The Development of a Dual Media Biological Sand Filter with Added Component of Activated Carbon for Use in Vietnam

Katherine E. Safford[1] Laura W. Lackey[2]

Abstract – The proposed solution is a Dual Media Biological Sand Filter with the addition of activated carbon. Considering the pesticides and other recalcitrant substances found in the Mekong River water, it becomes apparent that typical point-of-use filtration will not be an effective solution to treat the polluted water of Vietnam. In order to remove these uncommon substances, the system employs the use of two common filtration methods; a biosand filter and activated carbon filter. The filter is housed in a double bucket scheme. The first bucket contains mangrove charcoal produced in Vietnam that was activated using a 0.25 M NaCl solution; this adsorbent facilitated organic removal from the source water, while the traditional biosand filter removed potential microbial pathogens. A biosand filter is a simple, yet effective water purification system that uses cheap and readily available materials to create a sustainable and easily reconstructed system for developing countries [4]. The efficacy of the duel filtering system was evaluated using water quality parameters including conductivity, pH, chemical oxygen demand, coliform concentration, turbidity, and p-nitrophenol concentration. Preliminary examination of results for September 25 to November 25, 2013 found average removals for COD, coliform, turbidity, and p-nitrophenol concentration of 58.3%, 99.0%, 92.7% and 96.8%, respectively. An effluent turbidity of 0.55 NTU met both EPA and MONRE standards. A 2 log removal of total coliform and 100% removal of fecal coliform does not meet standards, however, based on previous biosand filter research it is not capable of removing all coliform from the source water. Based on these preliminary results the dual media filter significantly improves the drinking water quality of the source water.

Keywords: Point-of-use filtration, Biological Sand Filter, Vietnam, Mekong River Delta, Adsorption of Pesticides

BACKGROUND

Over 1.1 billion people around the world lack access to an improved water source with more than 2.4 billion people lacking access to any type of improved sanitation facility [1]. Without access to an improved water source, the polluted water can lead to problems such as helminthes, gastro intestinal infection, schistosomiasis, diarrhea and ultimately mortality [5]. Annually, 160 million people are infected with schistosomiasis, 133 million with helminthes and 1.5 million cases of clinical hepatitis A, causing a total of 3.5 million deaths per year from water related diseases [6]. According to the World Health Organization, "1.4 million children in the world die every year from diarrhea caused by unclean water and poor sanitation – this equates to 4,000 child deaths a day or one child every 20 seconds" [1]

Vietnam Water Problem

Access to clean drinking water is a major problem in developing countries, specifically in South Vietnam along the Mekong River Delta; refer to the yellow circled region shown in Figure 1. Vietnam has a dense river network consisting of 2,372 rivers, with 109 of them used as main avenues of transport leading to 600,000 square miles of watershed basins [7]. Although Vietnam possesses abundant water sources, the available water is unsafe for drinking purposes unless treated first. According to the Vietnam Ministry of Natural Resources and Environment

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"80 percent of the diseases in Vietnam are caused by polluted water" [2]. Annually 7,050,762 cases of diarrheal diseases occur in Vietnam, with 4,576 resulting in death [8]

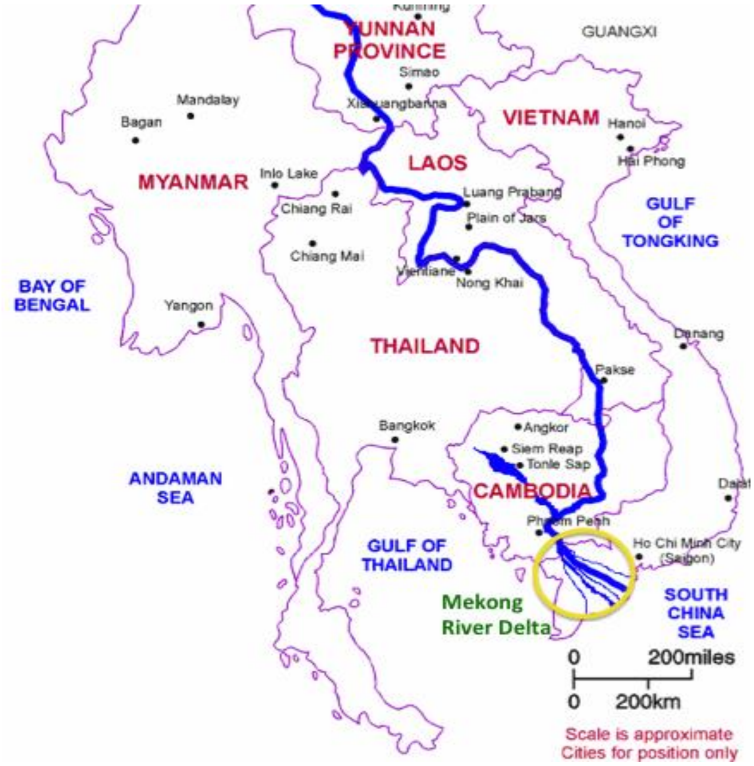

Figure 1. Map of the Mekong River [9]

The Mekong River Delta lies west of the Ho Chi Minh City, the largest city in Vietnam. Ho Chi Minh City, formerly Saigon, is a metropolitan area with a population of 9 million and growing [10]. Due to the recent socio-economic development, the rise in population, and the lack of government environmental regulations the quality of river water has drastically declined. There are five main basins that are considered severely polluted at alarm status in Vietnam, including the Mekong River Delta. With two-thirds of Vietnam's people living along these five severely polluted basins, the development of an appropriate technology to provide clean water is necessary [2].

Figure 2. Pictures of Mekong River [11] [12] [13]

The polluted water significantly affects the everyday activities of the 2.1 million families in South Vietnam who live on boats or floating houses along the Hau and Mekong Rivers. [14]. Before reaching the Mekong Delta in Vietnam, the Mekong River runs through five other countries leaving the Mekong Delta population at risk of exposure to contamination from upstream countries [15]. In these other countries the river runs through industrial areas, agricultural land, large cities and mining sites. The water flowing into the Mekong Delta gets further polluted from the Mekong Delta inhabitants themselves. More than half of the volume discharged into the Mekong river is produced from domestic wastage causing high organic and fecal concentrations. Industry and Agriculture equates to roughly the other half of wastage; therefore the water contains high concentrations of modern-day pollutants such as fertilizers, pesticides, herbicides, various chemical substances, heavy metals, silt, and suspended materials.

Point-of-Use Water Filtration

According to UNICEF, treating water at the household level has been proven to be one of the most effective and cost efficient methods to prevent waterborne disease in developing countries [16]. Treatment of water at the point-of-consumption is an advantageous solution because it limits recontamination of water from the transport process and requires little to no infrastructure. Point-of-Use Filtration (POU) is especially useful in rural settings where it is almost impossible to provide the infrastructure needed for large treatment facilities. The five most common Household water treatment options are: chlorination, filtration (biosand and ceramic), solar disinfection, combined filtration/chlorination, and combined flocculation/chlorination [16].

Biological Sand Filters (BSF) are a POU drinking water technology appropriate for many developing world applications; it is a simple technology that uses cheap and readily available materials to create a sustainable and easily reconstructed system. A BSF is capable of dramatically improving the microbiological quality of drinking water. BSFs can routinely remove 3- to 5-log coliforms in source waters characterized with low turbidity and organic content [17][18]. Shown in figure 3 is a schematic of a typical BSF consisting of 7 layers listed from top to bottom; a lid to prevent contamination, a diffuser to protect the biological layer from disturbance when water is being added, the biological layer or the schmutzdeke which removes the majority of pathogens, a fine sand layer which provides mechanical removal of solids, a metallic biocide layer which provides further removal of pathogens, a coarse sand layer, and a gravel layer which protects the outlet pipe and prevents sand from exiting in the effluent. A pipe with small holes runs along the bottom of the container and up the side to serve as an outlet pipe [19].

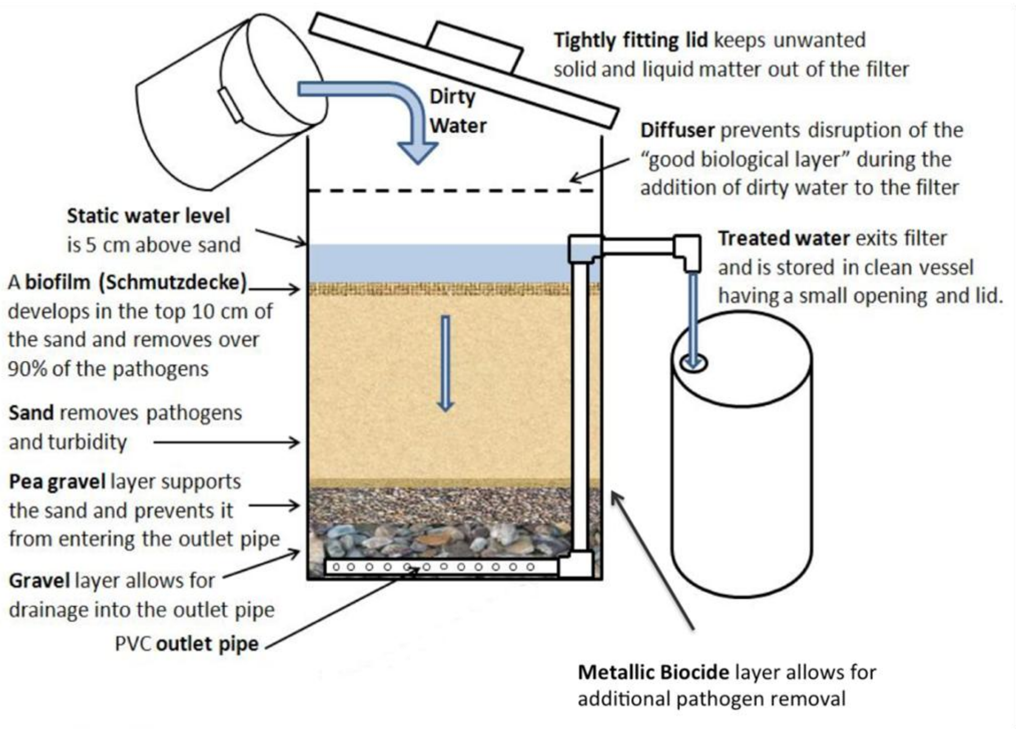

Figure 3. Typical Biosand Filter

PROPOSED SOLUTION

Mekong River water is highly turbid and contains elevated concentrations of fertilizers, pesticides, modern-day pollutants, bacteria, and viruses [2]. When considering pesticides and other recalcitrant substances found in the water, it becomes apparent that a typical point-of-use BSF will not be an effective solution to treat the polluted waters of Vietnam. The proposed solution is a Dual Media Biological Sand Filter (DM-BSF). The experimental, bench-scale system was housed in 40-L duel containers; the first was filled with activated carbon and the second was built and operated as a typical BSF [18]. The adsorbent will facilitate organic removal from the source water while the traditional BSF will remove potential microbial pathogens.

STANDARDS & REGULATIONS

The effluent water from the DM-BSF should at a minimum meet the specifications set forth by the Vietnam Ministry of Natural Resources and the Environment (MONRE). In Table 1, the Vietnam MONRE standards are compared to the World Health Organization (WHO) Standards and the U.S. Environmental Protection Agency (EPA) drinking water standards. The EPA and WHO standards require a higher quality effluent than the MONRE standards.

Table 1. Water Quality Standards Comparison

WATER QUALITY STANDARDS			
Standard	**EPA**	**WHO**	**MONRE**
Total Coliform (cfu/100mL)	0	0	50
Fecal Coliform (cfu/100mL)	0	0	0
Total Dissolved Solids Concentration (mg/L)	below 500	below 600	below 1200
Turbidity (NTU)	0.5-1	below 0.1	below 5

METHODOLOGY

Source of Carbon & Activation Methods

Mangrove forests cover roughly 192,000 hectares in the Southern Delta region of Vietnam [20]. Due to its availability, Mangrove trees are an important source of charcoal, timber and firewood. In the Mekong Delta region, mangrove charcoal is the dominant cooking method because it is slow burning and provides steady heat. Due to its low price and wide availability, activated Mangrove charcoal served as the adsorbent for the DM-BSF.

The mangrove charcoal was obtained from Vietnam, as un-activated logs of charcoal. These logs were crushed, washed and characterized with a effective size of 2.94 mm. A variety of methods were considered for activation; a cheap and regionally appropriate method of chemical activation was desired. Chemical activation was conducted using a 0.25M solution of sodium chloride. The crushed charcoal was soaked in the salt solution for 72 hours. Once activated the charcoal was thoroughly washed with DI water.

Filter Construction

As shown in figure 4, the DM-BSF was fabricated using two 40-L (10.5 gallon) containers. Both containers used a 1.27 cm (0.5 in) diameter PVC L-shaped outlet pipe. Twelve 0.32cm (1/8 inch) holes were placed on each side of the bottom leg of the outlet pipes; this portion of the effluent pipes were 24 cm (9.5 in) in length and were positioned 3.8 cm (1.5 in) from the bottom of each container and 7.6 cm (3 in) of protective gravel was placed above and below the outlet pipe. The following media was layered (from the bottom up) for the activated carbon filter: 5 cm (2 in) of pea gravel, 3.8 cm (1.5 in) of fine sand and 20.3 cm (8 in) of activated mangrove charcoal. The total mass of activated carbon added was 6.73 kg. For the sand filter, the following media was layered (from the bottom to the top): 5 cm (2 in) of pea gravel, 5 cm (2 in) of sand mixed with 75 g of copper shavings, and a final layer of 20.3 cm (8 in) of fine sand. The height of the final layer of sand was approximately 2.5 cm (1 in) below the outlet pipe to ensure the schmutzdeke remains saturated between the daily loading cycles. Using sieve analysis the effective size (D_{10}) of the fine sand and activated carbon was determined as 0.4mm and 3.06, respectively.

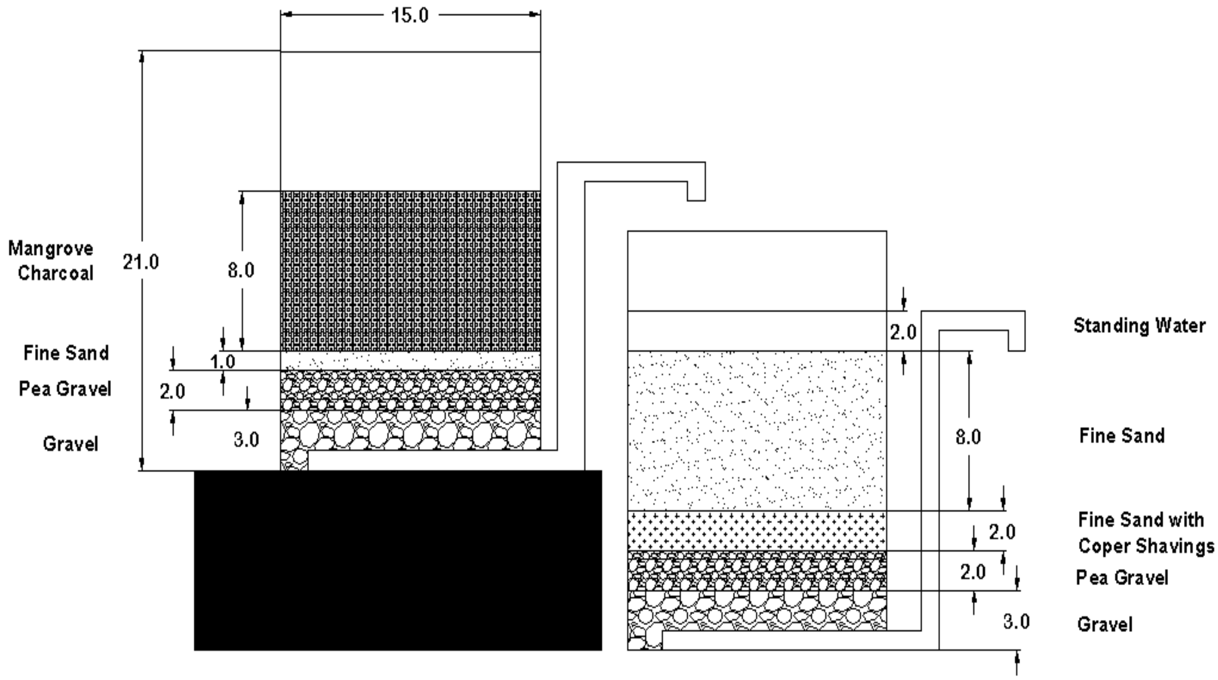

Figure 4. Dual Media BioSand Filter Construction Drawing

Filter Watering & Testing

The DM-BSF was loaded once per day with 10 L of Ocmulgee River water spiked with p-nitrophenol (4×10^{-5} M). Three months of testing was conducted. The efficacy of the DM-BSF was evaluated using water quality parameters including chemical oxygen demand, absorbance, coliform concentration, turbidity, pH, conductivity and flow rate. Total COD was evaluated through the use of Hach Low-resolution COD vials and a DR 2800 Portable Spectrophotometer. Absorbance of p-nitrophenol in the sample was measured at a wavelength of 402 nm using the spectrophotometer. Absorbance was related to p-nitrophenol concentration using a standard curve (p-nitrophenol concentration = 33869 × Abs(402 nm) + 0.0061). Total and E-coli coliforms were evaluated using membrane filtration and Hach m-ColiBlue24 broth following the procedure outlined in Standard Methods 9222D [21]. Using the Hach Turbidometer Model 2100Q and the accumet model 25 pH/ion meter, turbidity and pH were measured. Conductivity was measured using a portable HM digital EC/TDS/Temp COM-100 probe. Flow rate analysis was performed in order to determine if proper filtration was taking place. The ideal flow rate for a biosand filter should not exceed 1 L/min [4][19]

RESULTS & DISCUSSION

Experimental results from September 25th through November 25, 2013 are presented. Testing continued for an additional month. Influent characteristics of the water are variable due to changes in weather conditions. For example high turbidity values were generally associated with rainfall events. Conductivity is a measure of the waters ability to permit an electrical current and is largely affected by temperature and dissolved salts [22]. The conductivity of the DM-BSF effluent was always higher than the influent. The average influent and effluent conductivity was 128.42 μS and 200.82 μS, respectively. The increase in conductivity in the effluent is likely due to the use of a salt (NaCl) as the activation method for the carbon source. pH was not noticeably impacted by the dual filtration process. The average influent and effluent pH was equivalent and found to be 7.28. Flow rate is a key parameter for BSFs. For optimal removal literature suggests the BSF flow rate should never exceed 1 L/min [4] [19]. The average flow rate from the sand filter was 0.66 L/min confirming that proper filtration is taking place.

Figure 5 shows the turbidity values (NTU) of the influent (In), the effluent from the carbon filter (CO) and the effluent from the carbon and sand filter (CS). Average turbidity removal was found to be 92.7% with an average effluent turbidity of 0.55 NTU. Referring to table 1, this quality effluent meets both MONRE and EPA standards but does not meet WHO standards.

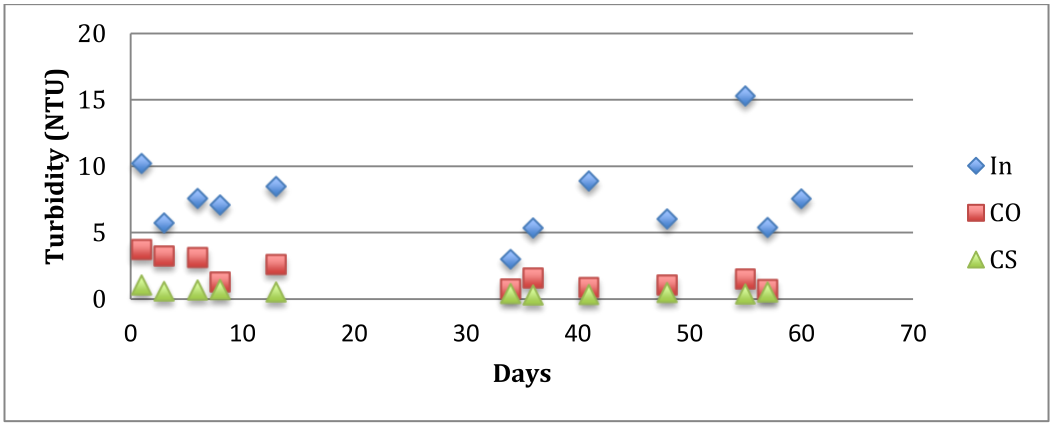

Figure 5. Turbidity trends from September 25- November 25, 2013. Influent is labeled as In, the effluent from the carbon filter as CO and the effluent from the carbon and sand filter as CS.

Figure 6 represents the Total Coliform colonies per 100 mL of sample. Literature suggests ripening time takes two to three weeks [4][19]. Due to this time for schmutzdeke maturation, coliform removal was averaged after the initial two weeks of testing. The data shows an overall negative trend for total coliform in the influent, this can be attributed to colder outdoor temperatures. Average total coliform removal was 99.00% (2-log removal) and average fecal coliform removal was 100%. All of the drinking water standards were met regarding fecal coliform however none of the standards were met for total coliform. Based on previous research, biosand filters are generally not capable of removing 100% of total coliform.

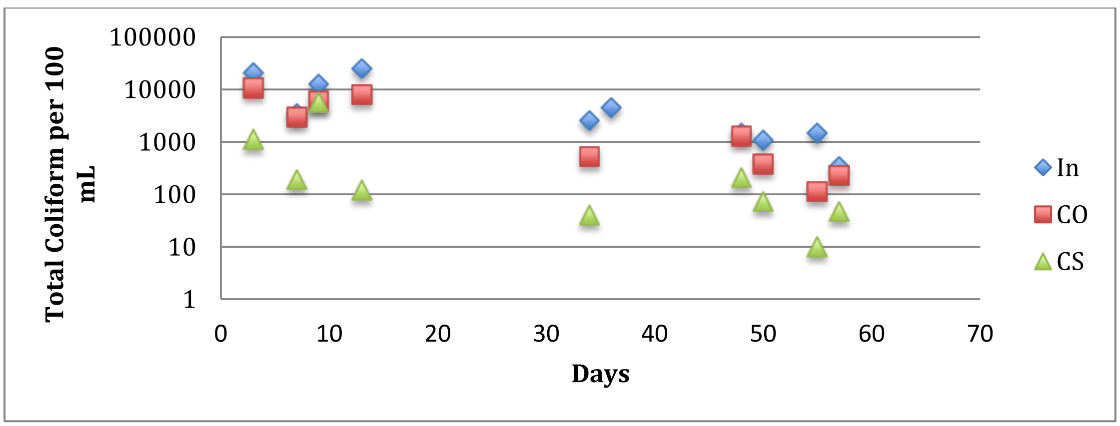

Figure 6. Total Coliform trends from September 25- November 25, 2013. Influent is labeled as In, the effluent from the carbon filter as CO and the effluent from the carbon and sand filter as CS.

Figure 7 shows the concentration of p-nitrophenol in the influent (In), the activated carbon bed effluent (CO), and for the effluent of the DM-BSF (CS). Results indicate that the majority of p-nitrophenol removal takes place in the carbon filter. On average the activated carbon removed 66.5% of the targeted organic. For the DM-BSF an average removal of 96.81% was found. There is no regulated standard for the concentration of p-nitrophenol in drinking water.

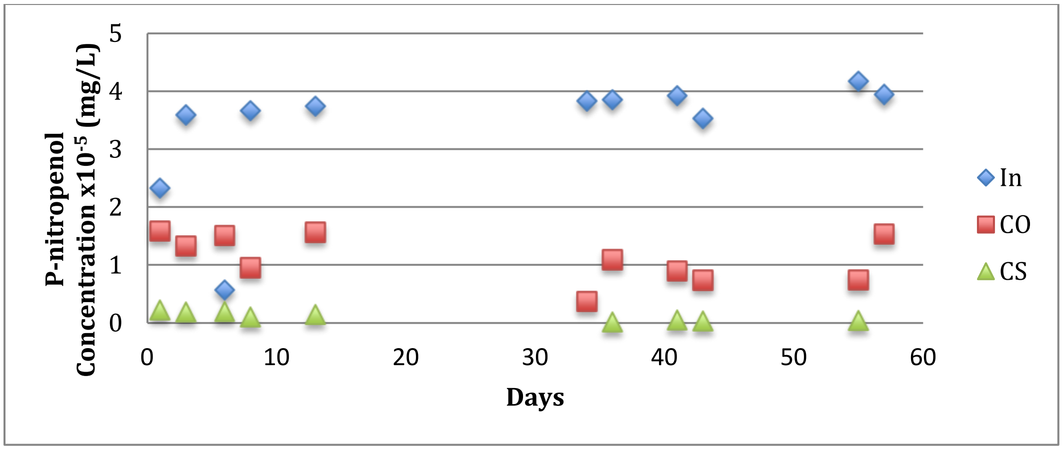

Figure 7. P-nitrophenol Concentration trends from September 25- November 25, 2013. Influent is labeled as In, the effluent from the carbon filter as CO and the effluent from the carbon and sand filter as CS.

Chemical Oxygen Demand is used to measure the amount of oxygen required to oxidize or degrade materials in a sample. Total COD contains both particulate and soluble COD. Particulate COD is easily removed by physical operations, while soluble COD requires a biological or chemical process. BSFs utilize both biological and physical processes to remove contaminants from the water source. Average COD Removal was 58.33% with an average effluent COD of 6.21 mg COD/L.

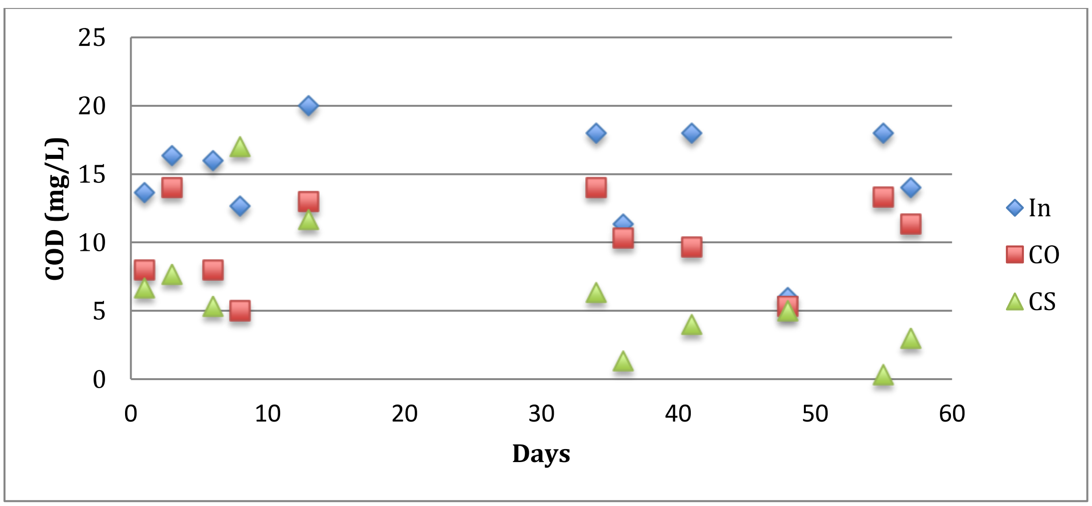

Figure 8. Total Chemical Oxygen Demand trends from September 25- November 25, 2013. Influent is labeled as In, the effluent from the carbon filter as CO and the effluent from the carbon and sand filter as CS.

Conclusion

Point-of-use biological sand filtration is an appropriate technology for providing clean drinking water to developing countries. It is an inexpensive, effective and sustainable method to treat water with high biological contamination. However, the water in Vietnam, specifically the Mekong River Delta, not only contains biological components but also contains elevated concentrations of pesticides, insecticides, herbicides and other modern-day pollutants. When considering these pesticides and other recalcitrant materials found in the water, it becomes apparent that a typical point-of-use BSF will not be an effective solution to treat the polluted waters of Vietnam.

The focus of this project was to determine the efficacy of a DM-BSF to treat the polluted surface waters in Vietnam. The proposed solution employs the use of adsorption in conjunction with biological treatment from a BSF.

Mangrove charcoal from Vietnam was activated using a sodium chloride solution. A packed-bed activated charcoal filter was used in series (as a pre-filter) with a traditional BSF. The DM-BSF averaged 92.7% removal of turbidity and 99% removal of total coliform. Removal of p-nitrophenol averaged 96.81% with approximately 2/3 of the removal occurring in the activated mangrove charcoal bed.

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