Performance of mineralwool as filter medium for the treatment of contaminated drain water in the urban context of Delhi, India.

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ABSTRACT

Delhi is facing a very rapid urbanization, making it difficult to keep up with the construction of sewerage and water treatment infrastructure. The LOTUS^{HR} project was created to research alternative solutions to treat mixed water streams and prevent pollution flows from urban drains into the environment.

Biofiltration was identified as a suitable on-site sanitation alternative to provide adequate water quality and hygienic conditions. In particular, this work is intended as a first step in the future design of the biofilter, by investigating the potential of hydrophilic mineralwool as a filtering medium for the Barapullah drain contaminated water. Mineralwool performance was tested, focusing on nutrients and heavy metals removal. The effect of different HRT's on biofilm formation was evaluated and the minimum length for optimal filter performance was researched. The fieldwork was conducted in Delhi between the 4th January and 9th February 2018. Four mineralwool filters were monitored, running with different operational parameters under the same environmental conditions.

Biological activity was identified as a key factor in increasing the removals of COD and NH_3-N. Bare mineralwool achieved PO_4-P reduction, independently from the presence of a biofilm. Moreover, a shorter HRT determined a selection pressure for attached biomass growth, leading to a more swift biofilm formation. Unfortunately, part of the obtained results showed a high error margin. Possible reasons for these error margins are discussed.

Hydrophilic mineralwool is an emerging material and not much research is yet available on its water filtering properties. This thesis suggests that mineralwool can be used as a pre-treatment step in the sanitation of polluted drains in rapidly urbanizing megacities.

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1 INTRODUCTION

India is recently facing a very rapid urbanization and industrialization. Growth of megacities beyond controllable limits makes it impossible for infrastructure development to cope with the demographic booming rate. Unplanned metropolitan expansion has severe impacts on the environment and on the provision of basic services such as sanitation. (CPCB, 2015; Delhi Government, 2016; Karn & Harada, 2001).

The cost of a sewerage system is usually more than four times that of on-site alternatives, making it unviable for developing countries to manage wastewater streams via centralised technologies. On-site sanitation techniques are typically installed in these areas, providing a satisfactory solution to communities lacking adequate sanitation. (Franceys, Pickford, & Reed, 1992; Wanko et al., 2016).

In the past decades, Delhi has been facing increasing domestic wastewater and industrial effluents discharges into the Yamuna river due to the large development of the city (R. S. Dubey, 2016). The river is primarily polluted from water ejections of urban drains, originally designed as storm water collectors and nowadays substituting the role of sewer systems (Smith, 2016).

This work fits in the context of the joint Indian and Dutch project "Local Treatment of Urban Sewage Streams for Healthy Reuse" (LOTUS^{HR}), providing a first step to the design of a biofilter to treat mixed water streams. The LOTUS^{HR} project poses its objectives on the reclamation of the Barapullah drain, one of the main canals of Delhi. The rejuvenation of the Yamuna river is addressed by preventing the diffusion of pollution flows from urban drains. A holistic approach to sanitation is pursued, combining the removal of contaminants with a resource recovery aim, in the optics of environmental impact mitigation and provision of adequate sanitary conditions within the urban area (Indian Institute of Technology Delhi, 2018; NIOO-KNAW, 2018; Press Information Bureau, 2018; Singh, 2018).

The pollution loads reaching the Yamuna river are diluted by heavy rains during the Monsoon period, mitigating environmental and sanitary impacts (Mandal, Upadhyay, & Hasan, 2010; Upadhyay, Dasgupta, Hasan, & Upadhyay, 2011). The biofilter was therefore intended to address the non-Monsoon period, when it is most needed.

Hydrophilic mineralwool blocks were identified as a promising water filtering medium due to their high absorbing capacity, high contact surface, low weight density and simplicity of replacement once saturation is reached (Loupasaki & Diamadopoulos, 2013; Wanko et al., 2016). This research was conducted between the 4th January and 9th February 2018 in New Delhi, assessing the nutrient and heavy metal removal potential of mineralwool blocks, using Barapullah water as feed.

1.1 RESEARCH BACKGROUND

1.1.1 Project background

New Delhi is the city with the highest demographic expansion and rapid urbanization of North India, requiring increasing amounts of clean water to satisfy its residents necessities. The Yamuna river is currently the main source of water for civil purposes, with a daily supply of 375 Million Gallons per Day (MGD). Irrigation and industry are largely dependent on the river, too. (Delhi Government, 2016; Mandal et al., 2010). This already significant water abstraction is only estimated to increase due to the steady population growth, further limiting the ability of the river to dilute the levels of solid waste and effluents released into it (University of Virginia, 2018).

A monitoring study carried out by the Central Pollution Control Board (CPCB) of India revealed that the stretch running across Delhi accounts for around 70% of the overall pollution load, in spite of its extension being only 2% of the total river length (CPCB, 2015). The abrupt reduction in water quality causes environmental and public health issues, contributing to the difficulty in matching water consumption and resource availability (R. S. Dubey, 2016).

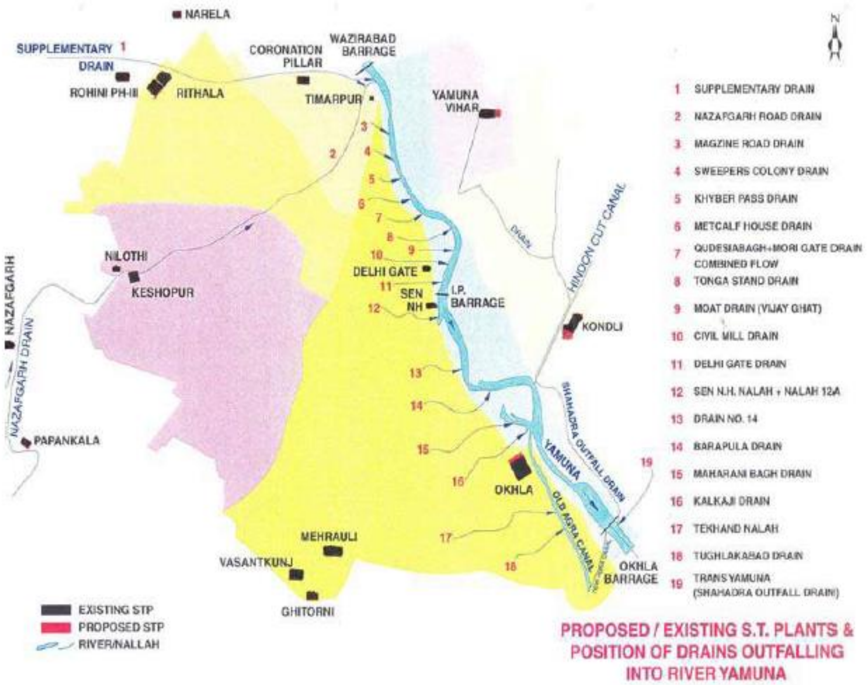

Figure 1: Proposed and existing STPs and position of drains outfalling into river Yamuna (Smith, 2016)

Twenty-two run-off drains contribute to the total urban effluent discharge into the river; of these eighteen have a direct injection outlet, as shown in Figure 1 (CPCB, 2015; Smith, 2016). The sewage treatment capacity of New Delhi is insufficient, covering around 67% of the required flow. The remaining raw wastewater overflows in the canals, either due to incomplete coverage by sewers or because of the partial exploitation of available treatment facilities (Delhi Government, 2016). The drains also serve as receiving bodies for numerous untreated industrial effluents (R. S. Dubey, 2016). Due to these circumstances, they are effectively transformed into open sewers, polluting the Yamuna with their discharge.

The New Delhi government resolved to tackle this issue by initiating several programs, ranging from improving the sewer network to cleaning the eighteen canals outfalling directly into the Yamuna river (Delhi Government, 2016; Delhi Jal Board, 2010; Smith, 2016). The Barapullah drain has been identified by the Delhi Development Authority (DDA) and the Indian Department of Biotechnology (DBT) as the most suitable for the set-up of an on-site experimental testing lab, as part of the "Local Treatment of Urban Streams for Healthy Reuse" scheme. LOTUS^{HR} is a research project aiming to demonstrate that producing water, nutrients and energy is possible from the Barapullah drain wastewater, while providing a show case on how to reduce pollution of the Yamuna river. Proven methods for cleaning the drain water are compared with new de-centralised technologies under development in the project facilities, striving to identify the best synergy of alternatives to suit the local context. (Press Information Bureau, 2018; Singh, 2018).

1.1.2 Mineralwool Biofilter

This thesis wants to pose the basis for the development of a modular removable biofilter, to be placed at several locations along the Barapullah in order to improve the water quality already within the urban area. The presence of sewage in the drainage system, in fact, other than causing environmental problems when released into the Yamuna river, is also a health hazard for the population. Houses situated in proximity of the major drains in Delhi started facing problems of corrosion of air conditioning equipment. This indicates high concentrations of SO_2 gas, irritating for humans and generated by the presence of bio-waste in the canals (Jaiswal, 2017). Other issues, such as pathogens and heavy metals contaminations, are also spread via inhalation of fumes or direct contact with the liquid waste.

The parameters that can affect the performance of a biofilter are the characteristics of filter media, hydraulic and organic loading rate, and filter backwash techniques (Chaudhary, Vigneswaran, Ngo, Shim, & Moon, 2003). In this research hydrophilic mineralwool was evaluated as a filter media as a first consideration in the biofilter design process.

Mineralwool was selected for its high porosity and surface area. These characteristics would favour contact of the wastewater with the biofilm, enhancing matter exchanges and thus removals. Additionally, the saturated water content of mineralwool was found to be twice as high as that of other granular media, such as sand. A large water retention capacity is hence observed, determining a positive influence on the hydraulic residence time inside the filter. The consequent increase in contact time between wastewater and the filter media will favour reactive transfer and improve the filtration performance. Mineralwool is also thought to have a slow degradation rate, thanks to the essentially mineral composition of the material. (Wanko et al., 2016).

Other materials exist with similar characteristics of porosity, surface area, availability and price. Loupasaki and Diamadopoulos compared them in several attached growth systems and a constructed wetland (CW) for the treatment of raw municipal wastewater, concluding that mineralwool and CW were the most effective systems. Unlike other technologies, moreover, compact filters and CW did not require any pre-treatment, eliminating the issue of primary sludge disposal. (Loupasaki & Diamadopoulos, 2013).

The climate of the Delhi region is of semiarid type with three defined seasons, being winter, summer, and monsoon. The latter spans from June to September and accounts for 87% of the annual rainfall recorded in the Delhi region. The water quality of the drains and the Yamuna river shows a considerable variation over the year. This is due to the dilution of the waste effluents by the storm-water flow which replenishes the riverbeds during the monsoon season. (Mandal et al., 2010; Upadhyay et al., 2011). The environmental and health impacts are therefore mitigated. The biofilter is intended to be employed during summer and winter periods in Delhi, when it is considered to be most necessary. The reduced flow, moreover, would be beneficial for the pollutants removal efficiencies by increasing the residence time within the filter.

1.2 RESEARCH QUESTIONS

The aim of the research is to evaluate hydrophilic mineralwool as a bio-filtering medium for cleaning the Barapullah drain water during the non-Monsoon season. Nutrients and heavy metals removals are assessed.

1. To what extent is mineralwool reducing the organic load of the water collected in the Barapullah drain?
2. What is the contribution of biological activity to the overall removal efficiencies of nutrients and heavy metals?
3. Are heavy metals removed when filtered through hydrophilic mineralwool blocks?
4. How does the filter’s retention time influence biofilm formation on mineralwool?
5. Is it possible to determine a minimum filter length?
    a. Is a clear nutrients conversion front observed within the filter?

2 METHODOLOGY

The research was conducted in New Delhi between the 4th January and the 9th February 2018, comparing the performance of four mineralwool filters. These were operated at ambient environmental conditions in a laboratory on the banks of the Barapullah and water from the drain was continuously fed to the filters from tanks refilled every other day. Grab samples of influent and effluent streams were regularly analysed to evaluate the removal efficiencies of nutrients in the wastewater.

2.1 SET UP

Three filters were set up as shown in Figures 2 and 3 below, by placing mineralwool blocks in a water-tight tub of rectangular base 75x18 cm. A height of 11 cm was reached, for a total working volume of around 15L. Drainblocks BV supplied the mineralwool blocks. A uniform mixture of two different block sizes was used, obtained by adding cubic blocks of 1x1x1 cm for one third of the volume and 2x2x2 cm blocks for the remaining two thirds.

Figure 2: Mineralwool filter set up

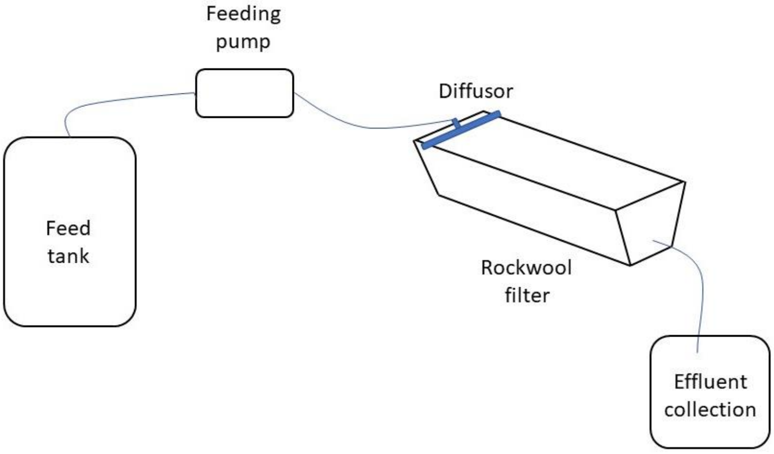

Figure 3: Set up schematics of the mineralwool filters

The mineralwool blocks were drenched with 15L of Barapullah water for each filter, letting the excess water flow out. The filters were then set running in a continuous mode, preventing interruptions for the rest of the research period. A pump ensured continuous feeding from a tank refilled with water directly taken from the Barapullah drain, outside the laboratory. The pump was chosen such that low flows could be attained and maintained over long operational periods. A diffusor was initially installed to ensure the influent would be homogeneously distributed over the side of the reactor; however it was later removed due to the low flow employed and the consequent lack of pressure which prevented it from well functioning. An effluent flow was obtained by gravity, guaranteed by placing the collection tank on a lower plane compared to the filter tub. A stirrer would have been necessary to prevent solids from settling between consequent tank refils; unfortunately though, this was not available.

Temperature and pH were monitored when possible, but not controlled. The filters were placed close to each other, to create comparable environmental conditions in each of them.

An identical filter to the aforementioned tests had been set up on the 6th October 2017 for a similar research topic. By the 15th January 2018, when the other filters were started, a biofilm layer had stably formed on its mineralwool blocks. This biofilter was running under a constant flow of 10 L/d. One of the new filters was hence set to run at the same hydraulic retention time (HRT) of 1.5 days, in order to compare the removals attained by either bare mineralwool or blocks on which biomass had time to establish. The other two reactors were operated at 7.5 L/d and 5 L/d to test the effects of different retention times on biofilm formation on mineralwool. The HRT's of the other two filters were hence 2 and 3 days, respectively.

2.2 WATER QUALITY AND FILTERS MONITORING

The efficiency of mineralwool as a filtering material was assessed by carrying out repeated analysis on the water quality of the influent and effluents to the various reactors. Grab samples were collected from the fresh effluent lines of the filters and from the feeding tanks. On the 30th January and 6th February, samples at intermediate levels throughout the length of the biofilter were taken by means of syringes.

The parameters to be monitored were selected as being the following, according to the WHO guidelines on wastewater, excreta and grey water reuse (World Health Organization, 2006).

- TSS
- VSS
- COD
- BOD_3
- TKN
- NH_3-N
- NO_3
- PO_4-P
- Temperature
- DO
- pH
- Heavy metals
    - Cadmium
    - Chromium
    - Cobalt
    - Lead
    - Nickel
    - Zinc

The TKN machine, unfortunately, had broken down, hence no measurements could be taken.

The BOD_3, COD, NH_3-N, NO_3 and PO_4-P analysis were all carried out according to the IITD standard procedure, as described in the IITD Waste Treatment Lab manual. A Cecil Aquarius spectrophotometer was used to determine the concentrations from the absorbance values.

TSS were determined by vacuum-filtering the grab samples onto 1 µm Axiva glass-fiber filters, which had previously been dried 2 hours in the oven at 105°C and whose empty weight had been recorded. The filters were then kept again in the oven at 105°C overnight. The difference between the new weight and the empty weight would provide the TSS value. The filters were then placed in the muffle furnace for 2 hours at 500°C to provide the VSS values. The remaining filtered water was sent to the lab to be analysed for heavy metals.

Whenever available, the EC, TDS, temperature and pH Hanna multiprobes were used to monitor the filters, together with the proODO Dissolved Oxygen probe.

2.3 ERROR DETERMINATION AND DATA SELECTION

Measurements were carried out twice to obtain any required valued. The average of the duplicates was then used for the interpretation of the results.

Random errors were calculated as $e_i = y_i - \bar{y}$, allowing to spot outliers and providing an indication on the validity of the results obtained. In this case, where only duplicates were present, standard deviation values coincided with the modulus of the random error, as shown below.

Variance σ_e^2 is defined as:

$$\sigma_e^2 = \frac{1}{m}\sum_{i=1}^{m} e_i^2$$

Where m = number of values; e_i is the random error of the ith value.

Moreover, the standard deviation is $\sigma_e = \sqrt{\sigma_e^2}$.

In the case of duplicate measurements, the distance from the mean will be the same for both values, implying equal random errors. It follows:

$$\sigma_e^2 = \frac{1}{2}(e_1^2 + e_2^2) = \frac{2e_i^2}{2} = e_i^2$$

Hence, the standard deviation for this case is:

$$\sigma_e = \sqrt{\sigma_e^2} = \sqrt{e_i^2} = |e_i|$$

■

Error propagation was considered when dealing with indirect measurements, i.e. values calculated on the basis of directly measured ones. Given the variances σ_x^2 and σ_y^2 of two direct measurements x and y, and an indirect value $q = g(x, y)$, the variance σ_q^2 of q can be calculated as follows:

$$\sigma_q^2 = \left(\frac{\partial q}{\partial x}\right)^2 \cdot \sigma_x^2 + \left(\frac{\partial q}{\partial y}\right)^2 \cdot \sigma_y^2 + 2\left(\frac{\partial q}{\partial x}\right)\left(\frac{\partial q}{\partial y}\right) \cdot \sigma_{xy}$$

As an example, the variance for the efficiency of removal, $q = \frac{x-y}{x}$, was given by the following.

$$\sigma_q^2 = \left(\frac{y}{x^2}\right)^2 \cdot e_x^2 + \left(-\frac{1}{x}\right)^2 \cdot e_y^2 =$$

$$\sigma_q^2 = \frac{y^2}{x^4} \cdot e_x^2 + \frac{1}{x^2} \cdot e_y^2$$

With

x: Average influent concentration

y: Average effluent concentration

e_x and e_y: Random errors of the influent and effluent concentrations

The covariance σ_{xy} was null, as the influent and effluent concentrations measurements were independent variables.

The standard deviation σ was used to indicate the error in all the results reported in this thesis. Values exceeding a 30% margin of error were discarded, with exception of NH_3-N values for which the threshold was set to 40%.

3 RESULTS

3.1 WASTEWATER CHARACTERISATION

The values of the Barapullah wastewater characterization obtained during the fieldwork are reported in Appendix I.

3.2 FILTERS PERFORMANCE

The nutrients removal efficiencies of the different filters are reported in the figures below. Values with standard deviation σ larger than 30% were omitted, unless otherwise stated.

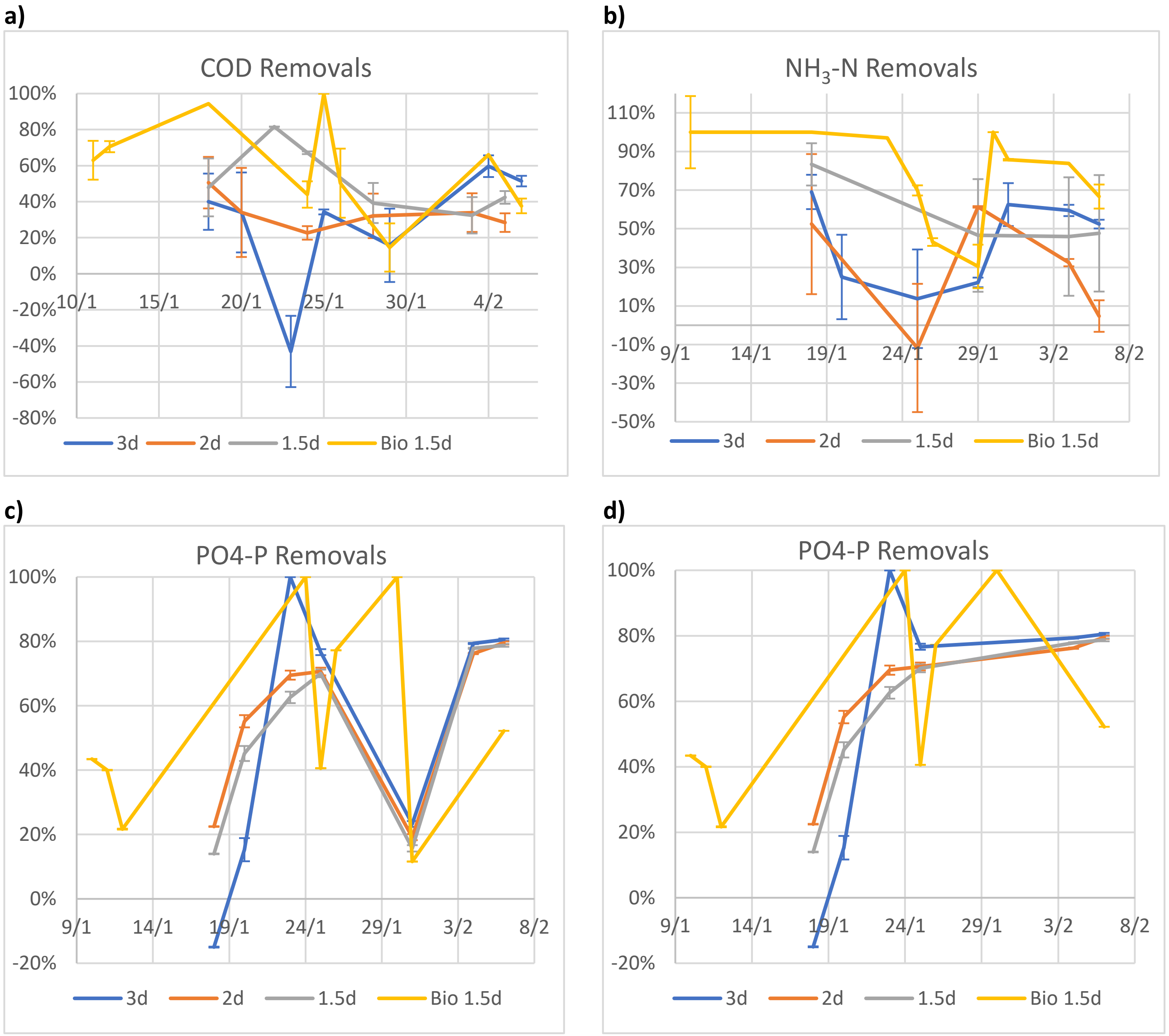

Figure 4: Nutrients removal efficiencies of the different filters

In Figure 4 a), the COD removals are depicted. Overall, the biofilter achieved the best performance, with an average efficiency of 60%, as reported in Table 1. The bare mineralwool filter running at an HRT of 1.5d started showing higher removals than the other two tests after four days. The margin of error, however, is such to create an overlap with the performance trends of the other two tests in which a mature biofilm was not yet present. Similarly, the large standard deviation does not allow to make clear distinctions between the trends reported by the bare mineralwool filters running at 2 and 3 days HRT.

Figure 4 b) above shows the removal efficiencies of ammoniacal nitrogen in the different filters. In this case, the maximum standard deviation threshold was set to 40%, keeping only values whose σ fell below this limit. The filter in which biological activity had developed achieved noticeably higher NH_3-N removals than the bare mineralwool tests. At first glance, the filter running at 1.5 days of HRT appears to be able to reach higher efficiencies. A closer look to the margin of error, however, reveals an overlap in the results from the three filters. Their performances are hence comparable, as much as such large standard deviations allow.

The phosphates removals of the filters are represented in Figure 4 c). All the filters without biological activity show similar trends, presenting almost identical efficiencies throughout the period of observation. The biofilter presents largely scattered values, reaching full efficiency on the 24th and 30th January, but touching as low as 22% in the beginning of the observation period. The removals of the biofilter oscillate above and below the trend of the other tests and seem more instable.

All filters show a fall in efficiency on the 31st January, suggesting irregular environmental conditions. Identifying this date as an outlier and correcting the graph accordingly gives the results depicted in Figure 4 d). A stable increase in removal efficiency can be noticed in the filters which were started up at the beginning of the fieldwork, as the observation period carried on.

In Table 1 below, a summary of the filters performance, in terms of average removal efficiencies, can be found. Table 2, instead, provides the average nutrients concentrations of the influent and effluent streams.

Table 1: Average Removal Efficiencies in the bio-filter and the mineralwool filters in which biofilm was yet not present, running at HRTs of 1.5, 2 and 3 days

Average Removal Efficiencies			
	COD	NH_3-N	PO_4-P
Bio 1.5 days	60%	81%	54%
HRT 1.5 days	44%	56%	52%
HRT 2 days	34%	28%	56%
HRT 3 days	27%	43%	51%

Table 2: Average nutrients concentrations in the filters' influent and effluent streams

Average Influent/Effluent Concentrations [mg/L]				
	COD	NH_3-N	NO_3-N	PO_4-P
Influent	264 ± 34	29 ± 4	0 ± 0	55 ± 1
Influent to Bio	297 ± 43	31 ± 4	0 ± 0	31 ± 1
Bio 1.5 days	180 ± 26	8 ± 1	15 ± 1	16 ± 0
HRT 1.5 days	172 ± 13	21 ± 4	2 ± 0	24 ± 1
HRT 2 days	196 ± 38	25 ± 4	0 ± 0	22 ± 1
HRT 3 days	174 ± 23	21 ± 3	0 ± 0	30 ± 0

3.2.1 Ammonia oxidation into nitrates.

Figure 5 below compares the concentrations of influent ammonia and effluent nitrates for the filters without biofilm. Initially, no nitrates can be found in the effluent of the filters without biofilm. However, ammoniacal nitrogen removals can be already observed during the initial phase of operation, as reported in Figure 4 b), four days after the set-up of the new filters. These could be associated to biomass growth. On the 6th February, 23 days from the set-up of the test, the bare mineralwool filter running at 1.5 days of HRT showed nitrates production for the first time, a possible indication of biological establishment on the filtering blocks. Unfortunately, the experiment was interrupted soon after and the biofilm development could not be monitored further.

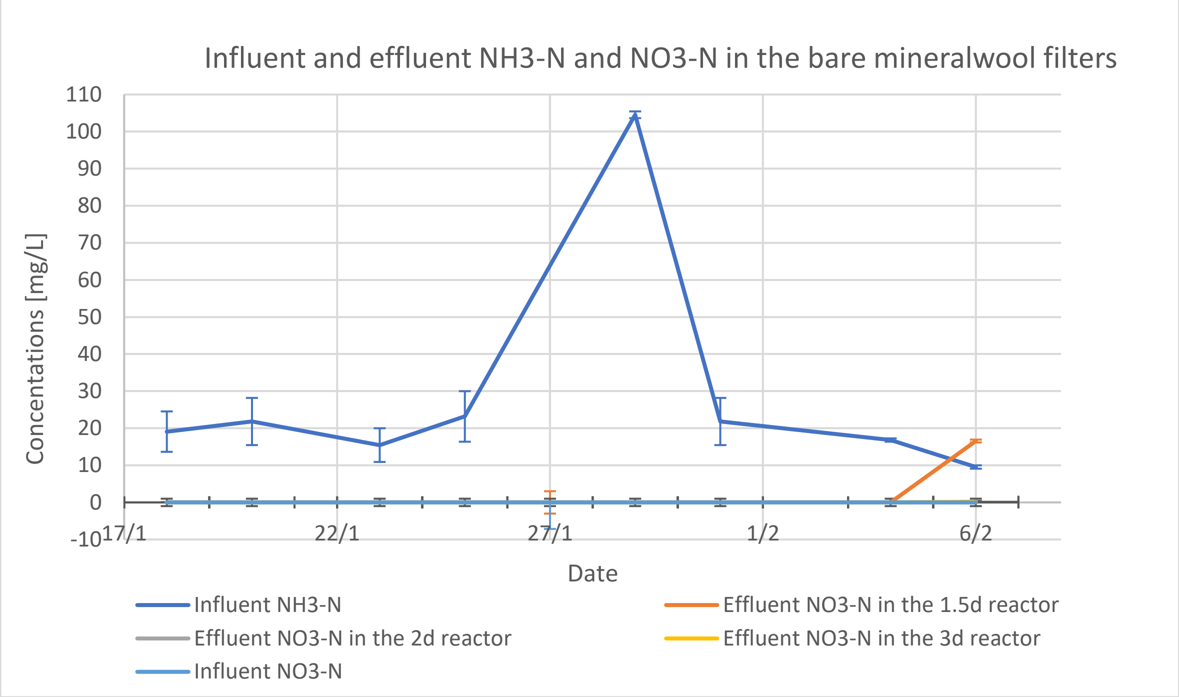

Figure 5: Influent NH3-N and NO3-N and effluent NO3-N in the filters without biofilm, running at HRTs of 1.5, 2 and 3 days

Similarly to Figure 5, Figure 6 below provides an overview of the influent and effluent concentrations of ammoniacal nitrogen (NH_3-N) and nitrate-nitrogen (NO_3-N) in the biofilter. It can be seen that nitrates are now present in the effluent, despite not being fed with the influent.

The 29th, 30th and 31st January show NH_3-N values higher than usual in both the influent and effluent streams. At the same time, NO_3-N levels in the effluent are rather low, especially when compared to those reported throughout the remaining period of observation. As already suggested when reporting phosphate removals, irregular environmental conditions must have occurred during those days. The error associated to the measurements carried out in those days is higher than usual, with standard deviation values of 16% on the 29th and 23% on the 30th January. However, a peak is still noticeable, even when considering the trend in minimum concentrations, supporting the first hypothesis of unbalanced surrounding conditions for the filters.

Excluding outliers, graphs in Figure 6 shows that ammonia was majorly removed from the effluent.

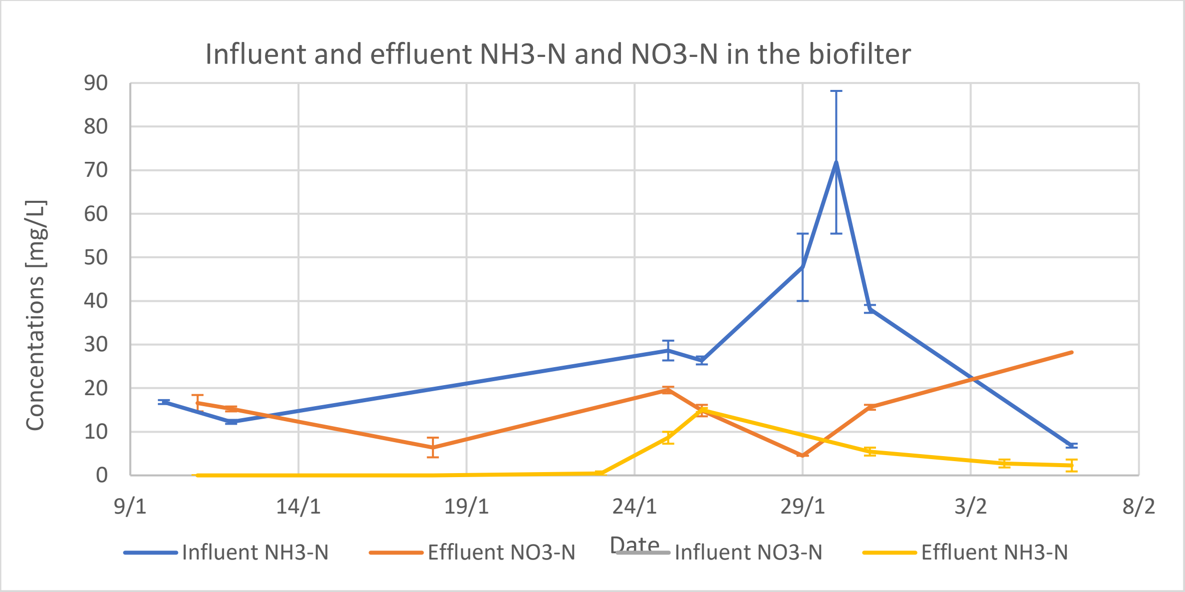

Figure 6: Nitrogen variations in the biofilter's influent and effluent. Influent and effluent ammoniacal nitrogen (NH_3-N) and Nitrate-nitrogen (NO_3-N) concentrations are reported.

3.3 SUSPENDED SOLIDS AND HEAVY METALS

Concentrations and removal efficiencies of suspended solids and heavy metals are fully reported in Appendix II. However, no results can be considered satisfactory due to the random variation of values.

3.4 NUTRIENTS CONCENTRATION GRADIENTS ALONG THE BIO-FILTER LENGTH.

The nutrient concentrations have been analysed along the length of the bio-filter on two days, the 30th January and the 6th February. The purpose was to identify any clear conversion front, as water passed through the filter. This would allow to detect a minimum length required to achieve target effluent limits when filtering the wastewater. Figures 7 and 8 below present the results.

Physical parameters, being pH, electrical conductivity, total dissolved solids (TDS) and temperature, were also analysed on all filters. All parameters appeared stable throughout the filter length, with only minor variations. Full results are reported in Appendix III.

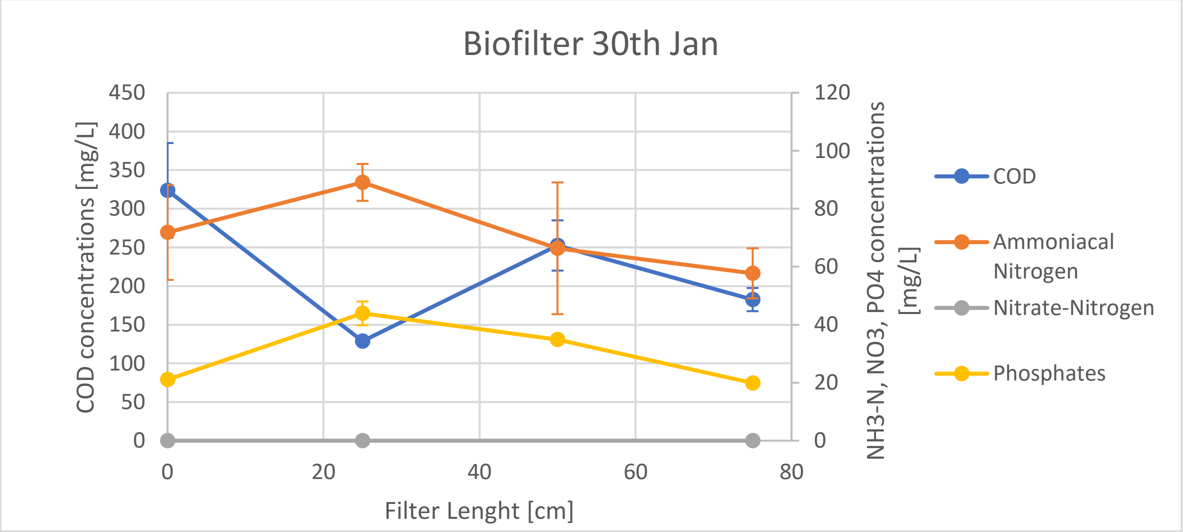

Figure 7: Variations in nutrients concentrations along the bio-filter length on the 30th January

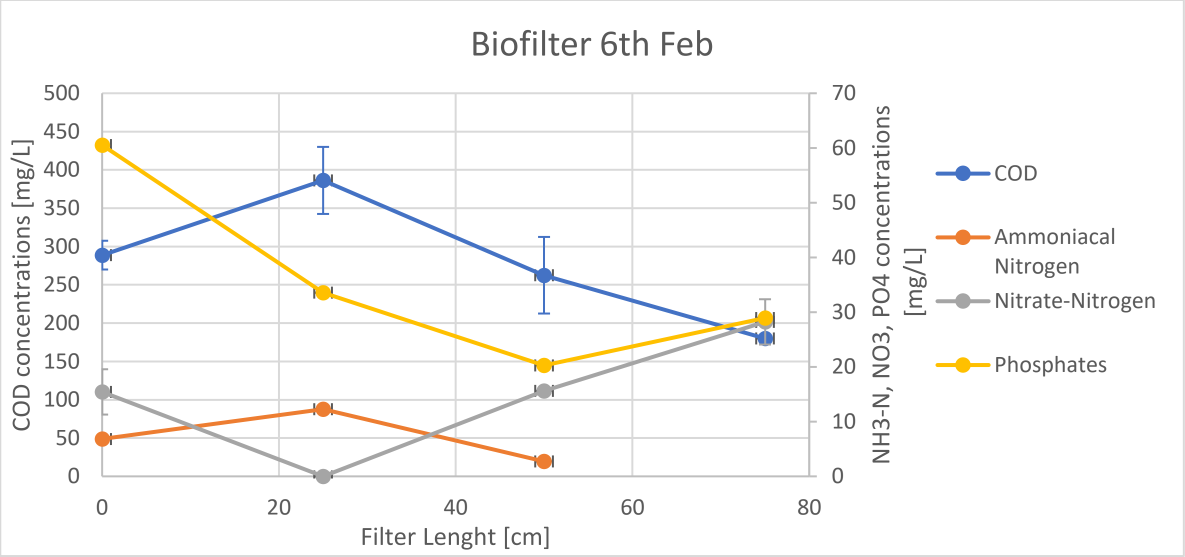

Figure 8: Variations in nutrients concentrations along the bio-filter length on the 6th February

4 DISCUSSION

4.1 MINERALWOOL FILTRATION AS PRE-TREATMENT OF THE DRAIN WATER

The average nutrients concentrations reported in Table 2 are still too high to be discharged in the environment and hence in the Yamuna river. The Indian legal effluent limits for sewage treatment plants are, in fact, as reported in Table 3 below.

Table 3: General Standards for Discharge of Environmental Pollutants (1986)
** The parameter limit has been updated with the "Environment (Protection) Amendment Rules, 2015"*
(Government of India, Ministry of Environment, 2015; Sawal, 1986)

Parameter	**Standard for Inland Surface Water**
*pH	6.5-9.0
Temperature	Shall not exceed 5°C above the receiving water temperature
*Biochemical Oxygen Demand mg/L Max.	10
*Chemical Oxygen Demand mg/L Max.	50
*Ammoniacal Nitrogen (as N) mg/L Max.	5
Nitrate Nitrogen mg/L	10
Dissolved Phosphates (as P) mg/L Max.	5

The mineralwool bio-filter carries out nitrification, lowering ammoniacal nitrogen to concentrations close to the legal discharge threshold. Nitrates, however, are produced, exceeding the limits.
Phosphates and COD are partially removed, but the mineralwool bio-filter alone is largely insufficient to meet the standards. Rather, it could be used as pre-treatment step in a multi-stage treatment scheme.
Post-treatment of the filter's effluent would be necessary as denitrification is not carried out. This may cause eutrophication problems in the receiving water body. Further biological removal of Nitrogen would be feasible as effluent COD concentration is around 8 times the residual nitrogen, in all the filters. A concurrent COD removal would take place. Phosphorus should then be tackled, for instance by inducing chemical precipitation. Unless recirculation or Sequence Batch Reactor (SBR) operation are possible, PAO's cannot be selected, making it impossible to carry out biological P removal.

4.2 BIOLOGICAL ACTIVITY

4.2.1 Bio-filtration attains higher COD removal

The bare mineralwool tests contribute to the removal of COD by physically filtering out part of the suspended solids (SS). To a certain extent, COD might also be taken up as substrate for the growth of heterotrophic microorganisms, which might have attached to the mineralwool blocks.

The main difference in COD removal efficiencies, however, seems to be due to biological activity. The biofilter, in which a mature biofilm was formed during the previous three months of operation, managed to achieve the highest removals.

The filter running at an HRT of 1.5 days seems to be performing better than the other two tests without biofilm. However, this might be due to the margin of error or to an effective positive influence of a shorter retention time on biofilm formation. No conclusions can be drawn.

4.2.2 Nitrification is the distinguishing factor in the filters' performances

The biofilter reaches the best performance in nitrogen removal, as shown in Figure 4b). This was attributed to the growth and activity of nitrifying microorganisms, as nitrates were found in the effluent, but not in the influent, as depicted in Figure 6. The remaining difference observed in the biofilter between influent ammoniacal nitrogen and nitrate-nitrogen can be attributed to biomass growth, partial oxidation into nitrites (NO_2^-) and residual ammonia concentrations in the effluent, also indicated by the non-fully efficient removals.

Comparing inflows and outflows of ammoniacal nitrogen, but also influent NH_3-N and effluent NO_3-N concentrations, in both Figures 5 and 6 suggests that the main factor determining a difference in the nitrogen removal efficiency of the filters is the ability to oxidise ammoniacal nitrogen into nitrates via the nitrification process. This consists of two steps: Nitritation, carried out by Ammonia Oxidising Bacteria (AOB), and Nitratation, carried out by Nitrite Oxidising Bacteria (NOB). The latter microorganisms depend upon the former for the provision of substrate. (U.S. Environmental Protection Agency, 2002).

It was only possible to test for NO_3, however analysing the presence of nitrites (NO_2) would have allowed to check if partial nitrification was occurring. Partial nitrification would indicate the necessity for a longer HRT in the biofilter, as nutrients were already sufficiently abundant in the incoming wastewater for biomass growth. Monitoring NO_2 concentrations in the bare mineralwool filters, on the other hand, could provide an indication on the progress of biofilm formation. Nitrite measurements could suggest whether AOB's are active, providing substrate to the NOB's and hence posing the base for nitratation, to reach complete nitrification.

The NO_3-N concentrations found on the 6th February (Figure 5) in the effluent of the bare mineralwool filter running with an HRT of 1.5 days could suggest that biomass had started its metabolic conversions. Being all other environmental conditions the same, a shorter retention time might have fostered biofilm development, as discussed later on in this report. Nitrite production was not encountered in the filters running at HRTs of 2 and 3 days. Unfortunately, the interruption of filter monitoring due to the end of the period of observation does not allow to compare to the successive days in order to draw any conclusion, leaving the possibility of a measurement error.

4.2.3 Phosphates removal does not rely on biological activity

Average removals calculated over the whole period of observation, shown in Table 1, do not indicate any difference between bare mineralwool and biofilter performances.

Trends reported in Figure 4 d) show a gradual improvement over the period of observation in the efficiency of the bare mineralwool filters. The bio-filter, on the other hand, presents scattered values, with removals ranging from 22% to 100%. On 23rd January a fully efficient removal is also found in the bare mineralwool filter running at an HRT of 3 days. This cannot be due to biological activity as not enough time had elapsed from the set-up moment. PAO's (Phosphorus Accumulating Organisms) would not have had the time, nor favourable conditions to develop. The enrichment of the PAO's population, in fact, requires an alternance of anaerobic and aerobic phases (Günther et al., 2009; Zeng, Van Loosdrecht, Yuan, & Keller, 2003), while the filters were operated continuously for this research. This suggests that the presence of biofilm is not increasing the efficiency and that the 100% removal points might be casual. Phosphorus removing microorganisms other than PAO's might be having an impact on the efficiencies. As suggested in the "Biological Phosphorus Removal" STOWA Report, other Poly-P organisms might be possible candidates to take this role, however this would require some deeper investigations to be confirmed for this case (Janssen, Meinema, & van der Roest, 2002).

An initial steady rise in efficiency is common to the three bare mineralwool reactors. This could suggest a stabilisation phase undergone by the filters. The biological filter, however, presents the same trend, despite having overcome the hypothetical stabilisation phase months earlier. Environmental conditions or variations in the wastewater are hence the most likely cause for this initial constant increase.

The phosphates removal in the filters could be due to several causes, for instance physical adsorption onto the mineralwool or chemical reaction of PO_4^{3-} with ions released by the blocks. Table 4 below shows the main composition of mineral wool. Other chemical elements such as Na, K and P compounds are present as well, although their abundance is much lower than Magnesium. According to Wanko et al. this mineral composition will have an influence on the interactions between mineralwool and the wastewater content. (Wanko et al., 2016).

Table 4: Atomic and mass composition of mineral wool main components (Wanko et al., 2016)

Element	O	Si	Al	Ca	Fe	Mg
Atom (%)	60.55	14.27	7.15	6.94	4.63	4.32
Weight %	42.78	17.70	8.52	12.29	11.42	4.63

Mg^{2+}, Ca^{2+} and K^+ are the most important counterions used in the charge neutralization of the polyphosphate chains, for them being polyanions (Günther et al., 2009). Their presence in the mineralwool composition might hence be beneficial to Poly-P microorganisms. Biological removal of P, however, does not seem feasible in the mineralwool biofilter, as alternating anaerobic and aerobic phases are of difficult implementation in the Barapullah drain.

Aluminium, Calcium and Iron salts are commonly used to drive chemical precipitation of phosphates in waste water (Metcalf & Eddy Inc., 2003). The presence of Al, Ca and Fe in mineralwool is reported in Table

4. Further research could be carried out to evaluate whether the interactions among PO_4^{3-} and the specific Al, Ca and Fe compounds composing the filtering medium might be triggering chemical P removal.

4.3 HRT INFLUENCES BIOFILM FORMATION, OTHER THAN COD AND NH_3-N REMOVALS

The graphs reported in Figure 4 a) and b), suggest that a shorter HRT fostered biofilm formation. The bare mineralwool filter running at an HRT of 1.5 days, in fact, achieved better COD and NH_3-N removals, while the initial efficiencies reported by all bare mineralwool filters were similar on the 18th January, i.e. the first day of analysis. In the case of COD removal, the margin of error has a smaller influence on the interpretation of the trend, as compared to NH_3-N.

The short HRT applied during this research is hypothesised to provide a selection pressure for the growth of attached biomass. Microorganisms which do not attach are flushed out of the mineralwool blocks, giving a competitive advantage to fixed microorganisms. (Caylet et al., 2011; Cresson, Carrère, Delgenès, & Bernet, 2006; Habouzit, Hamelin, Santa-Catalina, Steyer, & Bernet, 2014).

The different retention times considered in this research, on the other hand, do not seem to have distinct impacts on the phosphates removals (see Figure 4d). This lies in concordance with the independency of P removal from biological activity. Most likely, the minimum HRT here considered, i.e. 1.5 days, is larger or equal to the time required to reach the maximum removal of PO_4 (for instance due to saturation or having reached chemical equilibrium), after which no significant change occurs anymore.

4.4 FILTER LENGTH

A comparison of the results achieved on the 30th January and 6th February, presented in Figures 7 and 8, does not allow to make any conclusions. The graph points seem rather casual for all nutrients when the two days are compared, making it irrelevant to deduct any trend. It should be reminded, however, that irregular environmental conditions have been previously identified around the 30th January.

The bio-filter shows a better correlation between the nutrients removals and the filter length on the 6th February. Phosphates, COD and Ammoniacal nitrogen diminish proportionally to the length, while nitrate-nitrogen increases similarly. The minimum length, however, was not met yet within the 75 cm considered, as effluent concentrations were still above the limits for discharge into the environment.

4.5 ERROR

The margin of error of the measurements obtained during this research is very large. This is mainly due to a lack of resources, but also missed regular maintenance of equipment and some erroneous practices carried out in the lab. Both the accuracy and the precision of results are low, affected respectively by systematic errors and outliers and by random errors.

Error is given in this case by the cumulative contribution of the factors listed below, in addition to the normal error margin observed due to instrumentation, human and random errors.

- Reuse of disposable material, such as cuvettes, pipette tips, or gloves
- Hand washing of glassware and other equipment
- Contamination of the soap due to reused sponges in the same open container
- Preparing analysis reagents in the lab, rather than using test kits
- Inaccurate pipettes
- Pipette tips not always compatible with the pipette
- Machinery or probes not calibrated.
- Working problems of the instrumentation

- RO water often used interchangeably with drinking water

Data selection has been carried out as described in the Method section, however, standard deviations of up to 40% are still reported. Outliers were removed. Systematic errors, due for instance to improper instrument calibration, affect nevertheless the overall data set.

The accuracy in the interpretation of the results is limited by the high margin of error. Trends identified in the Discussion section should hence be regarded critically and can only provide an indication of the expected outcomes.

4.5.1 Suspended solids

The absence of a stirrer made so that settleable solids would not be fed to the mineralwool filters, sinking in the influent tank between two consecutive refills.

Negative values were obtained for VSS concentrations. This was probably due to the presence of organic matter in the glass-fiber filters, which burnt in the muffle furnace returning weights lower than the ones reported for the same initial empty filters.

5 CONCLUSIONS

The analysis carried out during this research were subject to a high margin of error. Nonetheless, the mineralwool filter on which biofilm was given enough time to develop was found to be the most effective in removing COD and Ammoniacal nitrogen concentrations. Phosphorus removal, on the other hand, was shown to be scarcely dependent on biological activity, suggesting physical-chemical methods of removal.

A minimum filter length could not be detected, as it exceeded the considered one. A longer filtration length could have been particularly relevant for P removal due to the interaction between compounds released by the mineralwool and PO_4^{3-} ions, as discussed. If the trends reported in Figure 8 on the 6th February had to be confirmed, a longer filter length would increase the removal of COD and NH_3-N, too.

Heavy metals results unfortunately did not lead to relevant conclusions. On the other hand, the HRT was found to create a selective pressure on attached biomass, favouring a swift growth of biofilm on the mineralwool blocks.

Hydrophilic mineralwool managed to attain average removal efficiencies of 60% for COD, 81% for NH_3-N and 54% for PO_4-P in the case when a biofilm was present. The biofilter could be used a pre-treatment for the Barapullah drain water, in in the optics of step-wise sanitation as already considered by the LOTUS^{HR} project.

6 RECOMMENDATIONS

6.1 IMPROVEMENTS AND ERROR MANAGEMENT

- Some improvements could be made to the set-up.
    - A stirrer could be added to the influent tank, preventing solids from settling before being fed to the filter. Neither clogging nor actual TSS/VSS removals can be evaluated in the current conditions.
    - An adequate diffusor could be attached to the feeding pipe, simulating uniform flow from the drain and preventing preferential flows within the filter.

    - Due to time constrain, it was only possible to evaluate the efficiency of mineralwool filtration arranged in a wetland disposition. It would be interesting to compare the performances of different biofilter designs. It would be recommended to adjust the thickness of the filtration layers, the size of the mineralwool cubes and, in a more advanced stage, try to insert aeration pipes in order to enhance the filtration efficiency. These parameters, in fact, are reported to have a significant impact on the filter's effectiveness. (Wanko et al., 2016).

- Ensuring the availability of a working DO, pH and T probe would allow a better monitoring of the filters.
- Being able to measure NO_2 would provide an indication upon the nitrification state and the possible necessity of a longer HRT in the biofilter.

- Error could have been reduced by:
    - Keeping samples in a cooling box during the return journey from the Barapullah drain site to the IITD lab. Alternatively, carrying out the analysis in situ, particularly when microbial activity is to be expected.
    - Washing the analysis equipment in a lab glassware washer or using test kits.
    - Making sure the machinery is regularly calibrated and well maintained.

6.2 FUTURE RESEARCH

- It would be interesting to continue monitoring the filters set up during this fieldwork after a biofilm layer has been formed on the bare mineralwool. Further research could assess the effects of different retention times upon the removal performances, once biological activity starts contributing to the overall efficiency. Running new bare mineralwool filters at HRTs shorter than 1.5 days, the minimum considered in this thesis, would also be interesting when evaluating the effects on biofilm formation.

- Phosphorus removal mechanisms could be investigated deeper. Analysis of the chemical composition of mineralwool and of the specific phosphate compounds present in the Barapullah wastewater would help to estimate the ionic equilibrium in the filter, identifying possible precipitate formation. Affinity of phosphates with the rock wool block could also be studied to understand adsorption mechanisms.

6.3 PRACTICALITIES

- The mineralwool blocks would eventually reach their saturation level, due to adsorption of contaminants and growth of biomass within the pores and over the whole surface area. Disposal of this waste material is hence an issue to be further investigated, analysing the overall scenario and the interconnections between water treatment and solid waste handling.

- The biofilter performance could be evaluated in comparison to a wetland design. A synergy between biofiltration and phytodepuration might reveal positive outcomes.

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8 APPENDIX I

Table 5:Characterisation of the water taken from the Barapullah drain during the period of observation, used as influent for the bare mineralwool reactors running at HRTs of 1.5, 2 and 3 days, respectively.

DATE	Influent																																
	T	DO	pH	TDS	Filtered volume	empty filter weight	Filter with solids	TSS	COD					BOD			NH3-N					NO3					NO3-N		PO4-P				
									Min	Max	Avg	Error	% Err	Min	Max	Avg	Min	Max	Avg	Error	% Err	Min	Max	Avg	Error	% Err	Conc	Err	Min	Max	Avg	Error	% Err
	°C	mgO2/L	-	ppm	L	g	g	g/L	mg/L	mg/L	mg/L					mgO2/L	mg/L	mg/L	mg/L			mg/L	mg/L	mg/L			mg/L		mg/L	mg/L	mg/L		
18/01/18									250	413	331	81	25%				14	25	19	5	29%	0	0	0	0	#DIV/0!	0	0	71	72	72	0	0%
19/01/18																																	
20/01/18					0,04	0,2211	0,223	0,05	40	78	59	19	32%				15	28	22	6	29%	0	0	0	0	#DIV/0!	0	0	50	55	53	2	4%
21/01/18																																	
22/01/18																																	
23/01/18	23,0	6,2	7,38		0,03	0,2289	0,2302	0,04	133	175	154	21	14%			380	11	20	15	5	29%	0	0	0	0	#DIV/0!	0	0	48	53	50	2	5%
24/01/18																																	
25/01/18	20,8	6,50	7,58		0,02	0,2165	0,2201	0,16	410	428	419	9	2%			750	16	30	23	7	29%	0	0	0	0	#DIV/0!	0	0	58	63	61	2	4%
26/01/18																																	
27/01/18	17,40	6,60	7,62	512												240						0	63	0	32	#DIV/0!	0	7					
28/01/18																																	
29/01/18	25,00		7,71		0,05	0,2236	0,2283	0,10	203	288	245	43	17%				104	105	105	1	1%	0	0	0	0	#DIV/0!	0	0					
30/01/18	25,00		7,42																														
31/01/18	19,00		7,41	0,70 ppt	0,05	0,2207	0,2269	0,13									15	28	22	6		0	0	0			0	0	15	16	15	0	1%
04/02/18	25,00		7,32						285	385	335	50	15%				16	17	17	0	3%	0	0	0	0	#DIV/0!	0	0	66	67	66	1	1%
05/02/18																																	
06/02/18	25		7,43						288	320	304	16	5%				9	10	10	0	5%	0	0	0	0	#DIV/0!	0	0	69	71	70	1	2%
07/02/18																																	
										Average	**264**	**34**						**Average**	**29**	**4**			**Average**	**0**	**0**					**Average**	**55**	**1**	

Table 6: Characterisation of the water taken from the Barapullah drain during the period of observation, used as influent for the biofilter. The cells in red represent values with standard deviations higher than 30%, hence discarded from the results.

DATE	Influent to Bio																									
	T	DO	pH	COD					BOD			NH4					NO3					PO4-P				
				Min	Max	Avg	Error	% Err	Min	Max	Avg	Min	Max	Avg	Error	% Err	Min	Max	Avg	Error	% Err	Min	Max	Avg	Error	% Err
	°C	mgO2/L	-	mg/L	mg/L	mg/L					mgO2/L	mg/L	mg/L	mg/L			mg/L	mg/L	mg/L			mg/L	mg/L	mg/L		
10/01/18												16	17	17	0	3%						24	27	26	2	6%
11/01/18				443	720	581	139	24%				0	5	5	2	50%	0	0	0	0	#DIV/0!	24	29	26	2	8%
12/01/18		5,1		155	168	161	6	4%				12	13	12	0	4%	0	0	0	0	#DIV/0!	22	25	23	2	6%
24/01/18				198	240	219	21	10%														19	19	19	0	0%
25/01/18	24,3		7,86	160	165	163	3	2%				26	31	29	2	8%	0	0	0	0	#DIV/0!	21	22	21	0	1%
26/01/18	23,9	3,30	6,59	100	435	435	168	39%				25	27	26	1	3%	0	0	0	0	#DIV/0!	67	68	67	0	0%
27/01/18		4,95																								
29/01/18	25,0		7,93	293	393	343	50	15%				40	55	48	8	16%	0	0	0	0	#DIV/0!					
30/01/18	25,0		7,42	263	385	324	61	19%				55	88	72	16	23%	0	0	0	0	#DIV/0!	21	21	21	0	1%
31/01/18												37	39	38	1	2%	0	0	0	0	#DIV/0!	16	16	16	0	2%
06/02/18	25,0		7,66	270	308	289	19	6%				6	7	7	0	7%	50	87	50	18	37%	60	61	61	1	1%
					Average	**297**	**43**						**Average**	**31**	**4**			**Average**	**0**	**0**			**Average**	**31**	**1**	

9 APPENDIX II

The following tables report the concentrations of heavy metals and suspended solids in the influent and effluent streams of the filter. Lead abundances (Pb 206, Pb 207 and Pb 208) were analysed, too, and found to be below detectable limits in every sample.

Table 7: Heavy metals, Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) in the influent to the bare mineralwool filters

DATE	Influent										
	52 Cr	59 Co	60 Ni	66 Zn	111 Cd	Filtered volume	Empty filter weight	Wt after oven 105°C	Wt after muffle furnace 500°C	TSS	VSS
	[ppb]	[ppb]	[ppb]	[ppb]	[ppb]	[mL]	[g]	[g]	[g]	[g/L]	[g/L]
20/01/18	5,1	0,1	3,0	293,4	0,1	40	0,221	0,223	0,219	0,05	-0,10
23/01/18	4,8	0,0	3,3	210,0	0,1	30	0,229	0,230	0,227	0,04	-0,12
25/01/18	0,9	0,0	3,2	118,1	0,0	22	0,217	0,220	0,214	0,16	-0,26
29/01/18	1,4	0,0	2,1	236,7	0,0	47	0,224	0,228	0,223	0,10	-0,12
31/01/18	3,9	0,0	7,5	76,6	0,0	47	0,221	0,227	0,220	0,13	-0,16

Table 8: Heavy metals, TSS and VSS in the influent to the biofilter

DATE	Influent to Bio										
	52 Cr	59 Co	60 Ni	66 Zn	111 Cd	Filtered volume	Empty filter weight	Wt after oven 105°C	Wt after muffle furnace 500°C	TSS	VSS
	[ppb]	[ppb]	[ppb]	[ppb]	[ppb]	[mL]	[g]	[g]	[g]	[g/L]	[g/L]
24/01/18	23,9	0,0	2,5	103,0	0,0	33	0,221	0,223	0,219	0,05	-0,12
25/01/18	0,7	0,0	2,6	184,5	0,0	35	0,212	0,212	0,209	0,01	-0,10
29/01/18	3,0	0,0	4,4	113,0	0,0	46	0,219	0,228	0,221	0,19	-0,15
31/01/18	5,8	0,0	2,9	254,4	0,0	45	0,221	0,226	0,218	0,12	-0,18

Table 9: Heavy metals, Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) in the effluent of the biofilter

DATE	Wetland Bio 10 L/d - Bio 1.5 days HRT																
	52 Cr [ppb]	59 Co [ppb]	60 Ni [ppb]	66 Zn [ppb]	111 Cd [ppb]	Filtered volume [mL]	Empty filter weight [g]	Wt after oven 105°C [g]	Wt after muffle furnace 500°C [g]	TSS [g/L]	VSS [g/L]	52 Cr Removal efficiency [%]	59 Co Removal efficiency [%]	60 Ni Removal efficiency [%]	66 Zn Removal efficiency [%]	111 Cd Removal efficiency [%]	TSS Removal efficiency [%]
24/01/18	6,4	0,0	5,1	201,7	0,0	37	0,226	0,227	0,224	0,02	-0,09	73%	#DIV/0!	-107%	-96%	#DIV/0!	58%
25/01/18	0,5	0,0	7,5	166,5	0,1	31	0,216	0,217	0,214	0,02	-0,11	34%	#DIV/0!	-189%	10%	#DIV/0!	-98%
29/01/18	9,9	0,0	4,0	182,5	0,1	46	0,222	0,224	0,220	0,04	-0,08	-229%	#DIV/0!	10%	-62%	#DIV/0!	77%
31/01/18	6,3	0,0	4,0	200,2	0,1	39	0,220	0,223	0,218	0,08	-0,14	-8%	#DIV/0!	-40%	21%	-200%	35%

Table 10: Heavy metals, TSS and VSS in the effluent to the filter running at 1.5 days of Hydraulic Retention Time (HRT)

DATE	Wetland 10 L/d - 1.5 days HRT																
	52 Cr [ppb]	59 Co [ppb]	60 Ni [ppb]	66 Zn [ppb]	111 Cd [ppb]	Filtered volume [mL]	Empty filter weight [g]	Wt after oven 105°C [g]	Wt after muffle furnace 500°C [g]	TSS [g/L]	VSS [g/L]	52 Cr Removal efficienc [%]	59 Co Removal efficienc [%]	60 Ni Removal efficienc [%]	66 Zn Removal efficienc [%]	111 Cd Removal efficienc [%]	TSS Removal efficienc [%]
23/01/18	1,4	0,0	5,5	51,4	0,1	28	0,221	0,221	0,218	0,01	-0,12	70%	#DIV/0!	-67%	76%	20%	84%
25/01/18	0,5	0,0	3,1	83,5	0,0	30	0,212	0,212	0,209	-0,01	-0,08	38%	#DIV/0!	3%	29%	#DIV/0!	106%
29/01/18	5,4	0,0	2,6	126,8	0,1	48	0,221	0,225	0,222	0,09	-0,07	-277%	#DIV/0!	-25%	46%	#DIV/0!	10%
31/01/18	3,5	0,0	4,2	87,3	0,0	42	0,227	0,227	0,223	0,01	-0,09	9%	#DIV/0!	44%	-14%	#DIV/0!	93%

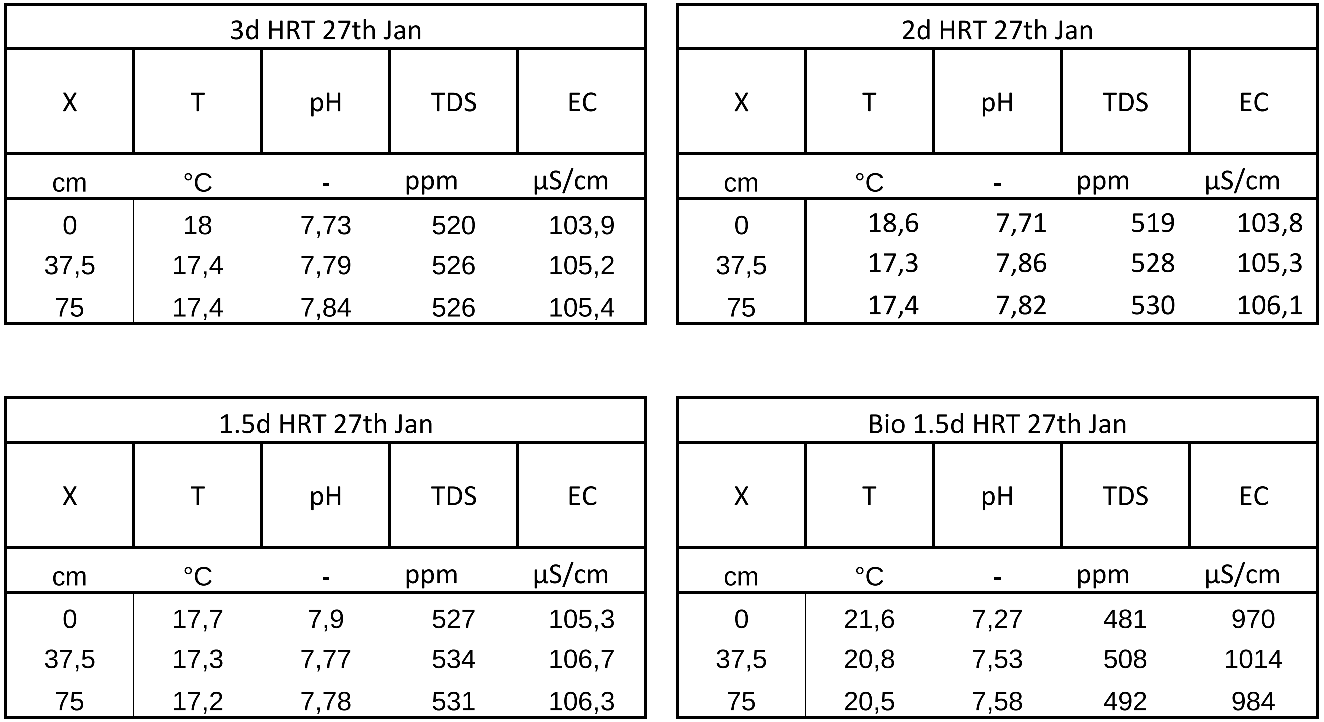
Table 11: Heavy metals, TSS and VSS in the effluent to the filter running at 2 days of HRT

DATE	Wetland 7.5 L/d - 2 days HRT																
	52 Cr	59 Co	60 Ni	66 Zn	111 Cd	Filtered volume	Empty filter weight	Wt after oven 105°C	Wt after muffle furnace 500°C	TSS	VSS	52 Cr Removal efficiency	59 Co Removal efficiency	60 Ni Removal efficiency	66 Zn Removal efficiency	111 Cd Removal efficiency	TSS Removal efficiency
	[ppb]	[ppb]	[ppb]	[ppb]	[ppb]	[mL]	[g]	[g]	[g]	[g/L]	[g/L]	[%]	[%]	[%]	[%]	[%]	[%]
23/01/18	0,6	0,0	2,9	42,2	0,2	37	0,224	0,225	0,221	0,01	-0,09	87%	#DIV/0!	10%	80%	-50%	81%
25/01/18	2,7	0,0	2,3	55,6	0,0	27	0,223	0,225	0,222	0,07	-0,10	-202%	#DIV/0!	28%	53%	#DIV/0!	57%
29/01/18	10,6	0,0	2,1	67,6	0,1	47	0,221	0,222	0,220	0,02	-0,06	-635%	#DIV/0!	0%	71%	#DIV/0!	81%
31/01/18	0,9	0,0	2,8	115,5	<0.000	44	0,220	0,224	0,220	0,08	-0,08	77%	#DIV/0!	63%	-51%	#VALUE!	41%

Table 12: Heavy metals, TSS and VSS in the effluent to the filter running at 3 days of HRT

DATE	Wetland 5 L/d - 3days HRT																
	52 Cr	59 Co	60 Ni	66 Zn	111 Cd	Filtered volume	Empty filter weight	Wt after oven 105°C	Wt after muffle furnace 500°C	TSS	VSS	52 Cr Removal efficiency	59 Co Removal efficiency	60 Ni Removal efficienc	66 Zn Removal efficiency	111 Cd Removal efficiency	TSS Removal efficiency
	[ppb]	[ppb]	[ppb]	[ppb]	[ppb]	[mL]	[g]	[g]	[g]	[g/L]	[g/L]	[%]	[%]	[%]	[%]	[%]	[%]
20/01/18	7,5	0,0	2,8	155,5	0,1	45	0,223	0,224	0,220	0,02	-0,09	-48%	100%	7%	47%	33%	49%
29/01/18	0,7	0,0	2,8	75,8	0,1	47	0,216	0,217	0,215	0,02	-0,06	50%	#DIV/0!	-36%	68%	#DIV/0!	79%
31/01/18	2,8	0,0	3,3	75,6	0,0	39	0,222	0,228	0,224	0,15	-0,12	28%	#DIV/0!	56%	1%	#DIV/0!	-15%

10 APPENDIX III



3d HRT 27th Jan				
X	T	pH	TDS	EC
cm	°C	-	ppm	µS/cm
0	18	7,73	520	103,9
37,5	17,4	7,79	526	105,2
75	17,4	7,84	526	105,4

2d HRT 27th Jan				
X	T	pH	TDS	EC
cm	°C	-	ppm	µS/cm
0	18,6	7,71	519	103,8
37,5	17,3	7,86	528	105,3
75	17,4	7,82	530	106,1

1.5d HRT 27th Jan				
X	T	pH	TDS	EC
cm	°C	-	ppm	µS/cm
0	17,7	7,9	527	105,3
37,5	17,3	7,77	534	106,7
75	17,2	7,78	531	106,3

Bio 1.5d HRT 27th Jan				
X	T	pH	TDS	EC
cm	°C	-	ppm	µS/cm
0	21,6	7,27	481	970
37,5	20,8	7,53	508	1014
75	20,5	7,58	492	984

Figure 9: Tables indicating the physical parameters measured in the biofilter on the 27th January 2018

3d HRT 31st Jan				
X	T	pH	TDS	EC
cm	°C	-	ppt	mS/cm
0	20,2	7,37	0,37	1,29
37,5	18,8	7,47	0,67	1,35
75	18,7	7,49	0,68	1,35

2d HRT 31st Jan				
X	T	pH	TDS	EC
cm	°C	-	ppt	mS/cm
0	18,7	7,49	0,66	1,33
37,5	18,3	7,52	0,66	1,32
75	18,1	7,54	0,66	1,32

1.5d HRT 31st Jan				
X	T	pH	TDS	EC
cm	°C	-	ppt	mS/cm
0	19,5	7,47	0,67	1,33
37,5	18,7	7,52	0,67	1,36
75	18,5	7,57	0,67	1,33

Bio 1.5d HRT 31st Jan				
X	T	pH	TDS	EC
cm	°C	-	ppt	mS/cm
0	22,5	7,3	0,66	1,32
37,5	21,9	7,28	0,68	1,35
75	21,5	7,28	0,66	1,33

Figure 10:Tables indicating the physical parameters measured in the biofilter on the 31st January 2018.
Note that the units of Total Dissolved Solids and Electrical Conductivity are different on the two days reported.