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Communication

Results of the First Improvement Step Regarding Removal Efficiency of Kanchan Arsenic Filters in the Lowlands of Nepal—A Case Study

Barbara Mueller

Bamugeobiochem, Horbenstrasse 4, 8356 Ettenhausen, Switzerland; bar.mueller@unibas.ch

Abstract: In Nepal as well as in other countries in Southeast Asia, the World Health Organization drinking water guideline of 10 µg/L concerning arsenic concentrations in ground water hosted in Quaternary alluvial sediments is often regionally exceeded. The commonly accepted theories include that arsenic in ground water stems from reductive dissolution of As-rich Fe(III)hydr(oxides) including microbial degradation of sedimentary organic matter. On the contrary, the influence of clay minerals in the sediments as hosts for As was clearly underestimated, as geochemical analysis depicted that As was generally associated with specific elements such as Na, K, Al, and Li. Moreover, there was a very weak correlation or decoupling between As and Fe in the ground water in Nepal, and this fact points to consequences for water treatment. The so-called Kanchan filters, used for the removal of As, installed in the lowlands of Nepal often exhibited effluent As concentrations well above Nepal's drinking water quality standard value (i.e., 50 µg/L). Ground water concentrations of Fe and As proved to be the most important geochemical factors regarding the performance of the filters. Moreover, the flow rate as well as the contact time to the rusty nails in the filter, intended to adsorb As on their surface, influenced the removal efficiency. The removal rate was severely influenced by the handling of the filters, too. This short communication provides an overview of the removal efficiency of 30 filters, their drawbacks, the influence of the aging material in the filters as well as measures of improvements to enhance the efficiency of the filters. Proper instruction for users of Kanchan filters is a major point that needs to be addressed in the future.

Keywords: Nepal; ground water; arsenic; Kanchan filter; removal efficiency

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1. Introduction

Nepal is among several countries in Southeast Asia affected by ground water contaminated with the highly toxic element arsenic (As) [1–5]. Negative health effects (skin lesions, ulcers, and cancer) are consequences of the long-term intake of arsenic-polluted drinking water. Changes in ground water parameters, such as pH, redox conditions, temperature, and solution composition, trigger the release of As from solid phases in aquifers. As late as 1999, a first report of this issue was published in [1], stating that the current drinking water guidelines of the World Health Organization (WHO), set at 10 µg/L for As, was frequently exceeded in several provinces in Nepal. The last local report concerning the arsenic crisis was published in [2], stating that 1.73% of 1.1 million tube wells tested exhibited an As concentration above Nepal's drinking water standard of 50 ppb, and in 5.37% of these tube wells, the As concentration exceeded the WHO's guideline value. By far, the most affected district is Nawalparasi, where proper water treatment units are urgently needed.

The origin of the arsenic contaminated ground water is purely geogenic: the southern lowlands of Nepal (the so-called Terai) delineates an active foreland basin consisting of Quaternary sediments (i.e., molasse along with gravel, sand, silt, and clay). The ample reservoirs of ground water are fed by heavy monsoon precipitation and snow-fed river [3]. These Quaternary sediments, themselves, constitute erosional debris being removed from the Nepal Himalayas—the most protruding mountain chain of the country—built up by different tectonics consisting of various rocks being metamorphic, sedimentary, and igneous in origin. At least some of the ground water arsenic heterogeneity found in the foreland and delta is caused by variable erosion of these rocks [4,5].

The district of Nawalparasi is the best characterized Terai province concerning local geology and arsenic contamination. This district represents the continuation of the Indo-Gangetic plain. Narayani is the major river of this district having its origin in the Higher Himalayas and exerting a grand influence on the unconsolidated Holocene fluvial deposits. Referring to [5], the generally fine-grained sediments here consist of sands, silt, and clay including micas. Commonly elevated concentrations of As are typically observed in areas with fine-grained sediments [6–9]. Arsenic is particularly incorporated in finer particles such as clay minerals [9–11].

Although the authors of [12] thought that As in the ground water appeared to be derived from reductive dissolution of As-rich Fe(III)hydr(oxides) driven by microbial degradation of sedimentary organic matter, the authors of [5] described As being concentrated in clayey sediments and mostly associated with some specific elements (Fe, Al, K, and C). The conclusion that alumosilicates, such as clay minerals, represent a substantial source of As in Nepal therefore seems warranted. An obvious decoupling between the concentration of Fe and As in the ground water as well as the positive correlation between concentrations of As, Na, and K in the ground water strongly advocate for clay minerals representing the major hosts of a substantial quantity of the arsenic [9].

To mitigate this arsenic related issue, so-called Kanchan filters were initially installed in Nepal as a joint venture between the Massachusetts Institute of Technology (MIT), the Environment and Public Health Organization (ENPHO), and the Centre for Affordable Water and Sanitation Technology (CAWST) [13–15]. The filters were developed to eliminate arsenic by sorption on Fe(II,III)(hydr)oxide phases formed via corrosion of ZVI (zero-valent iron) of small iron nails, placed in a perforated bucket above a thick sand layer (Figure 1). Yet, in [16], the insufficient performance regarding Kanchan filters installed in Cambodia was published. Later, it was stated that the removal efficiency of a majority of the Kanchan filters was unsatisfactory, and that the long-term performance of Kanchan filters in Nepal had rarely been tested [17]. Accordingly, more recent surveys of ground water treated with Kanchan filters still had effluent As concentrations well above Nepal's drinking water quality standard value (50 μg/L) with the concentration of As and Fe in the raw water being the main determining factors of removal efficiency [9,10].

The elimination of As by zero-valent iron media is based on the formation of Fe(II) and various Fe(II,III)(hydr)oxide phases by corrosion of ZVI material. Exfoliated Fe-particles with adsorbed As, which flow downward, are absorbed in the sand filter below. In [18], the authors evaluated factors influencing the removal of arsenic with iron nails in laboratory columns. They found that As removal increased up to 65–95% but was strongly dependent on the ground water composition.

To determine the reasons for the deficient elimination performance of the installed Kanchan filters, an ongoing research project, with starting points in October 2015 (post-monsoon) and in April 2017 (pre-monsoon), is analyzing As and other major and trace elements in raw ground water and in water treated with Kanchan filters. With this study, light should be shed on how to improve the removal efficiency of selected Kanchan filters reported with to have an insufficient removal rate within and around the municipality of Ramgram, the capital of the district of Nawalparasi. To achieve this goal, 30 filters were tested, and analyses of ground water (influent water), water filtered the nails only, and effluent drinking water were performed. Removal efficiencies were determined for the filters by comparing the ratios of ground water/water after passing the nail bed, water after passing the nail bed/effluent water as well as ground water/effluent water. With the application of this procedure, it was possible to determine the influence of the different layers of the filters on the elimination process as well as to rethink the design and improvements of the filters. This communication will focus on the results of the filtration process concerning removal efficiencies of the nail bed, the sand bed as well as the overall efficiency for the mentioned filters. Various factors, such as the age of the filtered material (i.e., nails and sand), maintenance, and mode of the operation by the users, exert an influence on the performance of the filters. The results of the geochemical constraints concerning the efficiency of the filters can be found in [9].

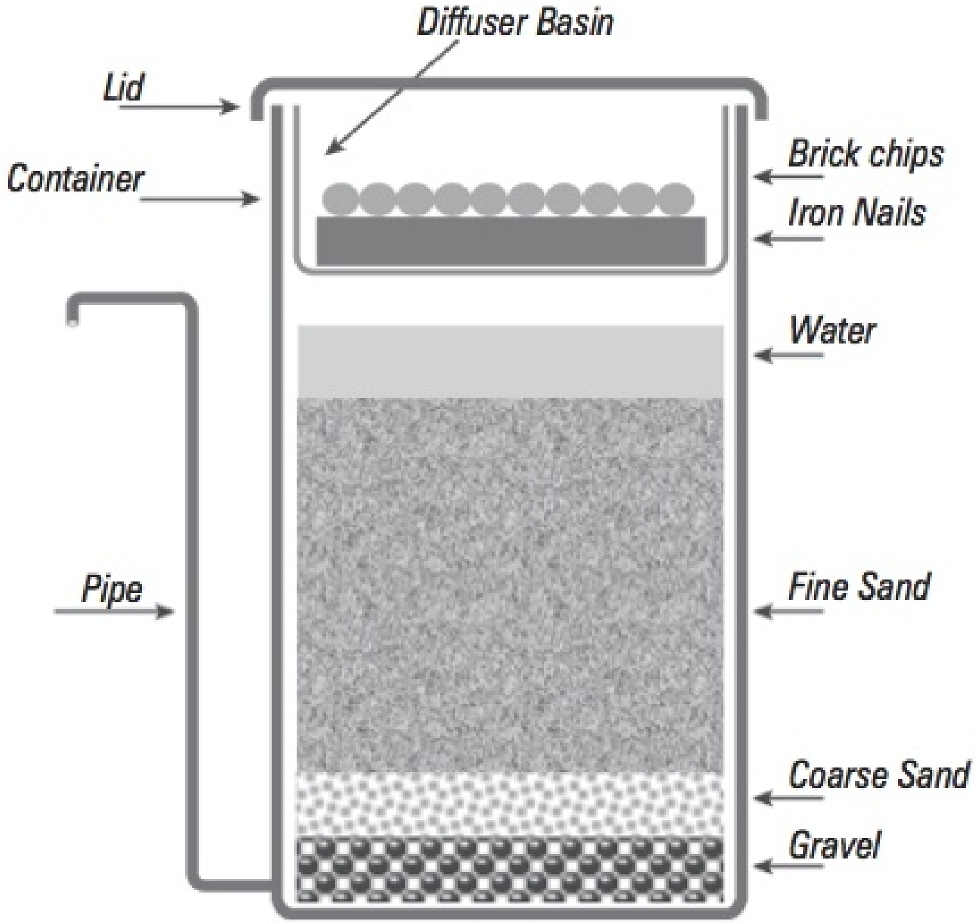

Figure 1. Diagram of the KAF showing the location and arrangement of its components [13].

2. Materials and Methods

As described in an underlying article, ground water trials were sampled within the urban area of Ramgram as well as around the villages of Manari, Panchanagar, Sukauli, and Tilakpur [9]. The depths of the privately owned tube wells, generally, did not exceed 25 m. The local soils were mainly built up of clayey sediments.

During the first field campaign in post-monsoon 2015, 30 usable ground water samples were allocated [9]. In order to re-evaluate the removal efficiency and the improvements concerning the removal efficiency after a first adaption procedure, 30 samples were again collected in turn during pre-monsoon 2018 and 2019. As some households in Manari were switching from filtered ground water to bought mineral water and others, Kanchan filters were no longer in use (mainly due to damaged parts), and those filters were replaced representatively according to a list provided by the ENPHO Kathmandu. All samples were later analyzed by ICP-MS at Eawag, Dübendorf, Switzerland. For a detailed description of the procedures see [9,18].

3. Results and Discussion

Table 1 lists all the removal efficiencies ever determined for the filters' feed with the respective ground water. Note that not all ground water samples used for investigations found in [9] were included in this table for reasons mentioned above. All filters mentioned in this table are solely those which could be accessed three times. In addition to removal efficiencies, ground water concentrations of Fe and As are listed, as these values present the most important geochemical factors regarding the performance of the filters. For all filters' samples for the first time in 2018, water samples were taken with the original configuration of the filter and instantaneously after adding an upper sand layer. Therefore, these filters exhibited the same concentrations of Fe and As (Kanchan filters SN1A to SN4C).

Table 1. Names of tube wells according to ENPHO and the respective removal efficiency in % of the Kanchan filters. Concentrations of Fe (mg/L) and As (µg/L) in ground water used to feed the filters.

Tube Well	Fe (mg/L)	As (µg/L)	Res. Time Original	R1 Original	R2 Original	OR Original	Fe (mg/L)	As (µg/L)	Res. Time New 2018	R1 New 2018	R2 New 2018	OR New 2018	Fe (mg/L)	As (µg/L)	Respective Time New 2 2019	R1 New 2 2019	R2 New 2 2019	OR New 2 2019
SN14 CS	1.44	622.6	15.1	30.1	−25.0	12.6	1.15	644.4	7.8	18.0	89.6	91.5	1.30	640.6	15.5	14.3	31.3	41.2
SN26 PR	3.75	266.3	8.1	54.5	−10.4	49.8	1.70	326.3	7.8	10.3	70.7	73.7	1.74	328.7	3.9	22.4	52.5	63.1
SN33 PR	2.60	363.6	12.9	15.6	51.2	58.8	1.86	363.4	16.1	17.7	37.0	48.1	1.60	401.6	17.0	27.7	27.9	47.9
SN35 PR	1.98	354.7	6.8	43.7	32.1	61.8	1.54	333.3	14.2	12.1	50.1	56.1	1.68	332.3	13.6	48.7	20.0	58.9
SN51 PR	1.23	200.1	12.0	8.4	24.6	31.0	0.30	239.8	5.4	7.5	92.7	93.2	1.07	259.8	4.7	17.8	46.7	53.7
SN53 PR	1.50	260.8	11.0	30.1	27.7	49.6	0.78	220.6	12.1	24.7	21.8	36.6	1.19	229.8	10.9	13.4	26.8	36.6
SN54 PR	1.62	281.7	9.8	17.3	35.6	46.7	1.53	277.8	9.7	22.9	40.2	54.0	1.21	265.2	21.3	39.3	3.8	41.6
SN55 CS	1.88	278.4	6.6	15.7	46.1	54.6	0.64	215.5	38.8	52.0	23.2	63.1	1.63	232.5	22.0	5.0	62.3	64.2
SN57 PR	2.73	179.6	26.4	37.9	44.8	65.7	2.31	188.1	29.4	28.2	49.3	63.6	2.12	214.4	29.4	35.4	47.3	66.0
SN62 PR	1.74	222.2	12.0	139	48.4	55.6	1.57	208.9	12.6	44.5	43.1	74.0	1.71	208.6	9.0	22.7	73.5	79.5
SN63 PR	2.25	158.3	5.7	28.0	90.5	93.2	2.60	96.54	14.9	18.8	67.9	73.9	2.29	98.58	12.3	28.5	59.4	70.9
SN64 PR	−0.27	100.66	9.7	−71.2	39.5	−3.5	2.21	164.8	13.6	23.0	59.6	68.9	−0.01	14.54	10.3	−17.1	−70.5	−99.6
SN66 PR	2.87	265.6	10.0	55.3	−2.4	54.2	2.65	257.3	13.6	25.4	48.9	61.9	2.15	242.8	14.2	34.3	37.0	58.6
SN67 CS	1.26	169.0	6.1	31.7	11.1	39.3	1.77	145.1		24.3	74.5	80.7	1.16	155.4	5.7	21.5	72.6	78.5
SN68 PR	1.18	192.9	6.6	15.3	48.0	56.0	1.08	169.0	18.1	6.6	40.7	44.7	0.002	192.9	25.8	17.5	11.8	27.2
SN69 PR	−0.27	280.3	19.8	−80.8	13.5	−56.5	0.85	398.6	23.9	−7.0	22.0	16.6	0.79	471.8	12.9	18.7	54.0	62.6
SN70 CS	0.95	502.1	5.8	10.7	29.0	36.6	0.40	470.7	6.5	1.6	−9.9	−8.1	0.53	480.1	5.2	2.0	−6.0	−3.9
SN72 PR	2.39	205.4	29.8	10.0	42.6	48.3	1.74	204.8	24.5	17.5	68.2	73.8	1.63	197.1	26.5	20.0	60.3	68.3
SN76 PR	1.17	140.5	8.7	7.3	−1.6	5.8	0.34	20.0	8.4	−24.8	−61.4	−101.4	0.88	139.1	9.0	16.3	66.6	72.0
SN56 PR	1.40	145.1	5.2	9.9	76.5	78.8	1.40	145.1	5.8	11.2	78.1	80.6	1.36	165.1	10.3	8.3	32.7	38.3
SN73 PR	1.94	446.6	10.3	9.7	58.8	62.7	1.94	446.6	11.0	45.3	33.0	63.3	4.22	556.9	8.4	92.0	−133.0	81.3
SN1A PR	2.11	44.57	9.7	48.8	75.1	87.2	2.11	44.57	10.3	26.4	82.0	86.7	4.59	96.23	9.7	77.2	41.4	86.6
SN1B PR	1.03	200.1	24.8	7.3	50.3	54.0	1.03	200.1	25.8	11.8	45.1	51.6	0.80	208.0	21.7	8.3	20.8	27.4
SN1C CS	5.27	114.3	29.1	−4.6	91.8	91.5	5.27	114.3	20.2	23.4	89.9	92.3	6.40	136.2	35.5	34.9	92.4	95.0
SN2A CS	1.03	161.7	11.6	22.0	35.5	49.6	1.03	161.7	12.4	12.6	46.1	52.9	1.17	166.9	10.8	6.4	−52.3	−42.5
SN2B CS	1.03	161.7	7.0	14.6	51.1	58.2	1.03	161.7	6.0	18.7	55.3	63.7	1.17	166.9	3.9	50.8	−73.9	14.4
SN3A CS	1.77	145.1	6.8	6.3	76.6	78.1	1.77	145.1	7.1	21.6	73.9	79.6	1.24	152.0	6.8	15.9	−60.8	−35.2
SN4A CS	1.27	735.6	32.6	17.3	96.5	97.1	1.27	735.6	31.7	39.4	95.1	97.1	0.38	634.3	32.6	12.5	93.4	94.3
SN4B CS	0.05	144.8	7.0	18.2	63.7	70.3	0.05	144.8	7.0	22.2	47.3	59.1	0.05	142.5	7.0	7.0	12.3	18.5
SN4C PR	0.19	119.5	3.5	8.1	56.1	59.7	0.19	119.5	3.9	22.6	48.1	59.8	0.20	108.6	3.9	33.8	37.2	58.4

$$\text{Removal efficiency 1 (R1, after passing nail bed): } 100 - (As_1 \times 100)/As_2 \quad (1)$$

R1 orig. = original version of the filter (without upper sand layer).
R1 new = adapted version of the filter (with upper sand layer).

$$\text{Removal efficiency 2 (R2, after passing lower sand layer): } 100 - (As2 \times 100)/As3 \quad (2)$$

R2 orig. = original version of the filter (without upper sand layer).
R2 new = adapted version of the filter (with upper sand layer).

$$\text{Overall removal efficiency (OR): } 100 - (As_1 \times 100)/As_3 \quad (3)$$

OR orig. = original version of the filter (without upper sand layer)
OR new = adapted version of the filter (with upper sand layer)
Whereas: As_1 = As concentration of ground water, As_2 = As concentration of water after passing the nail bed, As_3 = As concentration of finally filtered water after passing nail bed and lower sand layer.

CS = Concrete square filter;
PR = Plastic round filter;
Res. = Residence time in minutes.

Figure 2 exhibits the overall removal efficiency from 2015 in terms of dependence from Fe and As concentrations in ground water. Inspection of the data from 2018 and 2019 revealed that these dependencies did not vary considerably; therefore, the data from 2015 were taken for illustration. There was no correlation between the As concentration and removal efficiency, but there was a slightly positive correlation for Fe. Hence, other factors than the concentration of these elements regarding the performance of the filters must be evaluated.

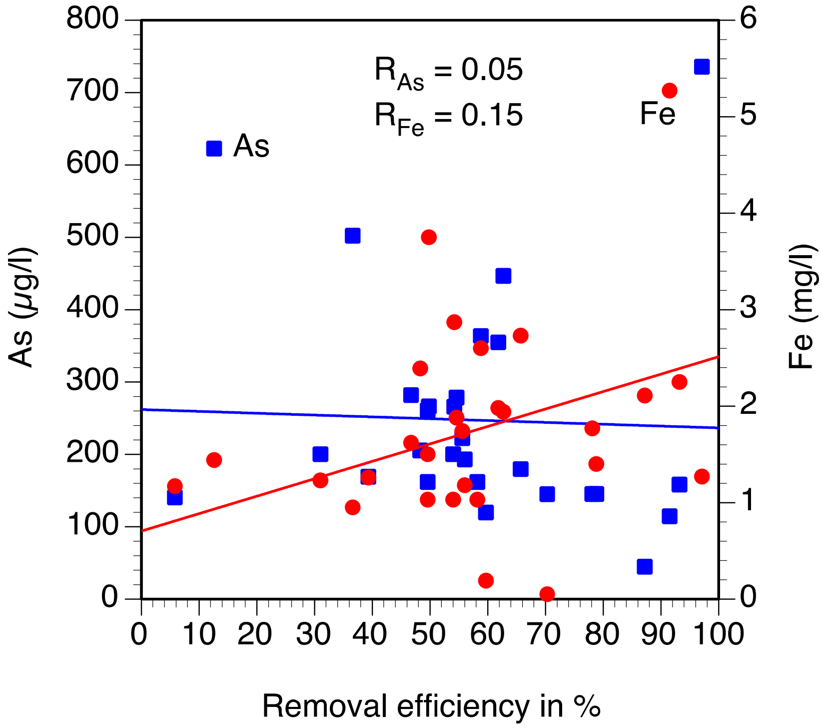

Figure 2. Overall removal efficiency from 2015 in terms of the dependence from Fe and As concentrations in ground water. Correlation coefficients are included.

On the occasion of the three mentioned ground water sampling campaigns (i.e., 2015, 2018 and 2019), in addition to ground water (raw water from handpumps), samples from partially filtered water only passing over the nail bed and totally filtered drinking water (after passing the sand layer) were collected. The concentration of As, Fe, and other major and trace elements were determined in these three samples from each filter. The removal efficiency (%) regarding the concentration of As was calculated as follows:

$$\text{Removal efficiency 1: } 100 - (As_1 \times 100)/As_2 \tag{4}$$

$$\text{Removal efficiency 2: } 100 - (As_2 \times 100)/As_3 \tag{5}$$

$$\text{Overall removal efficiency: } 100 - (As_1 \times 100)/As_3 \tag{6}$$

where As_1 = As concentration of ground water, As_2 = As concentration of water after passing the nail bed, and As_3 = As concentration of the finally filtered water after passing the nail bed and sand layer.

With the diameter of these basins, the weight of the nails, the density of the nails, and the flow rate through the whole filter being given, the contact time with the nails could be calculated. For the sake of clarity, the three different removal efficiencies are generally termed removal efficiency 1, removal efficiency 2, and overall removal efficiency. The efficiencies were calculated for the undisturbed original system, viz., as the filters were installed primarily. Samples were taken between 2015 and 2018 as some of the sampled filters were not in use anymore or abandoned in 2018.

The most striking feature is the wide range of the overall removal efficiency ranging from 5.81% (filter SN76) to 97.1% (filter SN4A). The omitted negative values of the overall removal efficiencies can be related either to a complete dry nail bed (SN69) or an irregular surface of the nail bed (promoting channels where the ground water can freely pass without contact to the nails) leading to a negative removal efficiency 1. The exhaustion of the lower sand bed to filter out tiny exfoliated particles from the nails are an alternative explanation for negative removal efficiencies. Medium removal efficiency 2 could not outcompete the mentioned irregular removal efficiency 1 due to year-long used sand in the lower sand layer. In general, this sand is hardly ever replaced according testimonies by queried residents. Filter SN76 was determined with a very low overall removal rate owing to the fact that nails and sand were hardly ever replaced. Residence times for filters SN69, SN64, and SN76 were determined to be 19.77 min, 9.69 min, and 8.70 min, respectively. The best performing filter, SN4A, was only three years old when probed the first time and hardly ever used, hence, maintenance was declared unnecessary by the residents; however, the nails were wet at the sampling time after purging the filter thoroughly before sampling. The significant overall removal rate was as high as 97.1%. Inspection of the other two removal rates (39.4% of the nail bed; 95.1% of the sand layer) clearly indicated the importance concerning the capacity of the fine-grained sand (grain size < 2 mm) to remove exfoliated particles from the nails above. Inspection of the calculated contact time with the nails revealed a time of 31.55 min for the SN4A filter, which was the highest of all, and it was determined so that the extremely high influent As concentration of 735.6 μg/L could be lowered to 21.65 μg/L, despite the low concentration of Fe (1.27 mg/L) [9,11]. In the second-best performer (i.e., SN63), with an overall removing efficiency of 93.2%, the nails were lightly covered with water, the filter was used regularly keeping the nails wet, and the sand was fresh. Removal efficiencies 1 and 2 were as high as 28.0% and 90.5%. The As concentration of the ground water feeding filter SN63 was rather low (158.26 μg/L), and the Fe concentration was higher than it was for SN4A (2.25 mg/L), whereas the residence time was calculated to be 5.74 min. The final concentration of As in drinking water from the SN63 filter was as low as 10.8 μg/L (WHO guideline of As concentration in drinking water: 10 μg/L).

Based on these findings, a first sand layer above the nail bed was installed in the spring of 2018 for all 30 filters in order to lower the flow through rate and to increase the contact time with the nails. The sand was separated from the nails by a cloth (cotton–polyester blend) so as to facilitate maintenance. Removal efficiency 1, removal efficiency 2, and the overall removal efficiency for all filters sampled immediately after applying cloth and sand are reported in Table 1. The best performer was, again, filter SN4A—hardly ever used with the nail bed dry at the time of inspection, leading to a lower removal efficiency 1 compared to the results without the upper sand layer applied (removal rate 1 wet nails and without upper sand bed: 39.4%; removal rate 1 dry nails with upper sand bed: 17.3%). The fresh lower sand layer was consistently removing As to a high degree (96.5%). Filter SN51 showed an increased performance to a remarkable degree: The overall removal efficiency without the upper sand bed added only up to 31%, as the nails were dry and glued together leading the water to find its way without filtration at the rims of the nail basin. As the plastic bucket containing the nails and the lower sand bed was broken and, therefore, the filter was leaking, a completely new assessment of this filter on the spot was unavoidable. Taking the already utilized nails and using the filter for three days regularly and keeping the nails wet before sampling while replacing the lower sand layer and applying an upper sand layer led to the observed increase in performance. The upper sand layer mainly kept the nails in place, therefore impeding the formation of irregularities in the nail bed itself and lowering the flow through rate, leading to an increased contact time. By this means, the initial As concentration of the ground water (239.8 μg) could be lowered to 16.2 μg/L despite a very small concentration of Fe in ground water (0.3 mg/L). The low performance of several filters (e.g., SN70, SN76, and SN69) was mainly caused by neglect and poor maintenance. The SN64 filter demonstrated a notable change in performance after the addition of an upper sand layer, preventing the displacement of the nails, which were immersed in water at the time of sampling. However, even the Fe concentration in the ground water (2.21 mg/L, SN64) was clearly higher than that of the SN51 filter (0.3 mg/L); the As concentration of the influent water was only lowered from 164.8 to 51.2 μg/L.

Sampling of all the mentioned filters in spring 2019 revealed that for most of the filters equipped with an upper sand layer, the performance could be improved (Table 1). Filter SN1C performed best even with a dry nail bed but with black nails at the time of inspection. This color is an indication of the formation of Fe(III)-oxides removing As to a high degree [18]. According to the users, the nail bed of this filter was usually kept wet and, interestingly, the Fe concentration of the ground water was high (6.4 mg/L), whereas the As concentration was only 136.2 μg/L. With an overall removal rate of 95.0%, the As content of the drinking water could be lowered to 6.7 μ/L. Filter SN4A had a lower performance due to the fact of an unrequested sort of usage: At the time of inspection, the upper concrete plate, sand layer, and nail bed were covered with ants. According to the children of the residents, they probably purged the filter with a sticky, sugary liquid (e.g., Coke). After dismembering and thoroughly purging the filter with ground water for 15 min., samples were taken. As the filter was used occasionally throughout the year, the performance was slightly lowered. The efficiency of the SN64 filter seriously declined due to the fat of poor maintenance, e.g., non-replacement of material such as nails and sand. Filter SN51, which was freshly installed in the spring of 2018, exhibited a lower efficiency owing to the aging lower sand layer. Nails from filter SN14, in turn, were completely immersed in water. Nails should be kept wet but not immersed, as the best removal efficiency was determined in filters with wet nails. Apparently, wet nails are oxygenated best, keeping the nail bed wet but not immersed in water.

A filter with the description SN45 could only be sampled in autumn 2015 and was therefore not included in the data set. The plastic bucket for this filter was leaking later and was no longer used by the residents of those premises. Ground water feeding this filter had a very high concentration of Fe (5.73 μg/L), but despite this desired fact, the filter did not perform as expected. The overall removal rate was determined to be as low as 70.7% despite the low concentration of As in ground water (170.2 μg/L). X-ray investigations of nails from some of the mentioned filters herein revealed the presence of siderite (FeCO3) [19]. This mineral is precipitated under still reducing conditions, as it contains Fe(II) indicating (i): oxidation to promote rusting of the nails is not complete and

(ii) siderite "seals" the surface of the nails therefore preventing As to be adsorbed on the nails' surface or co-precipitating with Fe(III)hydr(oxides) [18,20]. Inspection of the X-ray data clearly indicates that siderite is preferentially formed on nails in contact with ground water containing a high concentration of iron.

4. Future Improvements

Future improvements will include:

(i) Installation of the upper sand bed for all filters in order to prevent the nails from drying and moving while pouring ground water as well as diminishing the flow rate;
(ii) Regulation of the outflow by placing a tap at the outlet or by raising the outlet from the plastic bucket to above the level of the nail bed;
(iii) Replacing nails and sand on a regular basis;
(iv) Monitoring of the water quality and filter conditions by trained local inhabitants;
(v) Proper and regularly repeated instructions for the users.

5. Conclusions

Three different types of Kanchan filters are used in the province of Nawalparasi: plastic round, plastic squares, and concrete squares. The brick layer in square filters is commonly replaced by a 2–3 cm think perforated concrete plate keeping the nails in place. Especially, concrete square filters are difficult to maintain, as they are fixed on the ground it is a laborious work to replace the lower sand bed. Despite the perforated concrete plate, concrete square filters are not performing much better than filters of the other type.

The depicted highly variable removal efficiency clearly depends on several typical prerequisites:

(i) Geological background, e.g., Fe and As concentrations of the ground water itself [9];
(ii) Condition and aging of the material intended to remove As efficiently: nails and sand. Both nails and sand must be changed regularly. Sand, especially, has to be replaced on a yearly base (see filter SN51) in order to maintain its absorbing capacity;
(iii) The nails of the nail bed have to be wet constantly but not immersed in water in order to promote oxidation and formation of Fe(III)hydr(oxides);
(iv) Prevention of the formation of holes and dents within the nail bed, as the ground water has to be precluded to flow through the nail bed in nail-free channels. The ground water has to be poured slowly and carefully in order to prevent moving of the nails;
(v) Sufficient contact time between ground water and nails. A high concentration of As and a low concentration of Fe requires an increased contact time.

Before sampling, users were summoned to fill the filters according to their routine manner. This way it was possible to work out if filters were filled, handled, and maintained appropriately. It soon became obvious that residents using the filters were not instructed correctly: rapid pouring of the filters with ground water led to the formation of holes in the nail bed, filters were not used on a regular base and, therefore, the nail bed dried out. The lower sand bed was hardly ever replaced, leading to an exhaustion of the absorbing capacity of the aging sand. Moreover, the hand pumps were often placed in direct sunlight or long hoses were installed to transport the ground water from the pump to the filter. The higher the temperature, the less efficient the filters [18,20]. The applied upper layer of sand is capable of preventing the nails from moving while filling the filter with water. In order to facilitate cleaning of the filter, the upper sand layer was separated by a cloth from the nails [21,22]. As a consequence, it is imperative to instruct users of the filters correctly and carefully.

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