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Development of low cost household drinking water treatment system for the earthquake affected communities in Northern Pakistan

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ABSTRACT

The devastating earthquake of 2005 severely damaged over 4000 water and sanitation schemes in northern Pakistan. The present study aimed at testing a low cost household sand filter (HSF) in treating low quality drinking water in disaster-hit areas of northern Pakistan. Two villages were randomly selected for practical demonstration of a low cost drinking water treatment system in earthquake affected areas. The on-site performance of HSF was monitored during the operational period. The data was collected on people perceptions of water quality and handling of the household sand filter (HSF) through in depth focus group discussions, questionnaire and interviews. The results showed that pre-treatment values of drinking water for *Escherichia coli,* total coliforms and turbidity were 101 cfu/100 ml, 73 cfu/100 ml and turbidity 44 and 16 NTU, respectively. After HSF operation for 10 days, 97% reduction in *E. coli*, total coliforms and turbidity was evidenced. More than 67% of the respondents perceived turbidity as a prime water quality issue responsible for ill health consequences. It was concluded that the designed HSF was efficient in improving drinking water quality for illiterate communities and its success and dissemination to poor communities were prone to locally available construction materials.

1. Introduction

The northern Pakistan is prone to earthquakes due to its location on fault lines [1]. The October 2005 earthquake was the most devastating natural disaster that Pakistan has ever faced. It was estimated that more than 73,000 people lost their lives, 570,000 houses were damaged rendering 2.8 million people shelterless, over a million lost sources of income while around 70,000 were maimed [1,2]. The earthquake caused severe damage to over 4000 community-owned drinking water supply systems, 25 km of sewerage lines as well as drains, street pavements, public toilets and solid waste management systems. Water and sanitation facilities in 420 health facilities, and 5857 educational institutions, were destroyed [3]. The Government of Pakistan (GoP) in collaboration with Asian Development Bank (ADB), World Bank, WHO, and UNICEF estimated that nearly 5.2 billion US dollars were needed for the rehabilitation of the affected communities[3,4] along with another 32 million US dollars for the rehabilitation of water supply and sanitation sector of the affected areas [2]. Government of Pakistan under the umbrella of Earthquake Rehabilitation and Reconstruction Authority (ERRA) devised a strategy named "Strategy for Rehabilitation and Reconstruction of water Supply and Sanitation Sector" for the provision of essential water and sanitation facilities to the affected population [3].

Nearly 6 out of 10 persons in Pakistan have access to safe drinking water and the government has set target to provide safe drinking water to 93% of the population by 2015 and to the entire population by 2025 [5–7]. Around 70% of Pakistan's surface and groundwater sources are contaminated by organic, biological, and inorganic pollutants [8]. Current population of Pakistan is 170 million and is expected to reach 221 million by the year 2025. Such a huge increase in population will put immense pressure on the water resources to fulfill the demands of agriculture, industry, and domestic use. In 1953, the per capita water availability was 5600 m^3 which dropped to 1000 m^3 in 2006 [9,10]. The access to safe drinking water is the basic human right and its adequate provision to the whole population at an affordable cost and the delivery of such services is the responsibility of the GoP. But the policy draft had highlighted the concern over deteriorated drinking water quality. It stressed on special efforts for new pilot-scale approaches and appropriate technologies which help to improve access, efficiency, quality, effectiveness, and sustainability of drinking water [7].

To reduce the risk of outbreak of water borne diseases and to make it acceptable for human consumption, it is imperative to remove pathogenic organisms, fecal matter, suspended matter, organic matter, and harmful chemicals from drinking water supplies [11,12]. WHO assessed more than 37 different home based treatment technologies, products, and approaches for their effectiveness to deliver safe drinking water, but the evaluation reports of various technologies had showed the persistence of water quality problems [13–15]. Household Sand Filter (HSF) is one of the low cost drinking

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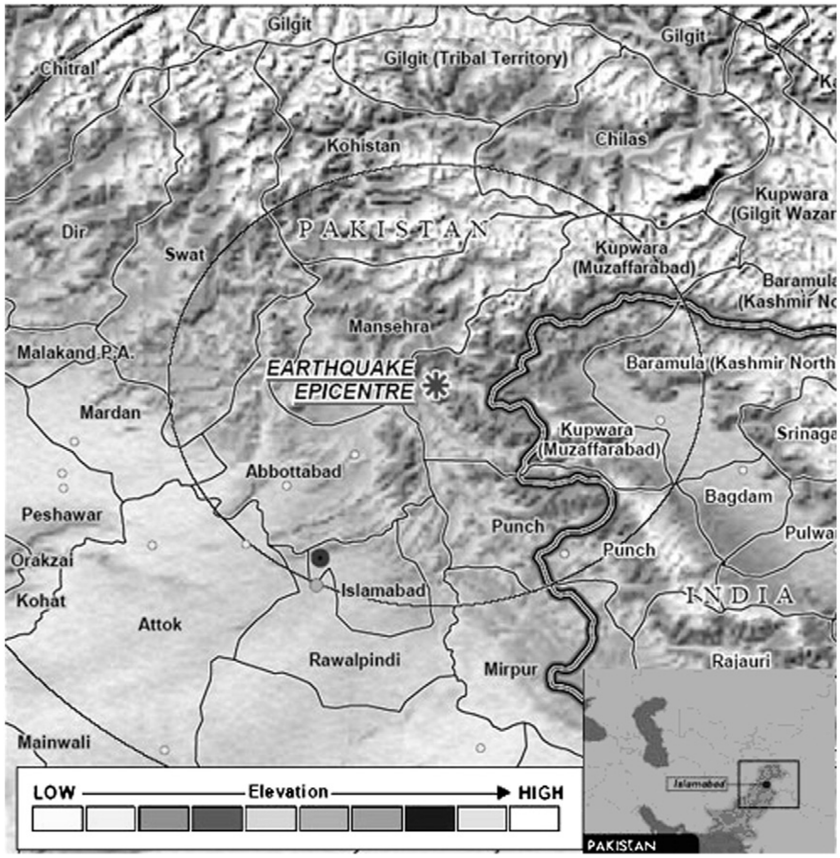

Fig. 1. Map of Pakistan showing 2005 earthquake affected areas and the location of the study site of the present experiment.

water treatment options that has been practiced for a long time and is handy to construct, operate and maintain.

The living standard is poor in rural areas of Pakistan in general and in the 2005 earthquake affected areas in particular and demand for clean drinking water is ubiquitous. Nearly sixty percent of water supply sources in earthquake affected areas especially in tehsil Allai, district Batagram were found to have biological contamination (Personnel communication with Dr. Abdur Rehman Project Coordinator of the currently implemented UNICEF funded project named WAQIPH "Water Quality Improvement and Promotion of Hygiene in the earthquake affected areas of Pakistan"). In view of this problem, innovative HSF containing locally available low-cost adsorbents that would meet the drinking water quality standards are strictly needed to save people from water-borne disease outbreaks. Therefore, the objectives of the study were: 1) to get insight into the local practices of water collection, handling and perceptions through Knowledge, Attitude and Practices (KAP) surveys, 2) to design and demonstrate innovative low cost treatment system for its effectiveness in improving drinking water quality of earthquake-hit areas.

2. Materials and methods

2.1. KAP survey

Two villages were randomly selected in the target area (Fig. 1) and KAP survey was conducted through focus group discussions (FGD), interviews using structure and semi structure questionnaires, and personnel observations [16]. These methods were employed where people were the focus of study [17]. The data gathering tools were used to determine how people obtained water and were subsequently handled at the household level. Knowledge regarding any household treatment options and the prevalent beliefs regarding the causes of gastrointestinal diseases and their linkages with the water quality were also investigated. A total of 42 KAP questionnaires were administered to 50% respondents from each target village during the study.

2.1. Design of HSF

The designed HSF was constructed from the locally available materials (cylinder gravel, and sand) (Fig. 2). The HSF was prepared for field-scale evaluation with the following specification: the inner diameter of the pipe was 15 cm; length of 90 cm; and wall thickness of 3.7 cm with 10 cm plain cement concrete at the bottom. It was

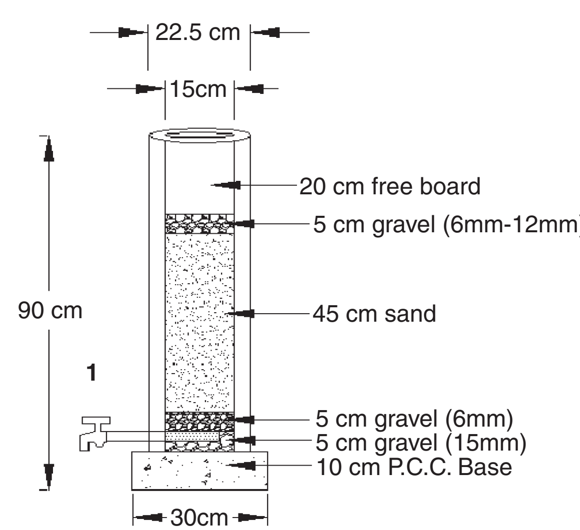

Fig. 2. Household Sand Filter (HSF) showing different depth of the filter media.

fitted with a half inch perforated galvanized iron outlet pipe near the bottom to drain water through unsaturated flow mechanism.

To HSF, the filter media was filled according to the following specifications. The drain gravels with effective radii of about 15 mm were packed at the bottom to the depth of 5 cm followed by another packing of 5 cm depth by support gravels with radii of about 6 mm. It was followed by 45 cm depth of sand with effective size (D10) which ranged from 0.19 to 0.22 mm in diameter and D60 whose size ranged from 0.66 to 0.90 mm and had uniformity coefficient (D60/D10) that ranged from 3.5 to 4.0 mm [18]. Finally, a gravel layer (6–12 mm diameter) of approximately 3 cm in thickness was placed at the top of the HSF that would help in maintaining equal water dissipation though the system.

Filter media consisted of sand and gravel which were obtained from the local vendor in Lawrrencepur (famous sand in the earthquake affected areas of Khyber Pakhtoonkhawa). The gravel and sand were properly washed to remove any adhering clay particles, organic constituents and other materials according to the standard procedures developed by Manz [19].

2.2. Area Selection for HSF demonstration

The areas for HSF demonstration were randomly selected based on the prevalence of high diarrheal cases, topography, and non availability of piped drinking water as well as water sources in the vicinity. One such village was Kuz Narsook consisting of 28 households situated in the Union Council Bateela and the other village was Dhonga Sar which was relatively bigger in size and consisted of about 56 households and was located in the Union Council Biari of tehsil Allai, district Batagram in the Hazara division of northern Pakistan. Tehsil Allai was severely affected during the earthquake of October 2005. All residents of these villages used to fetch water from far flung streams for different purposes and no water supply scheme was initiated either by the Government or by the NGOs due to non availability of water sources in the nearby locations.

2.3. Field water quality assessment

Water samples were randomly collected from the consumer points and were tested for different water quality parameters. Oxfam potable microbial water testing kit was used for *E coli* and Total coliform testing [20]. The pH of the water samples was determined on the spot by using calibrated pH meter (Hanna Instruments HI 98129) and turbidity meter (Loviband GmnH 44287 Dortmund PC 43637, Germany) was used to measured turbidity. The same procedures and instruments were used to analyze the treated water samples that were collected 10 days after the installation of HSF in each targeted village [21].

3. Results and discussion

3.1. KAP survey findings

The results regarding KAP surveys in both communities were presented in Table 1. Most of the respondents (66.7%) perceived that turbid water was not safe for drinking while 16.7% clearly recognized and understood that microbiologically contaminated water would likely pose a greater risk to their lives due to its greater potential to cause water borne diseases than turbidity alone. It clearly demonstrated that people living in these far flung areas of Pakistan were still not familiar with the presence of pathogenic organism in their clean looking drinking water and still believed turbidity as the sole culprit that make their drinking water unhealthy. There were 77.5% respondents in both villages that used separate vessel to store their drinking water. However there were only 22.5% respondents who were not exercising any care in storing their drinking water and were using open mouth buckets for both water supply and storage purposes. Most of the respondents (52.4%) in both villages did not prefer to use their stored water after 24 h of storage but 14.2% respondents were satisfied with the water quality even after 3 days of storage.

Table 1
KAP questionnaire survey focused areas about the targeted people knowledge about safe drinking water, length of water storage and belief about diarrhea in Villages Kuz Narsook (UC Bateela) and Dhonga Sar (UC Biari) tehsil Allai.

S. no	KAP survey focused area	Kuz Narsook ($n^* = 14$) n^{**} (%)	Dhonga Sar (n = 28) n (%)	Total (n = 42) n (%)
1	Knowledge about safe drinking water	14 (100)	28 (100)	42 (100)
	—Turbidity	11 (78.6)	17 (60.7)	28 (66.7)
	—Taste	–	2 (7.1)	2 (4.8)
	—Color	1 (7.1)	4 (14.2)	5 (12)
	—Pathogens	2 (14.2)	5 (17.8)	7 (16.7)
2	Knowledge about water storage	14 (100)	26 (92.8)	40 (95.2)
	—Separate vessel for drinking water	10 (71.4)	21 (80.8)	31 (77.5)
	—Not separate vessel for drinking water	4 (29.6)	5 (19.2)	9 (22.5)
3	Knowledge about the length of drinking water storage	14 (100)	28 (100)	42 (100)
	—Good till 1 day	7 (50)	15 (53.6)	22 (52.4)
	—Good till 2 days	5 (35.7)	9 (32.4)	14 (33.3)
	—Good till 3 days	2 (14.3)	4 (14.3)	6 (14.2)
4	Knowledge about diarrhea	14 (100)	28 (100)	42 (100)
	—God Almighty will	9 (64.3)	16 (57.1)	25 (59.5)
	—Contaminated drinking water	4 (28.6)	9 (32.1)	13 (30.9)
	—Others (mosquito bites, eating of unwashed fruits etc.)	1(7.1)	3 (10.7)	4 (9.5)

n^*: number of respondents interviewed.
n^{**}: percentage of respondents answered to each KAP targeted question.

The knowledge regarding diarrhea was interesting, majority of the respondents (59.5%) at both locations believed that water has nothing to do with the diseases and it was only because of sins that Allah Almighty punished the human beings for different diseases. Above 30% of the respondents linked diarrheal diseases with ingestion of contaminated drinking water and said that it also varied during the year and traditional medication was more common in the study area to treat such patients. Moreover, there were few respondents 9.5% who considered some other factors such as mosquito bites, eating of unwashed fruits etc. could be the potential sources of diarrhea.

3.2. Treatment of drinking water

Pollutant removal efficiencies were analyzed from the filtered water samples on the spot after ten days of HSF installation. Daily 20 l of water was poured through HSF in each village. Twenty liters of water sample was decided for filtration because it could fulfill the drinking requirement of a family consisting of 7 people. The results of pre and post filtration pH of the water samples at both villages were presented in Table 2. The results suggested a slight increase in pH of the post filtered water sample compared to the pre-filtration one. This might be due to slight dissolution of anions from the packing material of HSF. The respective pre-filtration turbidities of both locations viz. Kuz Narsook and Dhonga Sar were 44 and 16 NTU (Table 3), which dropped to 1.5 and 0.6 respectively after filtration. The HSF proved very effective in lowering the turbities of the water samples which decreased to values within the permissible limits of WHO i.e. 5 NTU. The packing material of HSF proved very effective in removing 96% of

Table 2
The variations in pH of the water samples in both pre and post filtration after 10 days of HSF operation.

Village name	Union council	Pre filtration pH	pH after 10 days of HSF operation	Increase in post filtration pH	WHO permissible limits
Kuz Narsook	Bateela	7.76	7.82	0.06	6.5–8.5
Dhonga Sar	Biari	7.70	7.80	0.10	6.5–8.5

Table 3
Turbidity removal after 10 days of HSF operation.

Village name	Union council	Pre filtration turbidity (NTU)	Turbidity after 10 days of HSF operation	% age reduction of turbidity	WHO permissible limits
Kuz Narsook	Bateela	44	1.5	96.6	<5
Dhonga Sar	Biari	16	0.6	96.2	<5

Table 5
Total coliforms reduction from HSF after 10 days operation.

Village name	Union council	Pre filtration total coliforms (cfu/100 ml)	Total coliforms after 10 days of HSF operation	% age reduction of Total coliforms	WHO permissible limits
Kuz Narsook	Bateela	70	2	97.2	Nil
Dhonga Sar	Biari	76	2	97.4	Nil

the turbidity from the tested water samples. As far as biological parameters of water quality were concerned, mean *E. coli* and total Coliforms in the pre-filtered water sample were 108 and 70 cfu/100 ml for the Bateela and were 94 and 76 cfu/100 ml for Biari Union councils, respectively (Tables 4 and 5). However, significant reduction in colonies forming units for both biological agents was seen at both locations. The water samples collected after HSF operation showed nearly 96% reductions in biological agents at both villages.

The results of KAP surveys indicated two valuable points regarding the perception of the people about water quality and gastrointestinal diseases. Vast majority of the respondents (67%) were of the opinion that turbidity was their prime issue as far as drinking water quality was concerned and they were not willing to accept that there might be some invisible biological agents in water responsible for such diseases. Sixty percent respondents were of the opinion that diarrhea or any other disease had no connection with water quality and that they suffered from the disease only because of their sins. Suffering from a disease constituted a punishment from the God Almighty. Traditionally, religious norms and values are strong among the aged group particularly in this part of Pakistan and generally the people of Khyber Pakhtoonkhawa are considered more conservative and religious [22]. During the field visits, children were seen fetching water from the far flung water sources and most of the water collection and handling activities were managed by young ones. Being a culturally conservative area women were not allowed to go out from their homes. Field demonstrations of our designed HSF attracted considerable interest of the local masses and willingness to adopt it for household use provided that the HSF construction and filter materials should be local and easily available. Moreover, there were some other reasons like socio economic viability, durability, light weight and homely easy maintenance of HSF that also attracted the attentions of people and their interest in its adoption for water quality improvement. Besides these characteristics, the HSF system also generated enough quantity of water which was not of acceptable quality. It is recommended that some disinfection may be carried out like boiling or chemical disinfection. The only requirement of implement of this HSF is the basic training to local masses regarding its construction and handling.

Increased post filtration pH indicated that sand particles contained some monovalent and divalent ions like Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+}, in the adsorbed as well as in the precipitated forms and subsequently released into the solution upon filtration, where hydrolysis of these cations was responsible for the increase in alkalinity of the post filtered water samples. Every day 20 l of water dispensed through the filter which kept the HSF sand column wet that favored more dissolution of the precipitated forms of the aforementioned cations in the system. The pH of the water generally controls the charge characteristics of plasma membranes of biological agents and thus their adsorption and retention on the adsorbents in the filter media. This was further supported by the study of Gerba et al., [23] who proved higher rate of adsorption of *E. coli* in the sand column at neutral pH than at pH 5.

Significant reduction in the turbidity of water samples at both study areas was seen which fell within the WHO permissible limits (Table 3). The turbidity values almost reached at equilibrium state in both villages after 10 days of operation. The increased head loss due to mechanical adsorption, attachments and sedimentation of the particles clogged some of the pores and hence improved HSF efficiency. Numerous forces are involved in turbidity removal but adsorption reactions on the adsorbent surfaces might involve different physico-chemical and molecular forces, which act as bridge between particles and serve as the attachment sites. The adsorption on filter media changed the surface properties of the filter media, as the raw water contained numerous types of sediments and clay particles. Pollutant adsorption would be high with smaller sand size, but in return of lower hydraulic flow [24].

Among the biological agents, significant removal of *E. coli* and total coliforms were achieved. Although the quality was not within the WHO limits, the bacterial counts almost followed Pakistan National Environmental Quality Standards (Table 4). However, it seemed that HSF pollutant removal potential would further increase as the filter media ripened. The current design and operation of HSF would allow unsaturated intermittent flow, and pollutants were mainly removed through adsorption, physical straining and natural die off from the raw water. Adsorption was important mechanism that was responsible for the attachment of small sized pathogens to different charged surfaces that adsorbent material in the filter might offer. This mechanism included the process of electrostatic attraction between different charge particles [25–27] and the bacterial cell which also possessed negative surface charges could be attracted to the positively charged organic matter [19]. During the natural die off process, many factors like aging and stress in HSF media might cause the pathogenic deaths [28]. Hence, these removal mechanisms caused >96% reductions of *E. coli* and total coliforms from the contaminated water samples. These findings are in agreement with those reported in the literature [29–31].

4. Conclusion

The HSF may be used to produce clean and relatively safer drinking water from turbid and biologically contaminated water during 10 days operation of HSF. KAP survey indicated that local people were eager to adopt such durable and affordable treatment system which was compatible with the local environment. Religious and cultural beliefs were found dominant while the linkage of diarrheal disease to water quality was almost non-existent. The home-made treatment technology was socio-culturally acceptable, technically simple, easily accessible, sustainable, cost effective, and user friendly possessing potential for dissemination. HSF system is a new approach

Table 4
The reductions in *E. coli* count from HSF after 10 days operation.

Village name	Union council	Pre filtration *E. coli* (cfu/100 ml)	*E. coli* after 10 days of HSF operation	% age reduction of *E. coli*	WHO permissible limits	Pakistan NEQS Limits
Kuz Narsook	Bateela	108	4	96.3	Nil	<4
Dhonga Sar	Biari	94	2	97.9	Nil	<4

in developing countries in general and Pakistan in particular, so, the development agencies and government departments may implement such low cost potable water treatment system on large scale, instead of spending huge amount on poor water quality aftermath health consequences.

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