# Performance of modified design pond sand filters

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## ABSTRACT

Two pond sand filters (PSFs) with modified design were constructed in Pathorghata Upazila of Barguna District located in southern Bangladesh. Performance assessment of the PSFs was done after commissioning in terms of quality of filtered water, ease of operation and maintenance, monthly check-up of production capacity/efficiency of the filters, users' participation and acceptability of the modified PSFs. Some important parameters such as total coliform, fecal coliform, turbidity, colour, total suspended solids (TSS), chemical oxygen demand (COD) and pH were measured for the raw water and at the various stages of treatment in order to determine the effectiveness of different units of the PSFs. Close observations were made to assess the removal of turbidity in the roughing/pre-filtration chamber to ensure trouble-free operation of the main filter bed. In combination with roughing filters, the average turbidity and fecal coliform removal efficiency of the sand filters were found to be 76 and 98%, respectively. Filter run of the modified PSFs was also found higher (about 3 months) than the existing PSFs.

**Key words** | fecal coliform, pond sand filter, total coliform, turbidity

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## INTRODUCTION

There are certain areas in the coastal belt of Bangladesh where tubewells are not successful, because groundwater is mostly saline even to depths of 200–300 m (DPHE-UNICEF 1989) and suitable fresh water aquifers are not available. In addition to this, arsenic contamination of groundwater in Bangladesh has been recognized as a major problem since 1993 (Ahmed & Rahman 2000). Substitution of tubewell water by an alternative safe and reliable source of water supply is necessary for these areas.

People in many places in the southern fringes of Khulna, Noakhali, Bagerhat, Satkhira, Barguna, Perojpur and Patuakhali districts mainly depend on pond water for drinking, cooking, washing and bathing. These ponds are replenished by rainwater during the monsoon and are not protected from contamination. The pond water contains high turbidity and bacteriological concentrations. Use of such contaminated water causes various diseases such as diarrhoea, dysentery and cholera among rural people, which results in a chronic impact on rural health and the economy of Bangladesh. Therefore, water from these ponds requires appropriate treatment prior to human consumption.

As sophisticated treatment is neither practicable for small community water supply nor economically feasible, it is essential to develop a low cost technology for surface water treatment in these areas. Pond sand filters (PSFs) were first introduced on a pilot basis in 1984 by DPHE-UNICEF jointly to overcome the problem.

PSFs are small-scale filtering devices with manually operated treatment units to treat the adjacent pond water based on the principle of slow sand filtration. Brick chips (*khoa*) and sand chambers are arranged in series in the unit. In this system, pond water is discharged by a hand pump in a small unit containing filter media and water collected through taps. The initial design of the PSF was developed under research and development activities and subsequently modifications were made. Later, the construction of PSFs was undertaken under development programmes. The NGO Forum has also been implementing PSFs and rain water

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harvesting systems since 1997 in the coastal area of Bangladesh.

Recent field reports (DPHE 2000) have revealed that the performance of the PSFs is not satisfactory. Out of 477 PSFs in Pathorghata upazila, only 36 (i.e. about 8%) are working and the rest of them are non-functioning. It is also reported (WHO 1998) that a number of PSFs are out of order for various reasons. In Khulna circle, out of 76 PSFs, 47 (67.85%) are functioning, while in Barisal circle, out of 54 PSFs, 16 (29.6%) are functioning. The major problems of the existing PSFs are small production volumes, poor performance in removing fecal coliforms, short filter runs and poor operation and maintenance. The users are not interested in frequent washing of the sand bed, necessary repair of the system, pumping to waste sufficient water before collection and so on. Consequently the acceptance of PSFs is gradually declining. Strategies for increasing social acceptance and modifications of the design for better performance of PSFs are essential.

Two modified PSFs were constructed in Pathorghata Upazila of Barguna District in October 2002. Pond water and filtered water were tested by BUET Environmental Research Laboratory for water quality parameters.

Some important parameters such as total coliforms, fecal coliforms, turbidity, colour, total suspended solids (TSS), chemical oxygen demand (COD) and pH were measured for the raw water and at various stages of the treatment in order to determine the effectiveness of different units of the PSFs. Close observations were made to assess the removal of turbidity in the roughing/pre-filtration chamber to ensure trouble-free operation of the main filter bed.

Performance assessment of the PSFs was also done in terms of the quality of filtered water through analysis of the water quality test results, ease of operation and maintenance, users' participation and monitoring of production capacity/efficiency of the filters.

## MATERIALS AND METHODS

### Descriptions of the modified design PSF

The modified PSFs consist of two pre treatment steps using a horizontal flow roughing filter (HRF) followed by a buffer zone (Zaman 1991) and a vertical up flow roughing filter (VRF). All the filters are placed in a circular chamber (3 m diameter and 1.8 m high) made of brick masonry and separated by a partition wall. A storage chamber (0.75 m diameter and 1.8 m high) is constructed at the centre of the circular chamber by a reinforced cement concrete ring. The storage and filter chamber are provided with a roof slab and manhole cover. Filter materials (brick chips) in the HRF and VRF range between 20 and 12 mm and 8 and 4 mm in size, respectively (Wegelin 1996), and are distributed as coarse, medium and fine fractions in the filter compartments. Depths of the filter media in HRF and VRF are 1.5 and 0.6 m, respectively. Lengths of HRF, the buffer zone and VRF are kept at 1.5, 0.5 and 1.0 m, respectively. The raw water from the pond is collected by a hand pump and discharged into the inlet compartment. The hand pump is operated from a raised platform to obtain an initial head of water. The raw water runs in a horizontal direction from the inlet compartment, and through a series of differently graded filter material separated by perforated ferro-cement walls. A perforated false filter bottom made of ferro-cement was provided under the VRF. Following the upflow VRF, water falls into the slow sand filter (SSF) chamber. The water then trickles down through the sand filter bed. The effective size ($D_{10}$), uniformity coefficient and bed depth of the filter sand in the SSF were 0.26 mm, 2.28 and 0.75 m, respectively. Filtration rates in the HRF, VRF and SSF were 1.0, 0.8 and 0.22 m/h, respectively (Wegelin *et al.* 1987; Wegelin 1996). A vertical PVC pipe connected to the under drainage system is provided into the storage chamber to ensure the minimum depth of supernatant water in the filter chamber (Schultz & Okun 1984) and to collect fresh water from the filter chamber to the storage chamber. Two galvanised iron (GI) pipes are used as washout pipes, of which one is from the storage chamber and other is from the filtration chamber. Finally, a platform was constructed to facilitate water collection and washing of dirty sand. Drainage facilities are placed at the inlet of each filter compartment to enhance hydraulic cleaning. Figures 1–3 show the flow diagram, layout and photograph of the modified design PSF, respectively.

### Pond water quality

The pond water for drinking, cooking, washing and bathing is collected from ponds that are replenished by

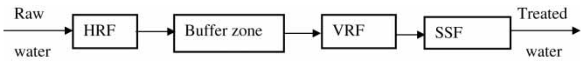


**Figure 1** | Flow diagram of the modified design PSF.

rainwater during the monsoon and are not connected with rivers or lakes. The pond water contains high turbidity and bacteriological concentrations. A field investigation report (Saiful 2002) has shown that most of the ponds for existing PSFs are not well protected from external pollution loads. Most of the ponds are not protected from bathing, washing and fish farming. For the laboratory investigation, pond water from 12 sites was collected and tested in the laboratory. Two of the ponds were selected for the modified PSF study. Laboratory test results on water quality of these two ponds are shown in the third column headed 'Raw water' in Tables 2–5. Water quality of the pond of PSF-1 was found to be better than that of PSF-2 and hence better removal efficiency was found in PSF-1. Highest turbidity, colour, total coliforms, fecal coliforms and TSS were 25 NTU, 86 Pt-Co unit, 700/100, 520/100 and 140 mg/L, respectively, in the pond water of PSF-2. Pretreatment of pond water with a high load of solid matter is necessary to lower the raw water turbidity for effective application of the SSF.

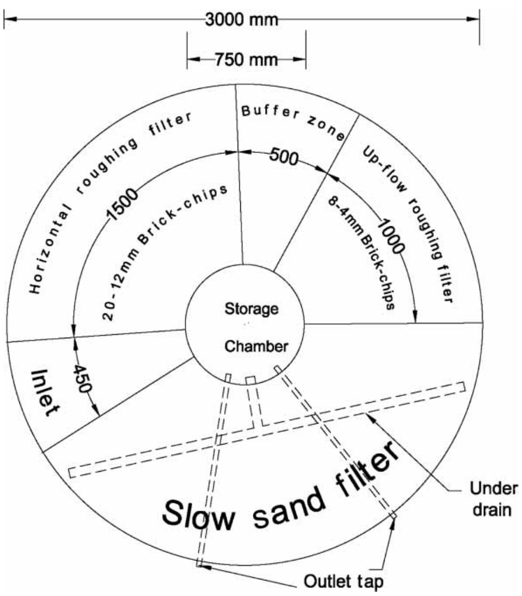


**Figure 2** | Layout of the modified design PSF.

**Figure 3** | Photograph of a modified design PSF.

## Method of sample collection and analysis

Raw and treated water samples were collected directly from the site at around a 4-week interval. The sampling points were: (i) raw water; (ii) the effluent after HRF; (iii) the effluent after VRF; and (iv) treated water after SSF. Figure 4 shows the sampling points on the flow diagram.

Samples for bacteriological analysis were collected in sterile bags and transported in an ice-box. Total coliforms and fecal coliforms were analysed by the membrane filtration method immediately after transferring them to the laboratory. Samples for analysis of other parameters were collected in two 500 ml plastic bottles and were analysed using *Standard Methods* (APHA/AWWA/WEF 1998). Some important parameters such as total coliforms, fecal coliforms, turbidity, colour, TSS, COD and pH were tested for the raw water and at the various steps of the treatment in order to determine the effectiveness of the unit processes of the modified PSFs. Close observations were done to assess the removal of turbidity in the roughing/pre-filtration chambers to ensure trouble-free operation of the SSF.

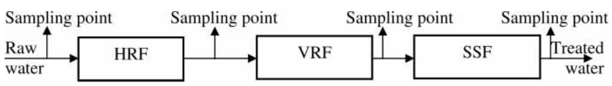


**Figure 4** | Sampling points on the flow diagram of the modified PSF.

Removal of bacteria, particularly fecal coliforms, and time intervals of washing the filter beds were also analysed. To observe the long-term success of the modified system, raw and treated water samples were also collected two years after construction of the PSFs.

## RESULTS AND DISCUSSIONS

### Yield capacity of the modified PSFs

The modified PSFs were operated with a design filtration rate of 10 L/min. For this purpose gate valves were provided to control the filtration rate. The gate valves of the delivery pipes of SSFs were fully opened during the determination of the yield capacity of the modified PSFs. The tubewells were pumped to raise the water level in the filtration chambers. Water discharged through the delivery pipe as a result of this head. The tubewell was pumped at a rate such that the head remains constant. The discharge through the delivery pipe per minute was measured. This discharge per minute represents the yield capacity of the modified PSFs at this constant head of 41 or 43 cm. The yield capacity was measured at a regular time interval. Table 1 shows the yield capacity of the modified PSFs. The yield capacity during the first 2–3 months of the monitoring period was found to be greater than the design filtration rate of 10 L/min and then decreased owing to head loss. Head loss increased with increasing filter run. Ultimately, when filter resistance becomes too high, cleaning of filter skin is required.

**Table 1** | Yield capacity of the modified PSFs

| Caretaker's name and location of PSFs | PSF ID | Running time (days) | Constant head level (cm) | Yield capacity (L/min) |
|---|---|---|---|---|
| Md. Abdul Mannan Kathaltali, Pathorghata | PSF-1 | 30 | 41 | 17 |
| | | 58 | 41 | 16 |
| | | 72 | 41 | 15 |
| | | 90 | 41 | 7.0 |
| | | 120 | 41 | 4.0 |
| Md. Alamgir Hossain Parishad, Kathaltali, Pathorghata | PSF-2 | 9 | 43 | 20 |
| | | 36 | 43 | 16 |
| | | 50 | 43 | 15 |

### Total and fecal coliform reduction

Bacteriological water quality is of major concern for surface water treatment. However, the removal efficiency is greatly dependent on the pollution load of the raw water. Raw water was found to be polluted because it was not well protected from external pollution loads. Table 2 shows the total and fecal coliform removal efficiencies of HRF, VRF and SSF and Figures 5(a), (b) and 6(a), (b) show the variation of total coliforms and fecal coliforms in raw water, the HRF outlet, the VRF outlet and the SSF outlet water of PSF-1 and PSF-2, respectively. Pond water of PSF-2 was found to be more polluted than that of PSF-1 and hence the removal efficiency of PSF-1 was found to be better than that of PSF-2. Although the treated water had initially somewhat elevated fecal coliform concentrations of more than the allowable limit (GoB 1997; WHO 1997), the effluent

**Table 2** | Total and fecal coliform removal efficiencies of HRF, VRF and SSF

| | | Total coliforms | | | | Fecal coliforms | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N/100 ml | % Removal | | | N/100 ml | % Removal | | |
| PSF ID | Filter running time (days) | Raw water | HRF | VRF | SSF | Raw water | HRF | VRF | SSF |
| PSF-1 | 30 | 200 | 40.00 | 60.00 | 85.00 | 60 | 66.67 | 75.00 | 90.00 |
| | 58 | 200 | 70.00 | 85.00 | 94.00 | 80 | 81.25 | 90.00 | 98.75 |
| | 90 | 100 | 70.00 | 80.00 | 100.00 | 60 | 83.33 | 100.00 | 100.00 |
| | 120 | 240 | 58.33 | 89.58 | 100.00 | 80 | 87.50 | 100.00 | 100.00 |
| PSF-2 | 09 | 700 | 82.86 | 85.71 | 90.00 | 340 | 94.12 | 95.59 | 97.06 |
| | 36 | 320 | 56.25 | 78.13 | 93.75 | 100 | 80.00 | 98.00 | 99.00 |
| | 67 | 180 | 83.33 | 88.89 | 94.44 | 160 | 93.75 | 99.38 | 100.00 |
| | 98 | 630 | 87.30 | 95.24 | 99.05 | 520 | 92.31 | 98.08 | 100.00 |

*Note*: Acceptable limit for total and fecal coliforms is 0/100 ml (GoB 1997; WHO 1997).

concentration levelled out to about 0/100 ml (around 100% removal) after the maturation of the SSF. It takes around 2–3 weeks to mature the SSF for first time of commissioning but about 1 week after scrapping and re-sanding of the sand bed. In this period, users are advised to drink the treated water after boiling. The average total and fecal coliform removal efficiencies of the modified PSFs were found to be 97 and 100%, respectively, after filter maturity. The average total and fecal coliform removal efficiencies of the existing PSFs were found to be 64.25 and 76.3% only (Saiful 2002). The removal efficiencies of PSF-1 and PSF-2 for fecal coliforms were found to be 98.13 and 97.27%, respectively, 2 years after construction.

## Turbidity, colour and TSS reduction

During the investigation period after the commissioning of the PSFs, expected turbidity, colour and TSS removal efficiencies were found after filter maturity. Table 3 shows the turbidity and colour reduction of the modified PSFs and Table 4 shows the TSS reduction of the modified PSFs. Figures 5(c)–(e) and 6(c)–(e) show the variation of turbidity, colour and TSS in raw water, the HRF outlet, the VRF outlet and the SSF outlet water of PSF-1 and PSF-2, respectively. The field survey revealed that the pre-filter chamber of the existing PSFs is very small in size (0.75 m × 0.45 m × 0.23 m), which is not sufficient to reduce the turbidity of raw water for trouble-free operation of the main filter chamber (Saiful 2002). In the modified PSFs, the horizontal roughing filters following the vertical up flow roughing filters in layers are used to reduce the load on the SSFs and to allow adequate operation. For PSF-1, the average turbidity reduction efficiency in the roughing filters was found to be about 71.26% (from 5.75 to 1.58 NTU) and the highest reduction efficiency in the roughing filters was found to be about 82.89% (from 7.6 to 1.3 NTU). For PSF-2, the average turbidity reduction efficiency in the roughing filters was found to be about 69.52% (from 19.73 to 5.7 NTU) and the highest reduction efficiency in the roughing filters was found to be about 79.6% (from 25 to 5.1 NTU). Raw water quality of PSF-1, in terms of turbidity, colour and TSS, was found to be better than that of PSF-2 and hence reduction efficiencies of the parameters were found to be better in PSF-1. It is noteworthy that the allowable turbidity range for adequate SSF operation is 10 NTU (Van Dijk & Oomen 1978; Wegelin 1996). So the roughing filter effluents were found to be acceptable for direct filtration by the SSF. Average turbidity removal efficiency of the existing PSFs, and modified PSFs were found to be 86.93 and 82.91%, respectively. One of the main objectives in developing the modified PSF

**Table 4** | TSS removal efficiencies of HRF, VRF and SSF

| PSF ID | Filter running time (days) | Raw water TSS (mg/L) | % Removal HRF | % Removal VRF | % Removal SSF |
|---|---|---|---|---|---|
| PSF-1 | 30 | 100 | 20.00 | 50.00 | 90.00 |
| | 58 | 46 | 34.78 | 56.52 | 84.78 |
| | 90 | 24 | 25.00 | 50.00 | 75.00 |
| | 120 | 17 | 29.41 | 58.82 | 76.47 |
| PSF-2 | 09 | 140 | 35.71 | 64.29 | 92.86 |
| | 36 | 12 | 25.00 | 41.67 | 66.67 |
| | 67 | 30 | 26.67 | 60.00 | 76.67 |
| | 98 | 25 | 28.00 | 56.00 | 68.00 |

*Note*: Drinking/treated water standard for TSS = 10 mg/L (GoB 1997).

**Table 3** | Turbidity and colour removal efficiencies of HRF, VRF and SSF

| PSF ID | Filter running time (days) | Raw water turbidity (NTU) | % Removal HRF | % Removal VRF | % Removal SSF | Raw water colour (Pt-o unit) | % Removal HRF | % Removal VRF | % Removal SSF |
|---|---|---|---|---|---|---|---|---|---|
| PSF-1 | 30 | 5 | 54.00 | 60.00 | 63.20 | 17 | 29.41 | 41.18 | 52.94 |
| | 58 | 6.9 | 60.87 | 71.01 | 83.04 | 17 | 41.18 | 58.82 | 64.71 |
| | 90 | 7.6 | 78.95 | 82.89 | 85.39 | 15 | 46.67 | 60.00 | 86.67 |
| | 120 | 3.5 | 65.71 | 71.14 | 80.29 | 16 | 56.25 | 62.50 | 68.75 |
| PSF-2 | 09 | 15.1 | 44.37 | 54.30 | 59.60 | 46 | 13.04 | 19.57 | 23.91 |
| | 36 | 22 | 68.18 | 72.73 | 77.27 | 86 | 31.40 | 37.21 | 41.86 |
| | 67 | 25 | 76.00 | 79.60 | 82.00 | 58 | 39.66 | 48.28 | 56.90 |
| | 98 | 16.8 | 70.24 | 71.43 | 76.19 | 50 | 28.00 | 34.00 | 44.00 |

*Note*: Drinking/treated water standard for turbidity = 10 NTU and for colour = 15 Pt-Co unit (GoB 1997).

was to increase the filter run. Laboratory investigation has shown that turbidity removal efficiency is acceptable for existing PSFs. But a field investigation report has shown that the average filter run of the existing PSFs is about 15 days to 1 month. As the SSFs were overloaded, frequent cleaning was necessary. On the other hand, the filter run of the modified PSFs was found to be about 3 months. Therefore, the modified PSF is to be cleaned less frequently; hence acceptance among the rural people will increase.

Colour reduction is also satisfactory for the modified PSFs. The average colour value for treated water after maturation of the PSF-1 was found to be about 5.25 Pt–Co units, which is below the allowable limit of 15 Pt–Co units. Highest and average colour removal efficiency in PSF-1 was found to be 86.67% and 68.27%, respectively. But expected colour removal efficiency was not achieved in PSF-2 because of the higher colour in the raw water, which might be caused by decaying leaves from trees around the pond. On the other hand, effluent colour values for most of the existing PSFs were found to be greater than 20 Pt-Co units. The average colour removal efficiency of the existing PSFs was found to be 42% (Saiful 2002). The removal efficiencies of PSF-1 and PSF-2 for turbidity were found to be 90.56% and 80.43%, respectively, and for colour were found to be 70 and 58.82%, respectively, 2 years after construction.

## Other water quality parameters of the modified PSF

Besides coliforms, turbidity, colour and TSS, other water quality parameters, such as pH and COD were tested at regular intervals. Table 5 shows the pH and COD of raw water and treated water of the modified PSFs. The test

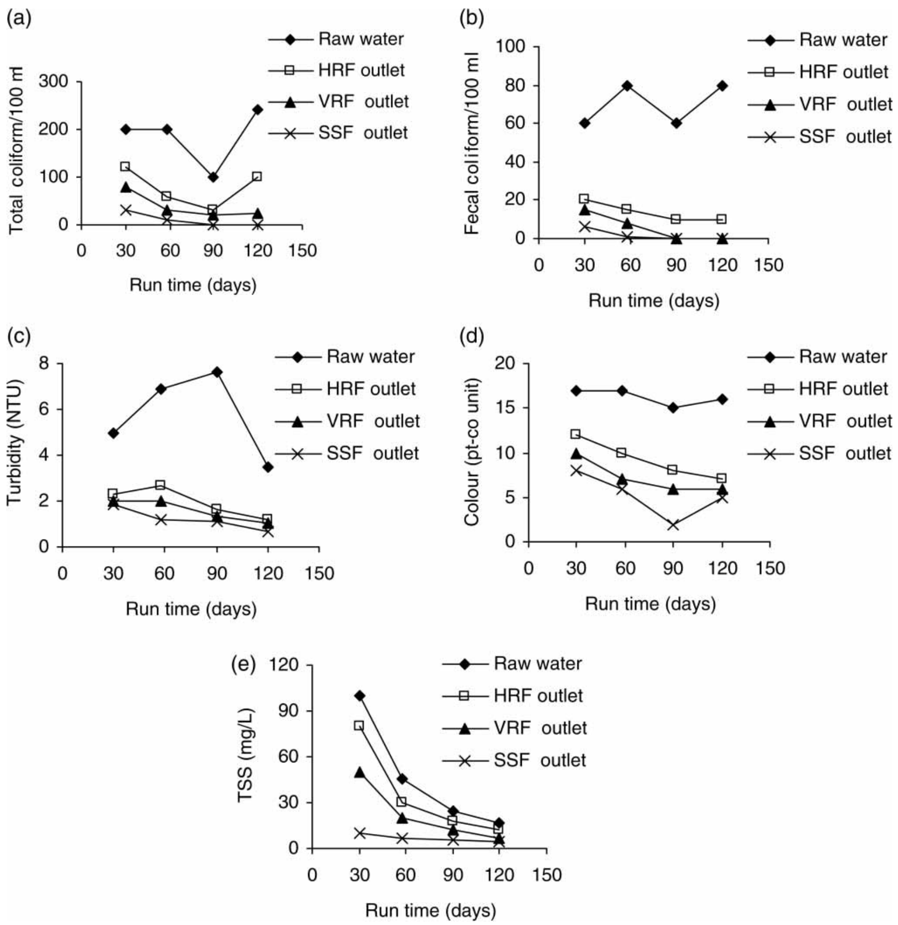


**Figure 5** | Variations of (a) TC, (b) FC, (c) turbidity, (d) colour and (e) TSS in raw water, HRF outlet, VRF outlet and SSF outlet water of PSF-1.

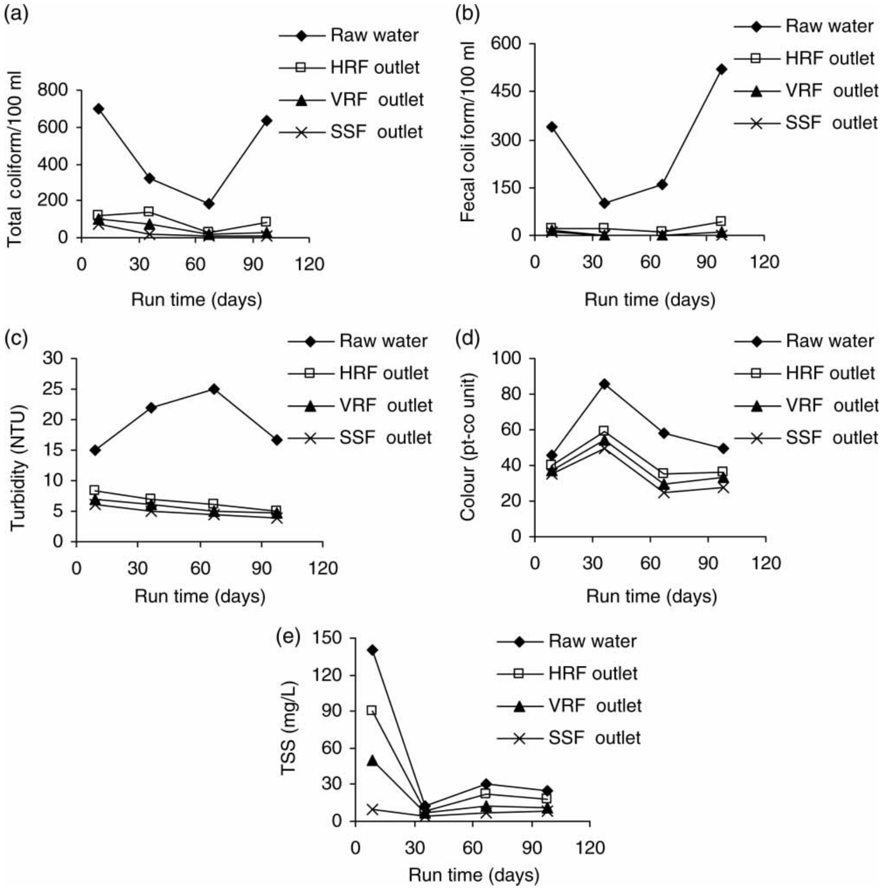


**Figure 6** | Variations of (a) TC, (b) FC, (c) turbidity, (d) colour and (e) TSS in raw water, HRF outlet, VRF outlet and SSF outlet water of PSF-2.

results show that the pH of the treated water was higher than that of raw water, the highest value exceeding the acceptable limit of 8.5. Higher pH values were obtained because of leaching of calcium oxide from cement that was used for construction. Iron, arsenic and chloride were tested occasionally and found to be within acceptable limits.

**Table 5** | pH and COD of raw water and treated water of the modified PSFs

| | | pH | | COD (mg/L) | |
|---|---|---|---|---|---|
| PSF ID | Filter running time (days) | Raw | Treated | Raw | Treated |
| PSF-1 | 30 | 7.69 | 7.85 | 40 | 20 |
| | 58 | 8.03 | 8.37 | 3.5 | 1.9 |
| | 90 | 7.98 | 8.28 | 4.7 | 2.5 |
| | 120 | 8.07 | 8.75 | 4.6 | 2.5 |
| PSF-2 | 09 | 7.46 | 9.37 | 30 | 20 |
| | 36 | 7.96 | 8.61 | 3.5 | 2.1 |
| | 67 | 7.97 | 8.55 | 3.6 | 3.1 |
| | 98 | 8.05 | 8.98 | 4.7 | 2.9 |

*Note*: Drinking water standard for pH = 6.5–8.5 and for COD = 4 mg/L (GoB 1997).

## Users' acceptance

On-site orientation was conducted during the filter running period and, later on, the users' operation and maintenance activities were supervised. Sufficient responses from the users were found during the orientation programme. On-site training of the caretakers was conducted at the start of the modified PSF operation. DPHE-Danida officials also initiated the caretakers' training programme.

Users' perception and acceptability of the modified PSFs were investigated during sampling. Beneficiaries' opinions towards the modified PSFs were also collected. The community are highly satisfied with the performance of the modified PSFs and the treated water both for drinking and cooking purposes. The filter run of the modified PSFs has increased sufficiently thereby reducing frequent washing, which makes them easier to use than the existing PSFs.

## CONCLUSION

In combination with roughing filters, the average turbidity and fecal coliform removal efficiency of the sand filters were found to be 76 and 98%, respectively. The increased sand bed depth (0.7 m) in the modified PSF has allowed the full bacterial activity in the filter bed and produces the desired quality of water. The filter run of the modified PSFs was also found to be longer (about 3 months) than that of the existing PSFs (about 15 days). The community are highly satisfied with the modified PSFs and the treated water both for drinking and cooking purposes. However, to maintain the good performance of the modified PSFs, the following conditions should be ensured:

- The pond shall be well protected from external pollution loads for efficient filter operation, and proper construction of the PSF shall be ensured.
- When filter resistance is too high and yield is very low (below designed capacity, 10 L/min), cleaning of filter skin has to be done. Filter skin shall only be scraped by trained personnel. SSF and VRF should never be kept dry. This will hamper the filter operation. The cleaning procedure should be done as quickly as possible.
- After opening the washout pipe of the roughing filter chamber, drain all of the water from the chamber and then repeated hydraulic wash shall be applied to flush the re-suspended solids out of the filter. In HRF, it is very important to start the cleaning procedure at the inlet side, as most of the solids are retained in this part of the filter. Manual cleaning is necessary if the solids accumulated at the filter bottom or, at worst, all over the filter, can no longer be removed hydraulically. If manual cleaning is applied, then each fraction of the aggregates should be cleaned separately. Re-sieving of the filter material is necessary if mixing of the different fractions occurred.
- User groups may be formed among the beneficiaries for regular monitoring and maintenance work.

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