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ORIGINAL ARTICLE

Evaluating pond sand filter as sustainable drinking water supplier in the Southwest coastal region of Bangladesh

M. A. Y. A. Harun · G. M. M. Kabir

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Abstract This study investigates existing water supply scenario, and evaluates the performance of pond sand filter (PSF) in meeting drinking water demand of Dacope Upazila in southwest coastal Bangladesh. Questionnaire survey to the villagers reveals that PSF is the major drinking water sources (38 %) of the study area followed by tubewells (30.4 %), rainwater harvesting (RWH) systems (12.6 %), ponds (10.3 %) and others (8.7 %). The spot test and laboratory analysis show that odour, colour, pH, dissolved oxygen, hardness, calcium, magnesium, nitrate, sulphate and phosphate of the PSFs water meet Bangladesh standard. The efficiency of PSF in reducing total dissolved solids (TDS) (15 %) and potassium (8.2 %) is not enough to meet the standard of 20 % PSFs for TDS and one-third PSFs for potassium. The study proves that PSF is unable to remove coliform bacteria by 100 % from highly contaminated water. Hence, disinfection should be adopted before distribution to ensure safe drinking water. Majority of the PSF's users (80 %) are either partially satisfied or dissatisfied with the existing system. The beneficiary's willingness to pay for drinking water technologies seems that the combination of PSF and RWH could ensure sustainable drinking water in coastal region of Bangladesh.

Keywords Sustainable · Coastal region · PSF · RWH · Dacope · Bangladesh

M. A. Y. A. Harun (✉) · G. M. M. Kabir
Environmental Science Discipline,
Khulna University, Khulna, Bangladesh
e-mail: harunkb@yahoo.com

Introduction

Providing adequate amounts of drinking water of an acceptable quality is a basic necessity, and ensuring sustainable, long-term supply of such drinking water is of national and international concern. The majority of the populations in developing countries still lack safe drinking water and more than 50 % of the populations have no access to potable water (UNDP 1992). Bangladesh, a densely populated developing country with very low literacy rate and sanitary awareness had achieved a great success ensuring safe drinking water to rural people through providing tubewells for extracting ground water by the year 1990 (Ahmed and Rahman 2000). Severe arsenic contamination of groundwater in Bangladesh has disrupted the idea of using shallow tubewells for safe drinking water throughout the country (Karim and Safiuddin 2003). WHO (2004) reported that in southwest Bangladesh (Khulna, Satkhira and Bagerhat district) the ground water is unsuitable for human consumption due to high salinity rather than due to arsenic contamination that may be of importance in the northern parts of Bangladesh. The availability of saline-free pockets in coastal areas is lower than the availability of arsenic-free pockets in the arsenic-affected rural villages, where in places neither ground nor surface water is saline-free (Rahman et al. 1997). Although deep tubewells of coastal areas provide a relatively reduced level of salinity, the water contains sand which makes deep well water undrinkable in coastal areas (Ahmed 1996).

To cope with this disastrous situation, different water treatment options and alternative strategies like rainwater harvesting (RWH) and pond sand filter (PSF) systems are tried to adopt in government and non-government sectors. A part of these, United Nations Children's Emergency Fund (UNICEF) and Department of Public Health

Engineering (DPHE) have been establishing PSF to purify pond water in saline affected coastal areas since 1983 (DPHE and UNICEF 1989). The PSFs which are made with brick, cement, sand, brick chips, net, hand tubewell, pvc pipe, filter media, etc. are established on the edge of pond to supply drinking water, in particular, in the salinity or arsenic-affected areas. Yokota et al. (2001) stated that PSFs can reduce both coliform and general bacteria, but it may not remove 100 % of pathogen from heavily contaminated surface water. Rahman et al. (2001) mentioned that the PSF system, being a low cost technology, with very high efficiency in turbidity, colour and bacterial removal, may be considered as an alternative water supply system for small rural communities.

The Southwest coastal region of Bangladesh has been severely facing pure drinking water crisis due to saline water intrusion on one hand and arsenic content of groundwater on the other where PSFs have been installed as an alternative water supply system. Hence, this paper first investigates the present water demand (cooking and drinking) and supply scenario in the study area and socio-economic aspects of PSFs. In addition, it evaluates the performance of PSFs in supplying safe drinking water through water quality analysis.

Materials and methods

Chalna Union of Dacope upazila in Southwest coastal region of Bangladesh has been selected as study area since the problem of safe drinking water is likely to be severely acute, and many PSF have already been established here as a supplementary drinking water source. Total number of households and population of Chalna union are 6,018 and 31,811, respectively (BBS 2001). A reconnaissance survey has been conducted prior to the selection of PSFs for study that helped to identify the active PSFs, and developed idea to prepare questionnaire. Water demand, existing water supply scenario and socio-economic aspects of PSF have been evaluated through questionnaire survey to the 10 % (602) of the total households. Grab sampling was followed for laboratory experiments, and Stratified Random Sampling (based on the household's income) has been adopted for field survey. Equal number of households has been surveyed for each income group. Water samples were collected from 12 active PSFs (1. Chalna Paurashava Lake, 2. Perchalna, 3. Baruikhali, 4. Dacope Upazila, 5. Dacope hospital, 6. Khatail, 7. Lakshmikhola, 8. Khona, 9. Deluti, 10. Asavhua, 11. Gaurkhati and 12. Khalisha) and the relevant ponds during June to August 2007 (rainy season) considering all precautions. The water quality data have been obtained by laboratory analysis of collected samples and spot tests (laboratory of Khulna University, BUET, and the microbiological laboratory of DPHE, Khulna). 3 replications have been adopted for every location and the average values are finally plotted. pH, salinity, EC and TDS were measured in the field using a portable pH meter (Hanna, pH 211), microprocessor salinity meter and EC/TDS meter (Hanna, H1-9635). Odour has been felt physically. Platinum-Cobalt Scale (ASTM D1209) method was used to measure colour. DO was measured using Winkler's method. Chloride (Cl^-) was measured using Ion selective electrode method (Cole-palmer chloride electrode, model no. 27502-13). Total hardness, magnesium (Mg^{2+}) and calcium (Ca^{2+}) concentration has been examined by standard titrimetric method. Potassium (K^+) was measured by flame photometric method (Flame photometer- models PEP 7 and PEP 7/C). Nitrate (NO_3^-) and sulphate (SO_4^{2-}) concentration was measured by turbidimetric method using UV–visible spectrophotometers (Helios 9499230 45811). Phosphate (PO_4^{3-}) concentration was accounted using ascorbic acid method (UV–visible spectrophotometers, Helios 9499230 45811). Arsenic concentration was measured using MERCK Arsenic Kit (no. 1.17926.0001). Membrane filtration technique was applied to study F. coliform.

Results and discussion

Water supply scenario and water demand

Chalna Union is a severely salinity intruded area in the Southwest coastal region of Bangladesh. PSF and tubewell are the major water supplier of the study area which is supplying about 70 % of the total drinking water (Fig. 1). RWH system, newly introduced sustainable water supplier is not getting popularity and only used by the rich people due to high establishment costs. Some poor people are using pond water just after boiling even for drinking purposes. In addition, they are also using water from river, dug well and tap though the combined percentage of these water users are very small (8.7 %). The use of tubewell water is decreasing rapidly as it contains arsenic, salt and sand in most cases. Demand of fresh water for cooking and drinking purposes highly depends on income of the households. Drinking water demand is inversely related with the income whereas, cooking water is directly related. The low income groups mainly labours hard work and need more drinking water than the other income groups. In contrary, the rich people need more water for cooking than the poor as they cook varieties of food items every day. The average drinking and cooking water demand per head in the study area is about 5 L day^{-1} (Table 1).

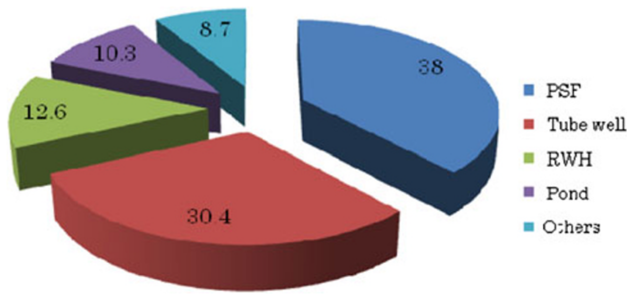

Fig. 1 Existing water (drinking and cooking) supply sources (%) in the study area

Table 1 Water demand for drinking and cooking purposes

Income groups US$ (Households)	Drinking (Liter $Person^{-1}$ Day^{-1})	Cooking (Liter $Person^{-1}$ Day^{-1})	Drinking + cooking (Liter $Person^{-1}$ Day^{-1})
<37	3	2	5.1
37– <60	2.5	2.5	
60–85	2	3	
>85	2	3.5	

Water quality of PSF

Physical parameters

The odour of all PSF's water seems to be satisfactory, though water of few ponds was slightly odorous. PSF shows high performance in removing colour (53–69 %) from pond water (Table 2) to acceptable limit (DoE 1997), while it reduces the TDS by 15 % (average) enough to meet the DoE standard for more than 80 % PSFs. Though PSF can reduce pH negligibly (0–3 %), pH of all PSF met DoE standard.

Chemical parameters

No detectable arsenic was found in the pond water. DO level of the studied PSF's water fall within Bangladesh standard. PSFs reduced salinity by 22 % (average) of the corresponding pond's water, but still the salinity level is more than the DoE standard in all cases (Fig. 2). However, the users told that the salinity level is within their tolerable limit, and claimed for no health effect. The results

Table 2 Water quality parameters of PSFs and concerned ponds

Location	Sources	Parameters													
		Colour (hazen)	TDS (ppm)	pH	Salinity (ppt)	Cl^- (ppm)	DO (ppm)	Hardness (ppm)	K^+ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	NO_3^- (ppm)	SO_4^{2-} (ppm)	PO_4^{3-} (ppm)	F. coliform (no./ml)
1	Pond	32	970	6.8	3	540.5	–	240.8	15.5	59	22.4	1.2	16.7	0.29	49
	PSF	11.2	840	6.7	2	538.6	6.5	215	13.4	56.2	20.2	0.82	10.6	0.18	0
2	Pond	34	984	6.9	2.6	545	–	237.5	14.5	57.4	22.8	1.01	49.2	0.32	247
	PSF	10.5	837	6.8	1.91	541.2	6.8	212.3	13.6	54.8	21.1	0.72	30.5	0.23	3
3	Pond	34.5	992	7.1	2.5	601	–	224	13.3	57	18	1.1	25	0.8	536
	PSF	12	821	7.1	1.6	601	6.4	192.5	11.5	54.8	13.5	0.77	17.3	0.44	8
4	Pond	19.3	512	7.2	1.9	159	–	132	8.5	34.5	13	1.15	18.5	0.15	30
	PSF	6.6	407	7	1.3	143.2	7.5	105.3	6.85	29.3	11.5	0.9	11	0.1	0
5	Pond	38.6	1560	7.3	3.25	978	–	287	12.5	60	36	1.28	65.4	1.1	793
	PSF	14.5	1415	7.2	1.96	969.8	7	258.7	11.7	52.3	32.1	1.13	40.1	0.5	15
6	Pond	36.8	1423	7.2	4	802.4	–	265.2	17.8	56	32	1.3	45.6	1.12	623
	PSF	13.7	1285	7.1	2.3	800	7.2	246	16.7	52	29.5	1.05	31.8	0.58	8
7	Pond	28.4	858	6.8	2.3	526.4	–	218	12.6	51.7	20.5	1	24	0.2	376
	PSF	9.8	735	6.7	1.85	526.4	7.5	191	11	46.5	17.6	0.8	16.2	0.12	2
8	Pond	30.3	980	7	2.5	537	–	225.6	13.5	55.6	25	1.08	28.6	0.32	197
	PSF	13.6	823	6.9	2	529.5	6.7	190	11.4	53.3	23	0.8	22.3	0.21	1
9	Pond	36	1035	7	3	658	–	247	12.8	59	28.2	1.18	47.3	0.7	324
	PSF	14	906	6.8	2	653.4	7	225.8	12	56.4	25.8	1.01	30	0.43	5
10	Pond	35.2	988	7	2.9	560	–	238.4	13.4	55.8	23	1.12	19	0.45	452
	PSF	15	825	7	2.1	560	6.4	218.2	12.1	52.5	20.4	0.87	12.2	0.24	6
11	Pond	28	897	7.1	2.2	525	–	220	10.8	50	19.7	1.06	27.6	0.28	175
	PSF	13.1	736	7	1.76	523.4	6.5	195.3	8.9	44.2	14.8	0.93	18.5	0.15	2
12	Pond	22.4	753	6.8	2	325	–	186.2	9.2	45.3	16	1.04	15	0.14	50
	PSF	8.5	608	6.7	1.57	312.2	7	150.8	7.8	39.1	12.8	0.77	9.1	0.11	0

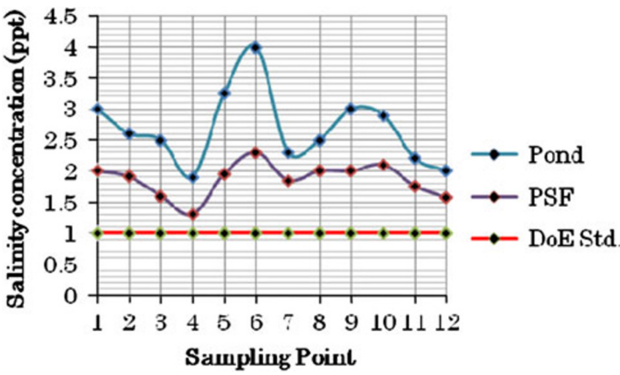

Fig. 2 Efficiency of PSF to reduce salinity in meeting DoE standard

expressed that PSF is able to remove hardness, potassium, calcium, magnesium, nitrate, sulphate and phosphate by 1.5, 12.3, 11.9, 8.2, 13.3, 22, 34.5 and 39.6 % (average), respectively (Table 2), and meet DoE standard except for potassium which exceeds the standard for one-third PSFs. PSF is unable to remove chloride, however, the negligible reduction of chloride (1.5 %) in our study might be due to the oxidation that is supported by literature (Dunlop et al. 2002).

Biological parameters

Though PSF is efficient in removing Coliform bacteria (98–100 %) however still few pathogens may exist in the PSF's water (Fig. 3) specially, while the pond is highly polluted. As most of the PSFs in our study did not meet DoE standard (0/100ml water) in terms of bacterial contamination, many users have been suffering from stomach diseases drinking contaminated water.

Comparison of PSF water with WHO standard

The analytical parameters of the PSF water were also compared with the recommended value of World Health Organization (WHO 1993). It was found that only chloride, potassium and F. coliform with values of 25, 33 and 75 % PSF water exceed the allowable limits of WHO, respectively (Table 3).

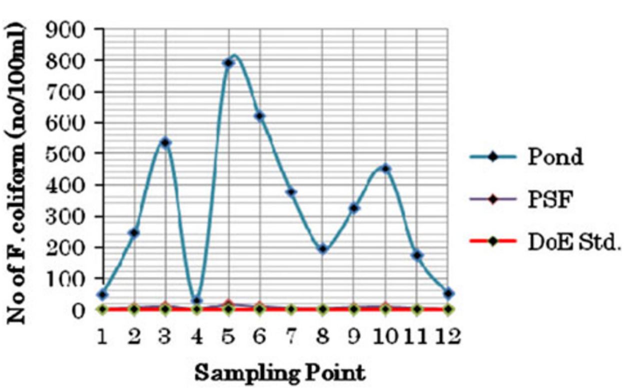

Fig. 3 Performance of PSF in removing *F. coliform*

Socio-economic aspects of water supply

Satisfaction level of PSF users

Only 20 % of the PSF users are fully satisfied using PSF's water which is so small in comparing partially satisfied (50 %) and dissatisfied (30 %) groups (Fig. 4a). The main reason for the dissatisfaction is waiting for long time in a queue to take water specially, to the women (mainly responsible to bring water) who also have to take care of the children, cooking, washing, etc. (Fig. 4b). About one-third of the users have observation of the scarcity of PSF as they have to walk a long distance (average 2 km) to bring water. Some users (10 %) also claimed about the water quality of the PSF, who think that due to lack of maintenance of PSF water quality is becoming poor and results in diarrhea, dysentery and other diseases of stomach, while a part (10 %) of the respondents have dissatisfaction for not to manage the pond properly (free from bathing, washing, aquaculture, agricultural outlets, etc.). The villagers think that the PSF could be a sustainable alternative drinking water source in the coastal region if it is installed within the tolerable distance of the users. They also have an idea of

Table 3 Comparison of PSFs water with WHO drinking water standard

Water quality parameters	WHO (1993)		Samples exceeding allowable limits	Percentage of samples exceeding allowable limits
	Desirable limit	Maximum allowable limit		
Colour (hazen)	–	15	Nil	Nil
TDS (ppm)	500	1,500	Nil	Nil
pH	7.0–8.5	9.2	Nil	Nil
Cl^- (ppm)	200	600	5, 6, 9	25
K^+ (ppm)	–	12	1, 2, 6, 10	33
Ca^{2+} (ppm)	75	200	Nil	Nil
Mg^{2+} (ppm)	50	150	Nil	Nil
NO_3^- (ppm)	45	–	Nil	Nil
SO_4^{2-} (ppm)	200	400	Nil	Nil
As (total)	0.01	0.01	Nil	Nil
F. coliform (no./ml)	0/ml	0/ml	2, 3, 5–11	75

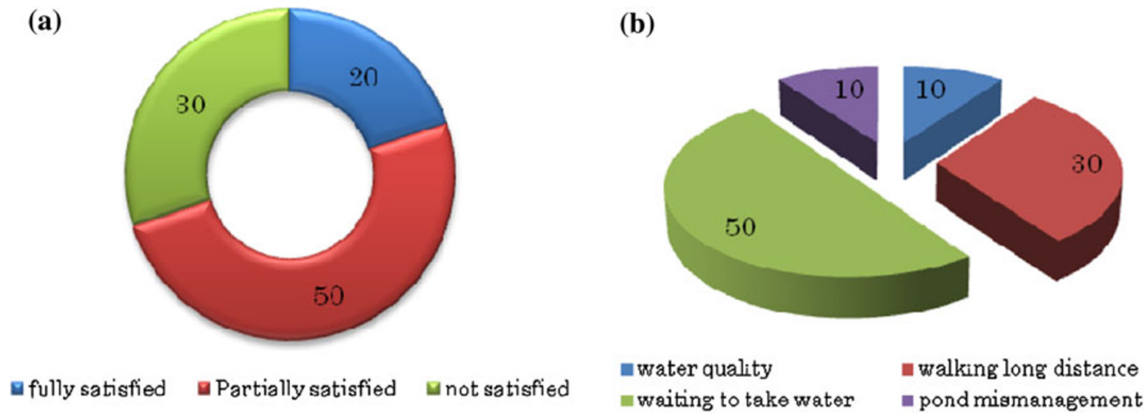

Fig. 4 **a** Satisfaction level (%) of the existing PSF water users, **b** reasons for dissatisfaction

proper pond selection, management of pond and maintenance of PSF periodically, test of water quality in a continuous basis, supplying bacteria free water, etc. to enhance the familiarity of PSF.

Economic feasibility

As the majority of coastal people are poor the viability of water supply technology predominantly depends on their willingness to pay. Table 4 shows the installment and maintenance cost of the suitable water supply technologies along with the number of households that could be covered by it. Though the coastal people badly need safe drinking water, their low income level limits the desire to pay for water (Table 5) while they have lack of foods. It seems from table 4 and 5 that about 39 % of the total households with monthly income level US$ 60 or more have the ability to afford RWH system both in terms of installment and maintenance cost in contrast with the majority of the poor households (about 61 %) who can only afford the PSF. In contrary, no household is able to afford ultrafiltration technology due to high installment cost.

Conclusions

The people in the study area have been still suffering drinking water problems both quantitatively and qualitatively. PSF is supplying the major percentage of drinking water in spite of having the limitation of water quality and scarcity. Both drinking and cooking water demand depends on income groups, for instance, low income people need more drinking water in contrast to the high income people who need more cooking water. The water quality of PSF highly depends on the water quality of the corresponding ponds. PSF is not appropriate for the ponds that contain high salinity, Potassium and Chloride. As most of the PSFs are unable to remove the coliform completely, disinfection must be adopted after filtration to ensure pure drinking water supply. Ultrafiltration technology, having the capacity to remove total coliform by 100 % is not effective to the coastal region of Bangladesh due to high capital cost (Arnal et al. 2009). Periodic water quality monitoring and maintenance of PSF along with the proper selection and management of pond could ensure the safe drinking water to the coastal Bangladesh. About 40 % of the inhabitants who have ability to afford RWH system could be occupied by it to avoid the load on PSF, and the installment of additional PSFs to a certain distance would minimise the walking and waiting for long distance and time, respectively, to bring water. Further study on using

Table 4 Cost of PSF, RWH and Ultrafiltration technology

Technology	Installment cost (US$)	Maintenance cost (US$ Year^{-1})	No. of family can use
PSF	493–740	49	60–100
RWH	49–62	12	Individual
Ultrafiltration	24000	Unknown	1000*

Source, DPHE 2009

* Calculated as of Arnal et al. (2009)

Table 5 Relation between income level and willingness to pay for drinking water technology

Households income level (US$ Month^{-1})	Percentage of total households	Willingness to pay for drinking and cooking water (US$)	
		Installment of technology (once)	For water (daily)
<37	35.45	6	0.025
37–<60	25.91	12	0.038
60–85	13.93	49	0.063
>85	24.71	62	0.088

Source, Field survey 2007 and BBS 2001

activated carbon in removal of excess salinity (Zou et al. 2008) and coliform (Matsunaga et al. 1994) of PSF water might make sense of using PSF with slight modification.

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