Seal Analytical Ltd.) were obtained on daily basis. The samples were frozen and used later analysis of DOC with the TOC-L TOC Analyser (Shimadzu Corporation). For DOC, they were pooled into a total of 13 monthly samples. The removal efficiency (*E* in %) was estimated using the mass balance approach as

Statistical analysis

For purposes of reliability of inferences to be made, the pH, turbidity, DOC and PO_4^{3-} data was first tested for normality using the Shapiro-Wilk test in SPSS Statistics 21 (IBM). The descriptive statistics used included skewness and kurtosis, normality plots and stem-and-leaf plots. A Pearson Product Moment correlation between pH and phosphorus removal efficiency and regression analysis were also performed. The significance of addition of biochar to sand was also performed using the SPSS' student T-test programme, assuming paired means with unequal variances at 5% uncertainty level (α).

RESULTS AND DISCUSSIONS

Filter characteristics and wastewater retention and discharge

Information from the suppliers indicated that the sand was a fluvial-type whilst the biochar was derived from wood (birch, alder and aspen wood chips) produced through a 500 ^oC pyrolysis process in a wagon retort process. The sieved sand and biochar consisted of about 39.8% and 34.2% of the 0.0 – <2.0 mm particle fraction and, 60.2% and 64.8% of the 2.0-4.0 mm fraction respectively. Moreover, the effective size (d_{10}) of the sand was 0.3 mm. As shown in table 1, the porosity (0.53) of the Sa-B filter was larger than that of Sa (0.45). Also, the estimated EBCT for Sa was shorter (1.5 – 1 hrs) compare to that of B and Sa-B (> 2 hrs). As was also observed by Abel et al (2013), the added biochar improved the water retention and treatment capacity of the sand filter.

As a product of weathering and erosion processes, the used fluvial sand in this study should have been more. Moreover, since it was mostly comprised of rounded and smooth particles, it probably derived most of its porosity (and hence pore volume) from inter-particle rather than intra-particle pores (Achak et al, 2009). The high porosity of biochar was suspected to have been caused by the elimination of volatiles (mostly oxygen- and hydrogen-containing compounds) from their feedstock due to the high heating temperature (500 ^oC) during pyrolysis (Brewer et al, 2014). As will be discussed later, the presence of B in the Sa column possibly improved not only its absorption but also adsorption capacity.

Temperature

The experiment commenced at the beginning of summer (April) when the room temperature was about 17.2 ^oC. It is possible that as it continued to rise, it favoured chemical or biological treatment processes (Herrmann et al, 2014) in the media. Even though it had few fluctuations the influent temperature was generally stable. Its range was from 20.1 ^oC (in summer) to 16.1 ^oC (in winter). Since the effluent collectors were not insulated, their temperature was almost always the same as that of the room but lower than that of the influents by 1 – 5 ^oC (data not shown). The range for the effluents was 19.7 – 15.4 ^oC (summer to winter).

Removal of the different parameters

From the Shapiro-Wilk test performed (data not shown), most of the turbidity, pH, PO_4^{3-} data fell within 68% of one standard deviation of their means. Also, almost all the data lied within the second and third quartiles of the data ranges while the skewness was approximately -1.96 to 1.96. However, two outliers were obtained in the turbidity and one in the PO_4^{3-} data. All in all, the statistics showed that the data was normally distributed. In total, 46 samples of both the influent and effluent were collected. The mean values of pH, turbidity and PO_4^{3-} concentration and DOC are presented in Table 2.

Table 2: Mean values and standard deviation of the observed parameters

	Influent	Sand effluent	Biochar effluent	Sand-Biochar effluent
pH	7.47±0.23	7.69±0.15	7.98±0.38	7.91±0.33
Turbidity (NTU)	150±210	2 ± 1	1 ± 0	1 ± 0
PO_4^{3-} (mg/L)	6.07±0.76	3.94±1.15	3.51±1.25	3.31±1.06
DOC (mg/L)	25.25±2.77	12.05±2.33	10.09±1.62	10.58±1.16

Table 2: Mean values of observed parameters (with standard deviation) for the entire period

pH trend

Both Sa and B had a high pH, and, B seemed to be more alkaline (pH 8.0) than sand (pH 7.45) (table 1). The pH of Sa-B was 7.75 and therefore higher than that of Sa but lower than that of B. Therefore, the added B in the SaB must have been more responsible for its pH than sand. A clear distinction between pH measures in the different effluents was also observed (table 2). The mean pH of Sa, B and SaB effluent pH was 7.69, 7.98 and 7.91 respectively. This showed that the effluent pH of SaB was higher than that of Sa. Since pH changes in substrates infiltrated by water or solution are often indications of occurrence of chemical reactions in them (Keemachevakul et al, 2011), it could be said that the presence of B in the sand column enhanced its chemical capacity to react with wastewater constituents.

Figure 2 shows the pH change with time in both the influent and effluent.

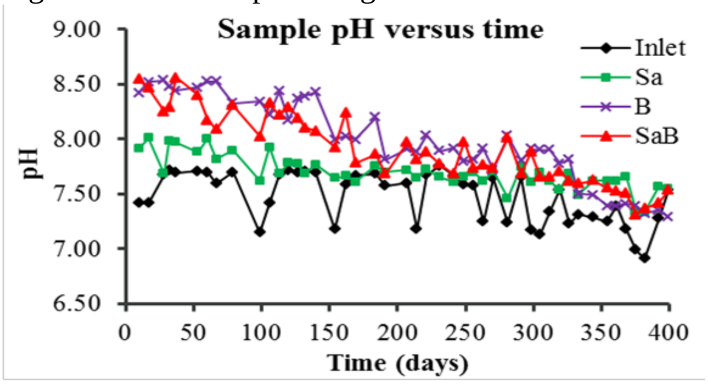

Figure 2: The pH trend with time for the entire study

The figure shows that the influent pH was a little above neutral pH for most of the time but dropped only a bit towards the end. The minimum and maximum recorded were pH 6.91 and pH 7.76. This showed that it had a very small range (<pH 1) and hence small fluctuations. The effluent pH was mostly >pH 8.0 during the first half (200 days) of the study period but slowly decreased later. Its range (and mean in brackets) was pH 7.33-8.01 (7.69), 7.29-8.57 (7.99) and 7.31-8.56 (7.91) in the Sa, B and SaB effluents respectively. Therefore, the B effluent had a slightly higher pH the other water streams. One peculiar observation in the pH trend of the inlet wastewater was that it seemed to show a slow decline whenever the wastewater was kept longer without adding new one to it. One likely cause could be the organic acids produced from biogenic decomposition of organic matter in the wastewater (Achak et al, 2009). Also, the pH tended to rise after new wastewater was added to the old wastewater in the distribution tank. Since pH can affect sorption processes, the pH of the new wastewater probably destabilized the performance of the filters through the adjustment of their pH or alkalinity (Keemachevakul et al, 2011). Another possible explanation could be that some of the pores in biochar probably provided some passage for barely treated water to percolate deeper and closer to the outlets.

Turbidity removal
Just like pH, the influent turbidity fluctuated throughout the entire period. The fluctuations were more predominant towards the end of the experiment. A closer look at its trend revealed that it seemed to be higher during between 99 and 154 days (that is, summer) compared to between 300 and 350 days (that is, winter). In the effluents, it was generally low, remaining below 10 NTU throughout the experiment, with only a maximum of (6 NTU) observed in the Sa effluent. (Figure 3).

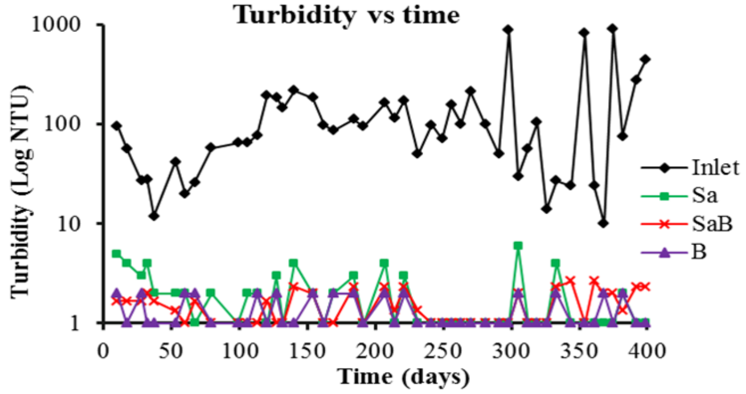

Figure 3: Turbidity trend with time for the entire study period

The statistical mean turbidity of the influent and Sa effluent was 150 NTU and 2 NTU respectively whilst it was 1 NTU for both B and SaB (table 2). The analysis showed that the standard deviation of the influent turbidity (210 NTU) was much greater than the mean. Most possibly, this may have been caused by the outliers (884, 820 and 907 NTU occurring at day 298,354 and 375). The lower outlier in the inlet turbidity was mostly due to the settling of the solids as the wastewater was kept longer without disturbance in the distribution tank. The high turbidity on the other hand occurred whenever new wastewater was added into the tank. Also, the elevated turbidity observed during summer may have been due to increased inflow of SS and dissolved substances from the households as the number of occupants increased. In general, all the filters achieved an efficiency of >98% turbidity removal. The World Health Organization (WHO, 2011) recommends 10 NTU as turbidity limit for effluents that are safe to dispose of. Therefore, the filters produced treated wastewater of acceptable quality.

DOC removal
The monthly amount of DOC measured in both influent and effluents is shown in figure 4.

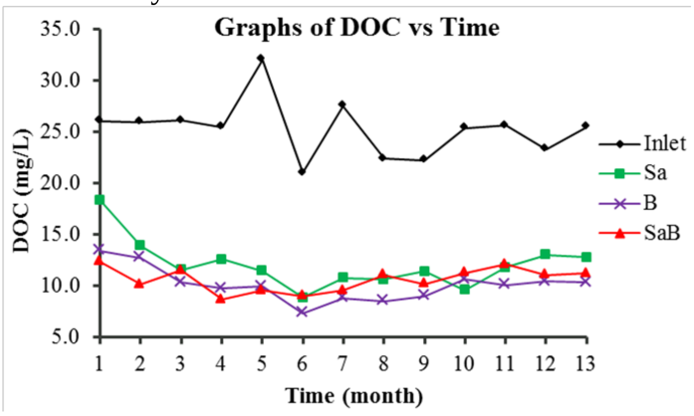

Figure 4: DOC trend with time for the entire study period

In the figure, some DOC fluctuations and peaks occurred in the influent between month 4 and 7 whilst none did in the effluents. However, the pattern in the effluents seemed to have a declining trend during the first half of the study period. As highlighted by Volk et al (2002), emergent DOC amounts in effluents of treatment plants mostly depend on the wastewater source, kind of treatment train, environmental (temperature, air) and operational conditions etc. Further, since DOC hardly settles in septic tanks, it often escapes them with little treatment. The sampling in this study was done on different days of the week and at different times of the day. Therefore, the fluctuations in the influent may be attributed to these differences. It is also possible that microbial activity in the media were favoured by the increasing summer temperature and thus degrading more of the DOC. A study by Katsoyiannis and Samara (2007) found that DOC levels in samples obtained on Mondays were always lower than on other days. That weekly variation is quite similar to the seasonal fluctuation observed in the current study.

On average, the mean influent DOC concentration was 25.25±2.77 mg/L per day. On the other hand, the ranges of concentration in the Sa, B and SaC effluents were 8.86-18.31; 7.32-13.40 and 8.63-12.33 mg/L respectively. This means that all the filters reduced the influent DOC by >50%. However, the sand seemed to be less effective (Figure 3). In general, the mean DOC measure in the effluents were in the order Sa<B<SaB (table 2). Calculations using mean influent DOC showed that the Sa was only able to achieve 52.3% reduction whilst the B and SaB removed up to 60.1 and 58.1% respectively. That further meant that the SaB was >6% more effective than the Sa filter. An activated sludge processes in the plant studied by Katsoyiannis and Samara (2007) reportedly achieved a DOC removal efficiency of 73%. Comparing this to the current findings, it could be said that the efficiency of the filters was normal and satisfactory. Regarding the null hypothesis that the improvement in the sand efficiency may have occurred by chance after adding biochar, T-Test statistics revealed that that the probability of error (p-value) was 4.3% ($p = 0.0267$). Therefore, it was concluded that the presence of biochar improved the sand capacity in treating DOC.

Sand filters rely on the formation of biofilms within them to remove DOC. Once the biofilm is established, the DOC is mostly reduced from the influent by absorption and biological degradation (Kang et al, 2007). In advanced treatment whereby granulated activated carbon (GAC) is commonly used (Volk et al, 2002), mechanisms of adsorption and ion exchange are mostly responsible for removing dissolved substances. Though, chemical analysis of the biochar in this study was not determined, its pH characteristics indicated that it probably possessed some of these capacities hence the significant improvement in DOC removal by the Sa with B. However, the negative charge of biochar may reduce its ability to remove anions from water or wastewater due to repulsion. Further, since its hydrophobicity often seems to be higher before it is colonized by fungi or pore-filled with water (Abel et al, 2013), this might have been a disadvantaging factor in its performance. However, the DOC removal by all the filters with B was believed to be substantial. As a porous material, there was a possibility of DOC removal by micro-pore filling mechanisms.

Phosphorus removal

The amount of influent PO_4^{3-} was higher during the first 180 days than in later days. There was a sharp peak also (8.03 mg/L between day 60 and 100) during that time. Figure 4 shows how it changed in both the influent and effluents.

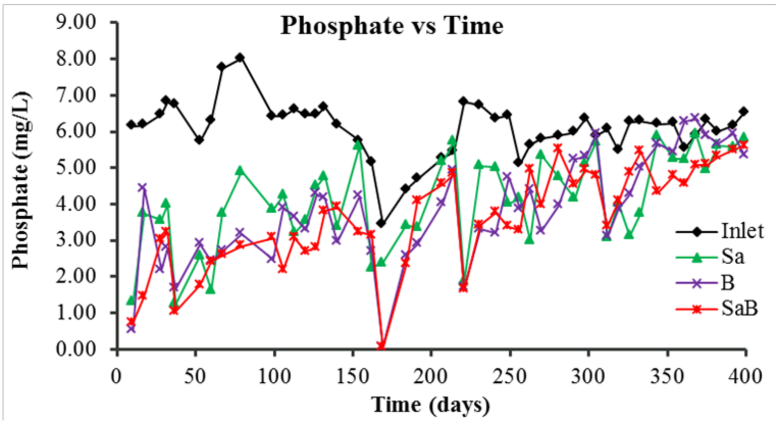

Figure 5: Phosphate trend with time for the entire study period

As indicated earlier, this occurred during summer, that is, when the number of occupants in the households, and wastewater production, increased. Therefore, it is likely that the amount of phosphorus production also increased. Another peculiar observation was a drop in influent PO_4^{3-} (3.45 mg/L) between day 154 and 207. It also seemed that as the wastewater in the distribution tank was kept longer without adding new one to it during that, it got clarified as well. The drop in PO_4^{3-} in the influent might have been due to increased uptake by the micro-organisms as they multiplied and also partly because of binding of part of it to the settling solids. The opposite seemed to occur whenever new wastewater was added to top up the remaining water in the distribution tank, that, the influent PO_4^{3-} tended to rise during that time. Therefore, this was one other cause of its fluctuations. Ultimately, the range and mean of the influent PO_4^{3-} were found to be 3.45-8.00 mg/L and 6.07±0.76 mg/L.

The PO_4^{3-} in the effluents tended to fluctuating similarly to that in the influent. For instance, when the influent PO_4^{3-} dropped to its lowest (3.45 mg/L), the effluent PO_4^{3-} also dropped substantially, with the SaB filter being the most responsive (producing about 1 mg/L) followed by B (1.86 mg/L). This indicated that if the pre-treatment step had been more effective in reducing the PO_4^{3-} in the inlet wastewater, the filters would have been more capable of attenuating much of the remaining. A steady increase in effluent PO_4^{3-} was observed towards the end. Perhaps the filters' capacities were getting exhausted. Overall, the range (and mean in brackets) of effluent PO_4^{3-} of the Sa, B and SaB were 1.25-5.94 (3.94), 0.52-5.92 (3.51) and 0.35-5.60 (3.30) mg/L respectively. From these findings, the SaB filter seemed to be most efficient in attenuating the influent PO_4^{3-}. However, comparing these values to the permissible limit in Sweden, that is ≤ 1mg/L (Eveborn et al, 2012), it could be said that the filters did not meet this quality standard. However, the improvement made by the biochar in the SaB was treated considered to be substantial. It should be noted that whilst the Sa was able to reduce the influent PO_4^{3-} (6.07 mg/L) by only 35%, the SaB's performance was higher, (>45%). The efficiency of the B filter (42.3%) was also a bit higher than that of Sa, thus providing evidence that adding it to Sa may have probably improved its efficiency.

Phosphorus sorption efficiency and capacity

Assuming that the set hydraulic loading rate (0.063 L) was maintained throughout the test period, then, the total amount of wastewater infiltrated through each filter column was 15.14 L. If the mean daily influent PO_4^{3-} (6.07 mg/L) is also assumed to have been constant, then, about 152.7 mg of PO_4^{3-} was loaded on each filter. Figure 6 shows how the amount trapped by each filter column varied with time.

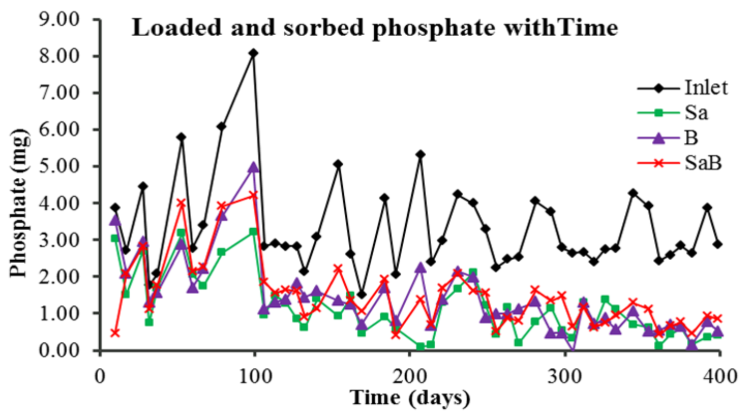

Figure 6: Loaded and trapped phosphate trend with time for the entire study period

From the analysis, the Sa, B and SaB filter respectively ultimately trapped about 53.7, 64.6 and 69.9 mg from the total loaded. These corresponded to sorption efficiencies of 35.2%, 42.3% and 45.8% by the Sa, B and SaB respectively. The SaB was therefore the most effective at removing PO_4^{3-} from the percolating STE. Even though these efficiencies were below 50%, it could still be concluded that the objective of the study was achieved, that is, to upgrade the efficiency of the sand filter in turbidity and PO_4^{3-}. Using SPSS' (IBM) T-test and linear regression (LR) models, it was obtained that the pH-PO_4^{3-} removal efficiency correlation of B (r = 0.82) and SaB (r = 0.83) were significantly stronger compared to that of Sa (r = 0.57). Moreover, the LR model revealed that 66% and 70% of variation in PO_4^{3-} sorption could be explained by the variation in pH of the B and SaB respectively whilst only 33% could do for Sa. Therefore, it was concluded that fortification of sand filters with biochar could significantly improve their performance in removing turbidity, phosphorus and DOC. However, there is room for improvement of this innovation. For instance, the hydraulic loading rate, order of packing of the media in the columns, particle size, frequency of dosing etc. were not varied to find out how they could affect the performance. The type of charcoal used could also prove to be another parameter to investigate. All in all, it could be said that, if all factors are considered in designing this kind of system, the idea of sand filter fortification with biochar could be prove to be a possible feasible alternative to improve STE quality.

CONCLUSION

This study successfully tested biochar on boosting the performance of sand in a treating STE The turbidity reduction by all the filters was satisfactory (>95%). After fortification, the sand-biochar filter proved to be better than sand alone in reducing DOC (by >6%) and PO_4^{3-} (by >10%). Therefore, it was concluded that sand-fortification with biochar could be a possible measure to improve treatment of wastewater in rural areas. However, further tests of different configurations of Sa and C are recommended to find possible optimal designs of the filters.

REFERENCES

Abel S., Peters A., Trinks S., Schonsky H., Facklam M., Wessolek G. 2013. Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. *Geoderma* 202 – 203,183-191

Achak M., Mandi L., Ouazzani N. 2009. Removal of organic pollutants and nutrients from olive mill wastewater by a sand filter. Journal of Environmental Management 90, 2771 - 1779

Bradl H.B. 2004. Adsorption of heavy metal ions on soils and soils constituents. Journal of Colloid Interface Science 277, 1-8

Brewer C.E., Schmidt-Rohr K., Satrio J.A. & Brown R.C., 2009. Characterization of biochar from fast pyrolysis and gasification systems. Environmental Progress & Sustainable Energy, 28 (3): 386 - 396

Brix H., Arias C.A. 2005. The use of constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines. *Ecological Engineering* 25, 491-500

Dawes L., Goonetilleke A. 2003. An investigation into the role of site and soil characteristics in on-site sewage treatment. *Environmental geology* 44, 467-477

Eveborn D., Kong D., Gustafsson J.P. 2012. Wastewater treatment by soil infiltration – long-term phosphorus removal. *Journal of contaminant hydrology* 140-141, 24-33

Gill L.W., Luanaigh N.O., Johnston P.M., Misstear B.D.R., Suilleabhain C.O. 2009. Nutrient loading on subsoils from on-site wastewater effluent, comparing septic tank and secondary treatment systems. *Water Research* 43, 2739-2749

Heistad A., Paruch A.M., Vråle L., Adam K., Jenssen PD. 2006. A high-performance compact filer system treating domestic wastewater. Ecological Engineering 28, 374-379

Helsinki Commission (HELCOM) 2009. Eutrophication in the Baltic Sea – an integrated thematic assessment of the effects of nutrient enrichment and eutrophication in the Baltic Sea Region, Report No. 5965, Helsinki, Finland

Herrmann I., NOrdqvist K., Hedström A., Viklander M. 2014. Effect of temperature on the performance of laboratory-scale phosphorus-removing filter beds in on-site wastewater treatment. Chemosphere 117, 360-366

Kang Y.W., Mancl K.M., Tuovinen O.H. 2007. Treatment of turkey processing wastewater with sand filtration. Bioresource Technology 98(7), 1460-1466

Katsoyiannis A., Samara C. 2007. The fate of dissolved organic carbon (DOC) in the wastewater treatment process and its importance in the removal of wastewater contaminants. *Environmental Science Pollution Resources International* 14(5), 284-292

Keemachevakul P., Polprasert C., Shimazu Y. 2011. Phosphorus recovery from human urine and anaerobically treated wastewater through pH adjustment and chemical precipitation. Environmental Technology 32(7), 693-698

Kolodynska D., Wnetrzak R., Leahy J.J. Hayes M.B.B., Kwapinski W., Hubicki Z. 2012. Kinetic and adsorptive characteristics of biochar in metal ions removal. Chemical Engineering Journal 197, 295-305

Kraus T.E.C., Anderson C.A., Morgenstern K., Downing B.D., Pellerin B.A., Bergamaschi B.A. 2010. Determining sources of dissolved organic carbon and disinfection by-products precursors to the McKenzie River, Oregon. *Journal of Environmental Quality* 39(6), 2100-2112

Öövel M., Tooming A., Mauring T., Mander Ü. 2007. Schoolhouse wastewater purification in a LWA-filled hybrid constructed wetland in Estonia. Ecological Engineering 29, 17-26

Renman A., Renman G. 2010. Long-term phosphate removal by calcium-silicate material polonite in wastewater filtration systems. *Chemosphere* 79, 659-664

Volk C., Wood L., Johnson J., Zhu HW., Kaplan L. 2002. Monitoring dissolved organic carbon in surface and drinking waters. Journal of Environmental Monitoring 4, 43-47

Withers P.J.A, Jarvie H.P, Stoatte C. 2011. Quantifying the impact of septic tank systems on eutrophication risk in rural headwaters. *Environmental International* 37, 644-653

World Health Organization (WHO), 2011. Guidelines for drinking water quality, 4th ed. WHO Library Cataloguing-in-Publication Data, WHO Press. Geneva

Yao Y., Gao B., Zhang M., Zimmerman A.R. 2012. Effect of biochar amendment on sorption of nitrate, ammonium and phosphate in a sandy soil. Chemosphere 89, 1467-1471