

Research Paper

Water quality before and after a campaign of cleaning and disinfecting shallow wells: a study conducted during and after floods in Khyber Pakhtunkhwa, Pakistan

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ABSTRACT

This study reports on a water quality assessment of the Water, Sanitation and Hygiene program implemented by the Swiss Agency for Development and Cooperation in the districts of Charsadda and Nowshera in Khyber Pakhtunkhwa, Pakistan, in the aftermath of the severe flood of 2010. During emergency operations, over 4,500 shallow wells were cleaned using the standard protocol suggested by the World Health Organization. Bacteriological analysis and chemical-physical parameters such as temperature, conductivity, turbidity and pH were tested before and after cleaning. Four to five years after the emergency operation, in 2014–15, a set of 105 representative wells was analyzed again, considering the same parameters and looking for additional contaminants (pesticides, arsenic and fluoride). The post-flood well-cleaning campaign was effective in the immediate reduction of fecal contamination of water (from 85% to 20% as measured 7–30 days after cleaning); however in the following months/years the rate of fecal contamination rose again (up to 62% of all measured domestic wells, $n = 105$). Along with laboratory analysis data, this study investigated the source of contamination of shallow wells and identified human practices in several cases. This information was useful for the design of future SDC interventions in the WASH sector.

Key words | flood, shallow well, water quality, well cleaning

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INTRODUCTION

Background and context

Wells are an important source of drinking water in many countries today. A large proportion of the world population is drinking water from wells of varying depth, water volume and water quality. Most of these wells are hand dug, having a diameter just large enough for the diggers, and they may

or may not be lined to protect them from surface water contamination. Many have no wellhead structure to prevent contaminants from entering them. This makes them very susceptible to pollution from agricultural activities as well as fecal contamination from improperly sited latrines. The health risk related to drinking water from private wells has been identified (Fewtrell & Bartram 2013; Wolf *et al.* 2014), not only in developing countries, but around the world including the USA, through the evaluation of risks for children consuming drinking water from private wells (Rogan & Brady 2009). However, the advantage of private wells

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lies in the fact that they are inexpensive to dig and can be accessed using simple manual methods such as a rope and bucket, eliminating the need for more complicated and expensive drilling and pumping equipment (Rowles 1995).

As stated by Bain *et al.* (2014), 'access to an improved source provides a measure of sanitary protection but does not ensure water is free of fecal contamination nor is it consistent between source types or settings'. The authors of this study agree with these conclusions, also supported by a strategical document jointly published by WHO & UNICEF (2017) (Sustainable Development Goals baselines) and recognize the need for enhancing monitoring strategies that include both indicators of sanitary protection and measures of water quality.

In 2010 the entire northwest of Pakistan was badly hit by floods that affected around 20 million people nationwide. In the province of Khyber Pakhtunkhwa (KPK), this flooding contaminated thousands of wells and presented a public health hazard that outlasted the immediate threat of the flood itself. According to Relief International (2010), 98% of the water and sanitation facilities in the area were severely damaged or unusable due to heavy rain or water flow in the two districts of Charsadda and Nowshera. The availability of drinking water became a big concern, as most water sources, including the groundwater, were contaminated and the wells were unusable.

Emergency relief efforts were provided during the floods and later measures were taken to assist the affected populations in getting through the winter. In August 2010, the Humanitarian Aid Unit of the Swiss Agency for Development and Cooperation (SDC-HA) started various reconstruction projects in the domains of public infrastructure, drinking water and disaster risk reduction (DRR).

Well cleaning and well rehabilitation

The immediate relief operations focused on 'well cleaning' using the standard protocol suggested by WHO and described in the 'Technical note on drinking-water, sanitation and hygiene in emergencies' Note No. 1: Cleaning and disinfecting wells (Godfrey & Reed 2011). This protocol was later translated in a more detailed technical guideline by the Swiss Agency for Development and Cooperation (Valsangiacomo *et al.* 2015). This included simple dewatering,

physical cleaning and disinfection with chlorine. The long-lasting program (extended until 2016) aimed at physically rehabilitating drinking water wells, mainly by adding a hand pump and/or protecting the wellhead.

Project area, geology and hydrogeology

The Peshawar intermountain basin is home to five districts of the KPK province of Pakistan. These include Peshawar, Nowshera, Charsadda, Mardan and Swabi. The area has an elevation of 276 meters above sea level and is home to one of the most fertile lands in KPK. The three rivers that caused the massive flood in 2010 flow through this area: the River Jindi, the Kabul River, and the Khiali (or Swat) River, all of which are the main sources of irrigation for tobacco, sugarcane, sugar beet, wheat, maize and vegetables.

Recent deposits from rivers, streams and flood plains underlie about 80% of the area. These belong to the Pleistocene age group and are classed into three types: (i) stream beds, containing fresh and/or recently deposited sediments, including sand, silt and gravel, with some clay material as well; (ii) fan deposits, composed of gravel, silt and sand with a small amount of clays. They exhibit loose to some binding effects between their composite grains, typically forming a fan or lobe structure around a stream mouth; and (iii) alluvium, which includes recent-to-old deposits of sediments containing fine-to-coarse sand, silt and clay deposits, and may be flood plain deposits, wind-blown deposits, or lake sediments.

Approximately 20% of the area is covered by other Paleozoic rock types. These rocks are typically revealed in the outcrops that stretch in a belt, which bounds the district from the northwest and along the entire western territory.

The Charsadda district is underlined by a thick sequence of fluvial and windblown sediments. The western and north-western portions are composed of piedmont deposits, the area between the Kabul and Khiali Rivers (locally called *Doaba*) contains fluvial sediments, and the eastern and northeastern portion of the district are predominantly loess (wind-blown) deposits.

The aquifer system mostly consists of large lens-shaped perched aquifers. Most of these are semi-confined in nature. The absence of significant changes in the groundwater depths over short distances suggests the hydraulic

continuity of the aquifers. The piedmont deposits act as recharge zones for the aquifers of the district. The depth of the water table is 25–50 meters. In the *Doaba* area, the water table is highly susceptible to changes in the Kabul and Khiali Rivers. The water table is shallowest (<3 to 6 meters) in the *Doaba* area, with frequent exchanges between the surface and groundwater. The water table depths in the loess plain range from 3–10 meters. The permeability ranges from low (piedmont plain) to medium (loess plain) to high (*Doaba plain*).

Traditional wells in the region are particularly vulnerable to contamination from surface water, they are characterized by brick casing, shallow water (sometimes less than 5 m, never more than 10 m) no apron and short distance to sanitation facilities and domestic animals. There were no consistent data on water quality before the flooding.

Objectives of the study

This study focuses both on the short- and long-term water quality effects of the SDC Water, Sanitation and Hygiene project in the district of Charsadda in KPK, which involved more than 100,000 beneficiaries using more than 6,000 domestic wells. This project included well cleaning and well-improvement measures as well as water treatment and hygiene awareness activities. Domestic wells were rehabilitated at the household level, and the technical staff of

service providers was trained in the management and maintenance of water supply facilities (where available). The two components of the program are illustrated in [Figure 1](#).

Ethical aspects

With the aim to build research partnerships in the most constructive, balanced and results-oriented manner, and recognizing that transboundary and intercultural research in partnership is challenging, the entire project has been conducted from the beginning (design) to the end (publishing) observing the 11 principles proposed by the Commission for Research Partnerships with Developing Countries ([Stöckli *et al.* 2014](#)).

METHODS

Water quality was measured before and after cleaning of 4,500 wells during the emergency phase, making this study the largest one of its kind performed during the humanitarian/emergency phase. Four years after the flood event, a set of 105 wells were again measured and compared with the initial results. The main objective of the second phase of the study, performed in 2014–15, was to conduct an extensive water analysis campaign (bacteriological and chemical investigation) on a selection of water points representative



Figure 1 | (a) 'Hard component' – well cleaning and well-rehabilitation activities after WHO Technical note No. 1 on drinking-water, sanitation and hygiene in emergencies: 'Cleaning and disinfecting wells'. (b) 'Soft component' – hygiene promotion, training of teachers and school children on water and hygiene.

of the hydrogeology of the project area in order to determine the different paths of contamination. Further, the study aimed to confirm or complement the overall information on beneficiaries in the project area, with a special focus on social information pertaining to the acceptance of awareness campaigns, effective change of habits, or the proper use of household water treatment and safe storage (HWTS).

Sanitary inspection of wells

The sanitary inspection of wells was performed according to World Health Organization procedures (1997), using risk-of-contamination scoring ranking from 1–11. This includes the evaluation of following diagnostic parameters: (1) Is there a latrine within 10 m of the well? (2) Is the nearest latrine on higher ground than the well? (3) Is there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well? (4) Is the drainage poor, causing stagnant water within 2 m of the well? (5) Is there a faulty drainage channel? Is it broken, permitting ponding? (6) Is the wall (parapet) around the well inadequate, allowing surface water to enter the well? (7) Is the concrete floor less than 1 m wide around the well? (8) Are the walls of the well inadequately sealed at any point for 3 m below ground? (9) Are there any cracks in the concrete floor around the well which could permit water to enter the well? (10) Are the rope and bucket left in such a position that they may become contaminated? (11) Does the installation require fencing?

An assessment was made of the priority for remedial action for each well based on the grading system of microbial quality and sanitary inspection risk scores (WHO 2011).

Sampling strategy

Sampling during the emergency phase ($n = 2348 + 2380$ analyses)

Of the 4,500 rehabilitated wells during the emergency phase of 2010 in the flooded areas of Charsadda and Nowshera, over half of them have been analyzed before ($n = 2,348$) and after cleaning ($n = 2,380$).

Sampling 4–5 years after the emergency phase ($n = 105$ analyses)

The analytical campaign conducted in 2014–15 included only a random sample of 105 wells. A random sampling strategy with regard to geographic distribution, hydrogeological information, potential sources of contamination and types of wells was designed in order to generate a representative sample for the entire study area.

Thirteen villages within a total of six union councils were selected for sampling of previously rehabilitated wells. Each village selected was representative of the entire union council, each one being very similar in terms of urbanization, industry-agriculture and socioeconomic context to the rest of the villages in the area. Two-three villages were selected within a union council where villages were small (less than 1,000 inhabitants) and the number of villages was large (more than five villages). Water samples were collected from the four corners of each village as well as in the middle of the village. One hundred and five wells were selected for analysis. Within each village, 10–12% of the rehabilitated wells were sampled and tested for fecal contamination (bacteriological analysis) and basic chemical and physical parameters. Samples were collected with sterile sampling bags in the field, according to WHO standards, and stored in a cool box in order to prevent exposure to sunlight during sample collection. To get accurate and reliable results, the samples were analyzed within the same day of collection, usually within 2 hours. The equipment for bacteriological analysis was tested against known samples (positive and negative samples) in order to check the efficiency of the procedure.

Analytical parameters

All analytical parameters were performed using a standard laboratory developed by SDC, except for biocides analysis, which was done at the Nuclear Institute for Agriculture and Biology (NIAB) located at Faisalabad, Pakistan. Bacteriological analysis, the most important parameter for determining fecal contamination, was performed using Hardy Diagnostics Compact Dry™ EC, a ready-to-use test method recommended for the isolation and enumeration of coliforms and *Escherichia coli* in

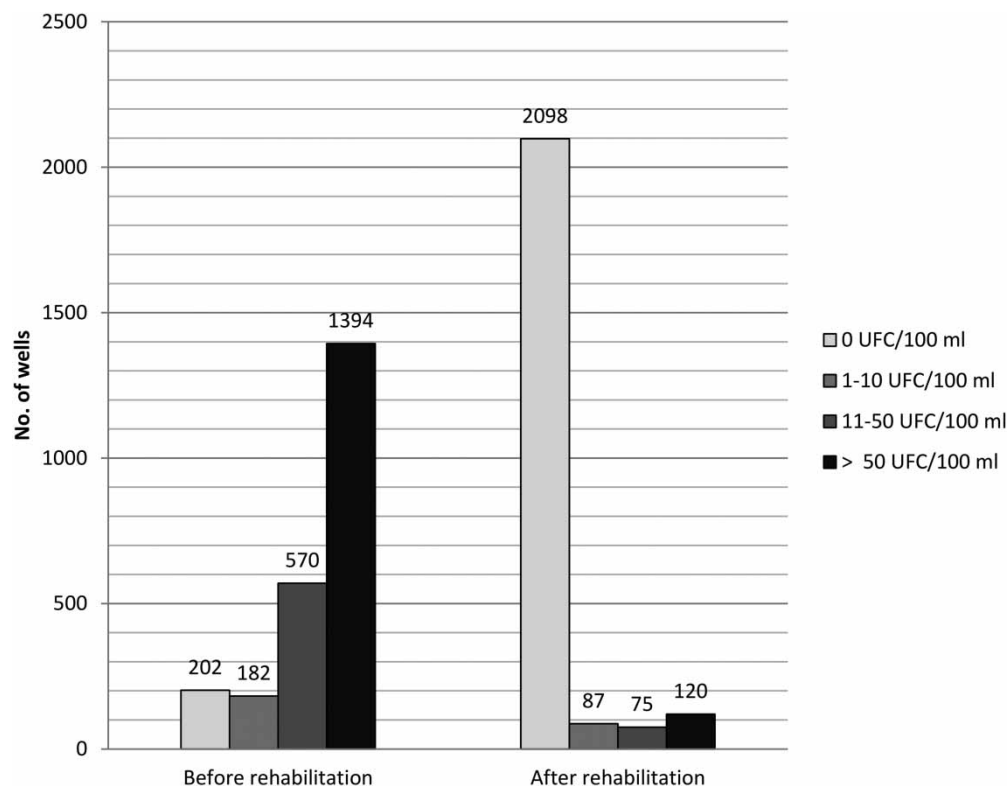


Figure 2 | Stages of bacteriological analysis: fecal coliforms and/or *E. coli*.

drinking water and validated by Bachmann & Lüthi (2003). Incubation was performed at 44 °C in order to detect fecal coliforms rather than total coliforms, as recommended by the WHO guidelines on drinking water quality (2011). During the emergency in 2010 the following parameters were tested before and soon after cleaning: bacteriological risk, temperature, electrical conductivity, turbidity and pH. During the second phase in 2014–15, biocides, fluoride and arsenic were added to the previous set of parameters.

RESULTS

Fecal contamination and sanitary inspection during and soon after emergency: 2010–13

Soon after the flood of 2010, over 4,500 wells were rehabilitated/cleaned, with over half analyzed before ($n = 2,348$) and soon after cleaning ($n = 2,380$). Figure 2 indicates the degree of contamination of wells with fecal coliforms and/or *E. coli* while Table 1 indicates the distribution of wells

Table 1 | Risk score and bacteriological contamination before and after cleaning

	Risk score of wells before ($n = 2,348$) and after cleaning ($n = 2,380$)				Bacteriological contamination	
	Low risk	Intermediate risk	High risk	Very high risk	Not contaminated	Contaminated
Before cleaning	0%	2%	17%	81%	15%	85%
After cleaning	88%	12%	0%	0%	80%	20%

according to their risk score as assessed by sanitary inspection (WHO 2011). The effect of the cleaning campaign and partial rehabilitation of wells is remarkable for both aspects, the risk score, considering also the sanitary inspection, and the massive drop in fecal contamination as measured with bacteriological analysis.

Analytical work 4–5 years after emergency (2014–15)

Several years after the flood event, 105 wells were retested for bacteriological contamination and chemical and physical properties.

Data on bacteriological analysis

The distribution of fecal contamination is illustrated in Figure 3. Bacteriological analysis showed a significant presence of bacteria indicating fecal contamination, with roughly 65% of the samples being contaminated. A significant difference was found between wells rehabilitated by the addition of manual pumps as compared to those without manual pumps (see Table 2 below). Wells with manual pumps, implemented in the village of Dildar, presented

nearly no fecal contamination. Hand-pump rehabilitation represents a significant improvement of the well, preventing it from external contamination, mainly caused by dirty buckets and/or ropes.

Data on chemical and physical analysis

Physico-chemical analysis of the samples did not show any major public health concerns with respect to the reference values suggested by WHO with the exception of EC, turbidity, SO₄, Cl, F and the values for biocides commonly used in the surrounding agricultural area. While major ions do not represent a significant problem (Table 3), widespread contamination with biocides in the water table (insecticides in particular) has been shown (Table S1, see Supplementary Information, available with the online version of this paper).

In Table 3, there are a few specific points to note. Regarding physical parameters, two samples presented some slightly increased turbidity (10 and 18 NTU); ten samples presented higher electrical conductivity (salinity); one sample presented increased total dissolved solids. However, these exceedances do not pose a major threat to

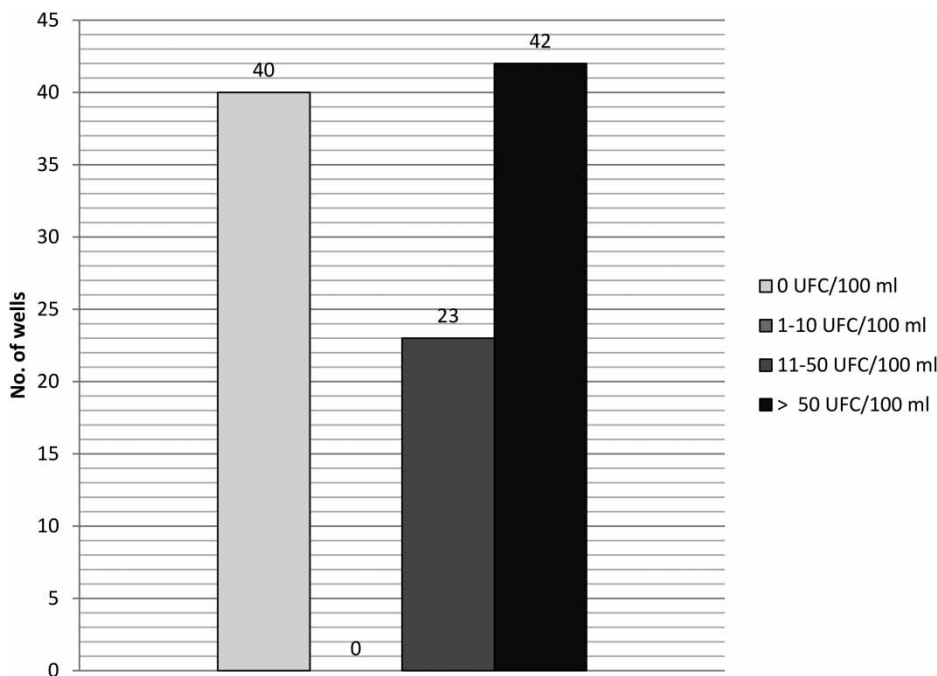


Figure 3 | Bacteriological analysis 2014–15: fecal coliforms and/or *E. coli*.

Table 2 | Comparison of fecal contamination with hand pumps or well covering

	Number of samples	Wells with fecal contamination (%)	Wells with no fecal contamination (%)	Wells rehabilitated with hand pumps (%)	Wells rehabilitated with well covering (%)
Jammat	17	64	36	0	100
Ghurambak	20	65	35	0	100
Totakai	2	80	20	0	100
DildarGarhi	11	27	73	100	0
Shekan	6	50	50	0	100
Kandari	19	58	42	0	100
Shamsudin	6	67	33	0	100
Nawi kali	5	80	20	0	100
Ghaladher	3	67	33	0	100
Hamza	3	33	67	0	100
Banaras	2	100	0	0	100
Zara maina	4	100	0	0	100
Tolandi	1	100	0	0	100
Mughulki	1	0	100	0	100

human health. With regard to chemical parameters, 11 samples presented slightly higher concentrations of sulfates, one sample presented a slightly higher concentration of

chloride, and one sample presented a slightly higher concentration of fluoride, a water parameter raising health concern. It is interesting to note that the values for nitrates and

Table 3 | Analysis of major ions (parameters presenting a maximum concentration above WHO reference values are in bold)

Parameter	Unit	WHO max. level (WHO 2011)	Mean	Median	Minimum	Maximum
Electrical conductivity	µS/cm	1,000	774.8	684.0	291.0	2,662.0
TDS	mg/l	1,000	395.3	353.0	145.0	1,331.0
pH		6.5–8.5	7.4	7.4	6.8	8.3
Turbidity	NTU	5	2.0	1.4	0.2	18.0
Temperature	°C				29.9	33.0
Ca	mg/l	250	123.2	120.0	60.0	250.0
Mg	mg/l	250	32.7	24.0	24.0	133.0
Fe	mg/l	2	0.1	0.2	0.0	0.4
SO ₄	mg/l	250				>400
Cl	mg/l	250	64.3	41.0	29.0	295.0
NO ₃	mg/l	50	6.5	3.0	0.0	50.0
NO ₂	mg/l	3	0.006	0.000	0.000	0.300
NH ₃	mg/l		0.39	0.25	0.25	1.00
Total hardness	mg/l	500			125.0	375.0
Alkali	mg/l		164.4	150.0	60.0	360.0
As	mg/l	0.01	0.0	0.0	0.0	0.0
F	mg/l	1.5	0.46	0.37	0.18	1.53

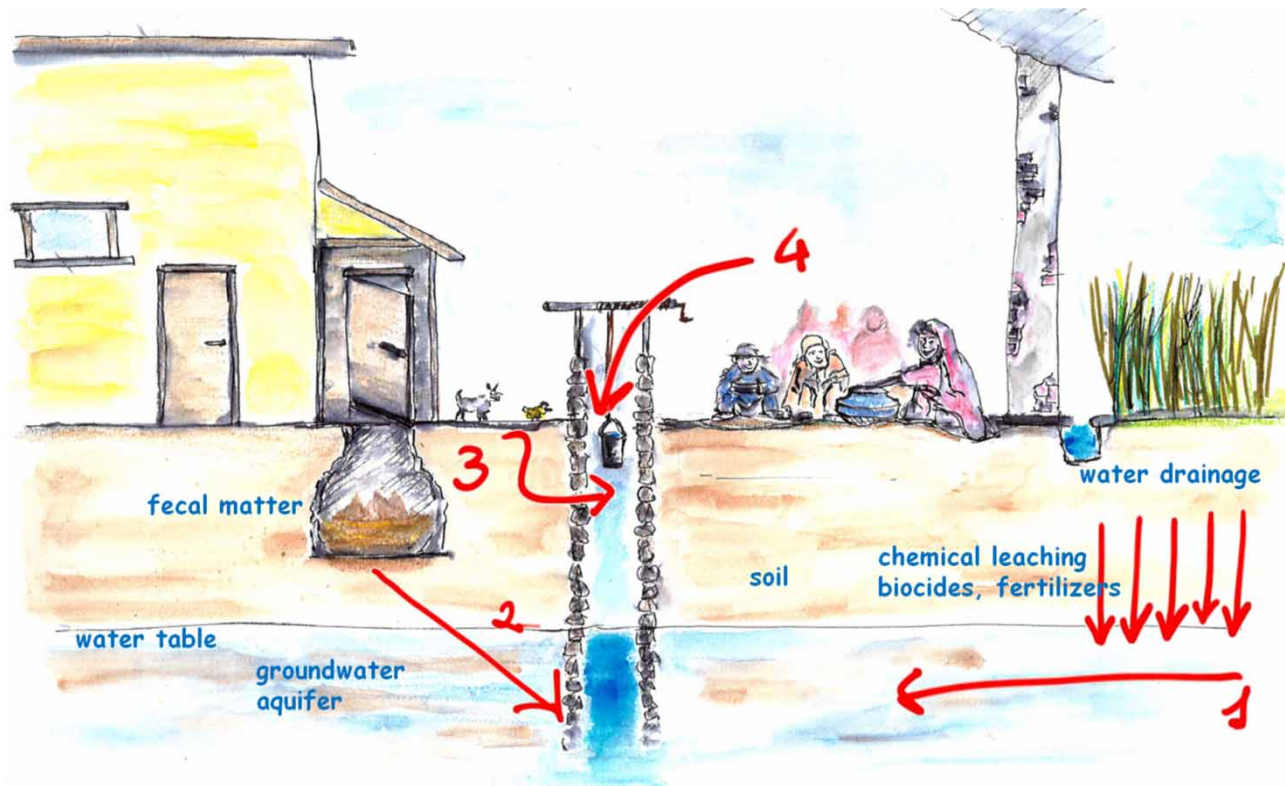


Figure 4 | Possible paths of contamination (drawing by Pamela Principi, SUPSI).

ammonia were relatively low, considering that latrines often do not fulfill the requirements for the minimum safe distance to wells. Further, fluoride and arsenic seem not to be a major health concern in this area of Pakistan. Finally, regarding biocides, a widespread contamination with the chemical residues of agricultural biocides can be detected in the study area. This finding represents a preliminary result that should be confirmed with a new collection of samples to be analyzed by a reference laboratory, including an analysis for heavy metals (fertilizers).

Paths of contamination

Various possible paths of contamination of shallow wells were identified (Figure 4): (1) generalized contamination of the groundwater aquifers with agricultural chemical residues; (2) direct contamination with fecal matter; (3) infiltration of surface water in the well due to poor construction, such as the lack of an apron; (4) lack of protection and

hygienically inadequate use of domestic wells: contamination with dirty bucket and/or rope.

In order to minimize risk of contamination, the following recommendations were delivered to the local authorities and to the community: (i) installation of hand pumps where possible; (ii) teaching the 'safe usage of open hand-dug wells' and the safe handling of clean water; (iii) local authorities should be informed and advised in order to take proper preventive actions to address contamination of groundwater with biocides, providing that this study finding is confirmed by a reference laboratory.

DISCUSSION

Contamination reduction

The well-cleaning campaign promoted by SDC soon after the floods was effective in reducing fecal contamination in the drinking water; contaminated wells dropped from 85%

to 20% in 7–30 days after cleaning. The subsequent well rehabilitation program, accompanied by a soft component of hygiene promotion, was necessary for preparedness in case of a future flood event. Initial cleaning was also necessary to restore functionality of mud-covered wells.

Bacteriological quality

The present study demonstrates that contamination with fecal matter (the presence of fecal coliforms and/or *E. coli*), as measured between 1 and 5 years after the emergency phase, appears again in 62% of the domestic wells. Hygiene promotion and proper well construction seem to be the only effective instrument to prevent this type of contamination.

Chemical contamination

While major ions do not represent a significant problem, a widespread contamination with biocides (insecticides in particular) was detected.

Paths of contamination

Path 1 represents a diffuse contamination of the groundwater with agricultural chemical residues (e.g., biocides). Direct contamination with fecal matter due to the lack of Minimal Safety Distance of latrines (Path 2) and infiltration due to the lack of adequate aprons (Path 3) seem to be important, but Path 4, lack of protection and hygienically inadequate use of domestic wells, seems to be the main source of contamination with fecal matter.

Considering the precision of the analytical methods, a discussion of the results in terms of hydrogeological processes will be limited to electrical conductivity (EC), total dissolved solids (TDS), nitrates, *E. coli*, and biocides.

CONCLUSIONS

The results of this study should be useful for any organization implementing well-cleaning/rehabilitation campaigns after floods. The well-cleaning campaign promoted by SDC for gaining access to mud-covered wells and reducing

fecal contamination in drinking water proved to be effective. The subsequent well rehabilitation program, accompanied by a soft component of hygiene promotion, was necessary for human health. Well-cleaning actions should always be conducted during emergency operations in the wake of floods in locations where domestic wells represent the main source of drinking water. However, this action does not guarantee water safety in the long term. The present study demonstrates that contamination with fecal matter, as measured several years after the emergency phase, appears again in domestic wells. The main source of contamination seems to be related to human practices, such as the use of dirty buckets/ropes, animals defecating close to open wells, and unprotected wells collecting surface runoffs. The reason of this return to the initial situation might be due to a lack of behavioral change within the population. Given that a change in sanitary infrastructure, mainly pit latrines, may take time or not occur at all, to improve bacteriological quality of domestic wells, better protection of the wellhead is the recommended action. This means changing the way in which water is taken from the well by installing hand pumps and closing the wellhead to avoid runoffs entering into the wells. Hygiene promotion and behavioral change appear to be effective instruments for preventing this type of contamination. Fecal contamination is a more locally restricted problem, occurring at the domestic well level. Regarding chemical contamination, while major ions represent rather a minor problem, the widespread contamination of the aquifer with biocides (insecticides in particular) presents a major health concern.

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