How to cite: Angala, H.A.N., Tandlich, R., Ngqwala, N.P., Zuma, B.M., Moyo, S. (2019) *Citizen Science, Treatment and Compliance Monitoring of Microbial Water Quality In Namibia*. 2019 "Air and Water – Components of the Environment" Conference Proceedings, Cluj-Napoca, Romania, p. 323-338, DOI: 10.24193/AWC2019_32.

CITIZEN SCIENCE, TREATMENT AND COMPLIANCE MONITORING OF MICROBIAL WATER QUALITY IN NAMIBIA

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DOI: 10.24193/AWC2019_32

ABSTRACT. Namibia has experienced challenges in the provision of drinking water to its population. A combination of various solutions should be explored to provide drinking water to the population. In this study, a combination of the raw water treatment with the Grifaid® filters and the compliance monitoring of microbial quality using the hydrogen-sulphide test kit was tested in two villages in Northern Namibia and one informal settlement in central Windhoek. The efficiency of treatment by site operators was limited as 100 % of samples taken at two of the sampling sites were positive for faecal contamination. Only at the Windhoek sampling site was the treatment of raw water by site operators partially successful, as 67 % of the treated water samples taken were negative for faecal contamination. Concentrations of faecal coliforms in the control samples ranged from below 0 to 6 CFUs/100 mL, with the correspondence rates with the H_2S kit test ranging from 20 to 80 %. Recontamination of the water after treatment is the most likely cause of the positive signal in the H_2S kit. The site operators found the Grifaid® filters easy to use, but stressed that proper training is required for operating the filters. The users stated that the use of the Grifaid® filters are only suitable as a short-term solution in drinking water provision to the target communities. Future research will have to focus on the testing of the chemical and physical characteristics of raw and treated water; and more detailed examination of the microbial composition of the water samples will have to be conducted. In addition, the citizen-science strategy will have to be modified to assist the community in preventing re-contamination of the treated water.

Keywords: Grifaid® filter, H_2S kit, participatory approach, Namibia.

1. INTRODUCTION

Namibia receives about 370 mm of rainfall annually (NPC, 2017) and water losses are high due to high evapotranspiration (Dahan et al., 2008; British Geological Survey, 2018). The country receives most of its water from perennial rivers such as Kunene and Okavango, which are located along its borders with other Southern African countries

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(Christelis and Struckmeier, 2001-2011). Ephemeral rivers are also significant source of water, when seasonal flooding occurs, e.g. in the Kuiseb river in Western Namibia (Dahan et al., 2008). Surface water from Namibian rivers often used for groundwater recharge (Christelis and Struckmeier, 2001-2011). Water demand in Namibia had been estimated to be 3.341×10^8 m^3 per annum in 2015, and was expected to increase to about 5.834×10^8 m^3 per annum in 2025; and should peak at 7.178×10^8 m^3 in 2030 (NPC, 2017, pages 36-38). Meeting the increasing water demand targets can prove challenging, as Namibia has recently been impacted by drought, leading to the president declaring a state of emergency in 2016 (GGRN, 2016). Together with the drought, challenges in the provision of drinking water in Namibia include infrastructure and treatment problems, as well as the need to improve water demand management (NPC, 2017, pages 36-38).

In spite of the above challenges, 91.0 % of the Namibian population gained access to improved drinking water by 2015 (IndexMundi.com, undated). This has been the result of innovative strategies that have been implemented in Namibia and its territory over the past few decades. Examples include the direct planned reclamation of (household) wastewater, its treatment and recycling for drinking water in the Capital City of Windhoek (Anderson, 2003; Rygaard et al., 2011). This source has contributed between 4 and 31 % of the total drinking water in Windhoek, depending on whether the city is experiencing normal water supply or a state of drought (Anderson, 2003). The volumes of drinking water produced through the direct planned reclamation have been increasing steadily through installation of new technologies and capacity upgrades since 1968 (Anderson, 2003). Reasons have included the growing demand for potable water and population growth in Windhoek (Haarhoff and van der Merwe, 1996). Recycling and treatment of wastewater in Windhoek has helped to increase water self-sufficiency in term of drinking water supply in the city (Rygaard et al., 2011). This is critical in an arid country such as Namibia, with a vast geographical territory that is sparsely populated and many communities are isolated (Boutin et al., 2011).

Human activity and approach to development in recent decades have resulted in localised nature of water cycles across the globe (Rygaard et al., 2011). In addition, some reviews of literature indicate that it is unlikely that implementation of programmes for drinking water provision, that are based on a single solution/technology, can help increase water self-sufficiency in a given geographical area (Rygaard et al., 2011). This especially holds true in Namibia, where various legislative and governance changes on drinking water provision since 1990, have often resulted in non-payment for water supplied to various users, lack of end-users buy-in in provision initiatives and in ongoing technological challenges in water supply (Hossain and Helao, 2008). Further to this point, it must be said that the water supply models, historically applied in developed countries, are often not feasible in developing ones (Newman, 2001). Namibia is a developing country and a multi-pronged strategy to provision of drinking water has been implemented across the country's territory (Hossain and Helao, 2008). However, local water self-sufficiency remains a problem in various areas of the country (Hossain and Helao, 2008; Boutin et al., 2011).

Water self-sufficiency could be improved throughout Namibia by use of localised and decentralised initiatives for producing drinking water close to the raw water source and by taking local water cycles into account (Newman, 2001). Such raw water resources will include groundwater and captured flood waters from ephemeral rivers, with additional sources being available in some areas. If these water resources are located in the vicinity of human settlements, where end-users of the produced drinking water reside, then these end-users can be involved in the drinking water treatment (Boutin et al., 2011). Besides treatment, initiatives must take into account local conditions, e.g. the possibility of groundwater contamination from septic tanks in urban areas (Mapani, 2005) and faecal contamination of water resources in rural areas of Namibia (Boutin et al., 2011). As a result, microbial quality of the produced drinking water needs to be tested with a certain minimum frequency in the process of compliance monitoring (Luyt et al., 2012). Compliance monitoring is necessary to prevent potential exposure of the water consumers/end-users to pathogens from upon consumption of contaminated drinking water. Thus, compliance monitoring is also aimed at preventing outbreaks of waterborne diseases.

Involvement of the community, who are end-users of the intervention tools, can improve success of water, sanitation and hygiene (WASH) interventions in developing countries (Srikanth, 2009; Boutin et al., 2011). Most WASH interventions include drinking water provision (Srikanth, 2009; Boutin et al., 2011). Some of the interventions also include a compliance monitoring component of microbial quality of the produced drinking water by the end-users (Tandlich et al., 2014). Compliance monitoring is necessary for the ongoing risk assessment of the human consumption of the produced drinking water (Boutin et al., 2011). In addition, sustainability of the implemented technical solutions can be improved past the end of the intervention, if consumers of the drinking water are involved in the treatment and compliance monitoring. Under such circumstances, raw water treatment for drinking should be based on decentralised solutions (Boutin et al., 2011) and the compliance monitoring should be done using low-cost methods that can be performed without access to laboratory facilities, in programmes that are implemented using citizen science (Groulx et al., 2017).

In the current study, raw water treatment was conducted with the use of the Grifaid® filter (Grifaid/Save Water Trust, Cleadon, Sutherland, United Kingdom) depicted in Figure 1 below. The Grifaid® filter system is designed to eliminate microbial contamination from treated water, as its pore size is 10 nanometres, i.e. designed to remove all pathogens including viruses from treated water (World Health Organization, 2008). The filtration rate of 90 litres/hour can be achieved with the Grifaid filter (Angala, 2018). Most of the filters in this study were operated by attachment to a bucket filled with raw water (see red circles in Figure 1). The drinking water was then produced by hand-pump action of the blue handle. It does not rely on electricity or batteries and thus can be applied in decentralised settings and regardless of the level of human development in an area. The filter comes with a clear, easy-to-use operating manual (Angala, 2018).

Compliance monitoring of the presence or absence of the faecal contamination was conducted, in the current study, using the hydrogen-sulphide test kit (designated as the H_2S kit in further text). The H_2S kits were manufactured by the authors according to the procedures outlined by Luyt et al. (2011). This test has been shown to correlate reasonably well with the results for the concentrations of thermotolerant *E. coli* (Tandlich et al., 2014). The H_2S kit compliance monitoring of microbial water quality can be performed by trained citizen scientists (laypersons with or without a formal scientific education after a short training session; Tandlich, et al., 2014). In this way, microbial quality data could be available within a reasonable time frame to the end-users of a particular drinking water source and local government in the target community. Combination of the Grifaid® filter and the H_2S kits, along with the application of principles of citizen science, was aimed at developing a two-way communication/working relationship between the authors and the target community.

a)

b)

Fig. 1. Picture of Grifaid® filter as attached to a bucket (Fig. 1a and Fig. 1b).

2. DATA AND METHODS

The study activities were performed according to the protocol approved by the Faculty of Pharmacy Ethics Committee at Rhodes University (Grahamstown/Makhanda, South Africa) under the tracking number PHARM-2017-01. All necessary gatekeeper permissions and informed consents were obtained prior to the beginning of the study (Angala, 2018 and see acknowledgements in this paper). At all sampling sites and in the execution of all project activities, authors followed a participatory approach. This means that the aim of all project activities reported in the current study was to produce knowledge in a cooperative fashion between the authors and the end-users. The strategy is similar to the approaches adopted by the Namibian government in implementation of the water service delivery in rural areas (SOA, 2008). Only adult members of households at all sampling sites were officially involved in the project activities. All photography took place in public areas of the settlements, where no study participants could have had an expectation of privacy. The photographs taken throughout from the project were anonymised in all cases.

The sampling sites were chosen as two villages in Northern Namibia and one informal settlement in central Windhoek. These three settlements represented three regions of Namibia, namely the Oshana, territory on the border between regions of

Omusati and Ohangwena; and the Khomas region. The respective villages were Ondjadjaxhwi in the Oshana region, Okambebe near the border between Omusati/Ohangwena and Goreangab in the Khomas region. In further text, the above sites will be referred to as Nam 1, Nam 2 and Nam 3 for Okambebe, Ondjadjaxhwi and Goreangab, respectively. The number of sites selected was based on budgetary and logistical considerations of the project, as well as to meet the mandate of the grant funding (see the Acknowledgements section for the funding agency details). For the interview part of the study, data saturation was assumed to have been achieved with the number of sites and 3-4 site operators used/recruited in the study. One Grifaid® filter was installed per study site and one/two site operator(s) was recruited per study site to form part of the compliance monitoring programme.

Recruitment of potential site operators was done after an introductory session was held at Nam 1, Nam 2 and Nam 3 to provide information and communicate the background/aims of the project and answer any questions potential site operators might have (Angala, 2018). At each site, the Grifaid® filter was used to produce drinking water for an extended family of varying sizes (see Results and Discussion below for further details). After the introductory session, interested potential site operators were requested to sign the informed consent form (Angala, 2018). Literacy and cultural sensitivities of the community, where the Grifaid® filters were installed, were taken into account in the execution of all project activities and participatory approach was followed throughout the study (SOA, 2008). The information provided to site operators was complete and the content of informed consent forms/project documents was translated into the vernacular of the site operators by a senior hydrologist from the Department of Rural Water Supply (Windhoek, Namibia) to provide more clarity.

Upon the return of consent forms, site operators were trained to operation and use of the Grifaid® filter, the H_2S kit and the recording the data in the following way. During a one-hour session, the first author and the senior hydrologist explained the functionality of the Grifaid® filter and the H_2S kit in English and the first language of the site operators. Next, operation of the Grifaid® filter was demonstrated by the first author and by site operator for consistency at Nam 1, Nam 2 and Nam 3. Site operators were then given an information package providing further information about the H_2S kit, which consisted of the following information and tools (Tandlich et al., 2014; Angala, 2018): a results sheets, information on operation, performing sampling and the underlying scientific principles of the H_2S kit. Site operators were provided with the H_2S kits and sterile gloves for sampling throughout the study. This was to ensure that there was no post-filtration contamination of the produced drinking water prior to testing and use. They also received bleach that was added to the spent H_2S kits and the contents was disinfected. After disinfection, the spent H_2S kits were open and the contents was discarded safely at Nam 1, Nam 2 and Nam 3.

Test kit monitoring was done by site operators once a week for a period of three months between June and August 2017. For every testing round, five test H_2S kits were used per site and the site operators were provided sufficient test kits to be able to monitor their drinking water source for the duration of the study. On a given sampling occasion, the site operator was instructed to put sterile gloves on and sampled the produced drinking water as follows. The H_2S kits were open by the site operator without touching the inside and 20 mL of filtered water was add to the contents of the H_2S kits. Those were closed with lids and hand-shaken briefly before incubation at room temperature (anticipated to be between 18 and 25 °C) for 72 hours (Luyt et al., 2011). Site operators were required to record the date of each sampling and to further check the samples every 12 hours for the presence of a black precipitate. Jars that turned black after 72 hours of incubation were reported as positive, while those that remained brown/clear (the initial colour of suspension) or which turned grey without going black within the 72-hour time limit were reported as negative.

Control samples were taken with each sampling run at each site using sterile 500 mL plastic bottles by the first author. Control samples were analysed for *E. coli* and faecal coliforms at the analytical laboratory of NamWater in Windhoek for Nam 3 and Oshakati for Nam 1 and Nam 2. The most probable number or the membrane filtration method was used as outlined in Standard Methods (APHA, 1998) and in relevant literature (Geldreich et al., 1965; Rose et al., 1975; Lin, 1976; Presswood and Strong, 1977; Green et al., 1980). The H_2S kits were prepared at Rhodes University according to procedure of Luyt et al. (2011). All consumables were purchased from Spellbound Labs (Port Elizabeth, South Africa) or Merck (Pty.) Ltd. (Cape Town/Johannesburg, South Africa).

3. RESULTS AND DISCUSSION

3.1 Site description

We will start with the site description of Nam 1, Nam 2 and Nam 3. Two of the sites were part of the water infrastructure development in the scope of the SCORE project (MET, undated). Targeted to run from 2015 until 2019 (UNDP, 2015-2019), the SCORE project has been aimed at increasing the resilience of the population in Northern Namibia against floods, drought and to improve agricultural production under the conditions of climate change (MET, undated). The Grifaid® filter at site Nam 1 was set up to complement a man-made well, which had a pulley system installed under the auspices of the SCORE project. The aim of the installation was to allow the community members to access groundwater more easily. The well was also covered with a steel lid to prevent pollutants from entering the well, when this is not in use. The lid had also been installed to stop animals and children from falling into the well. According to the site operator at Nam 1, the water collected from the well is used for drinking, cooking, bathing, washing clothes and animal husbandry. Prior to receiving the filtration system, the water collected was treated by boiling it.

Site operator at Nam 1 and members of their household reported occasional use of chlorine/flocculant tablets/powder acquired from the local clinic for decentralised water treatment for drinking and domestic uses. Five grams of tablets/powder acts as a disinfectant/flocculant and is added directly to 20 L of water; and mixed. The treated water is then allowed to stand for 15 minutes to allow sediments to settle at the bottom. After settling, clean water was decanted into a separate container by filtration through a cloth to collect the chlorinated/potable water for subsequent domestic uses. The Grifaid® filter complemented the current practice at Nam 1 and enabled larger volumes of water to be treated for domestic use.

The site operator's household consists of 30 people, of whom 16 were children and 6 are pensioners. Adults were employed in the household work and in professions such as bartending, security and day-care. According to the South African legislation, Rhodes University, its staff and students are obligated to protect the privacy and maintain anonymity of the data derived from research that involves human participants (DOH, 2015). As the study was also conducted by Rhodes University researchers they were bound by this legislation. Therefore only the GPS coordinates of the Okambebe village, Namibia are provided as listed on Google Maps, i.e. 17°27'44.1"S and 15°35'12.1"E.

At site Nam 2, the raw water was extracted from a man-made earth dam that had been constructed by the Ministry of Agriculture, Water and Forestry; and enabled by the SCORE project (MET, undated; UNDP, 2015-2019). In the dam, inhabitants of the village collected rainwater for domestic use, irrigation and animal husbandry. Prior to the beginning of the current study and the use of the Grifaid® filter by the community, water from the rainwater collection dam at Nam 2 was treated by boiling. The site operator's household at Nam 2 consisted of 11 family members. In more detail, 4 household occupants were elderly people, 2 were adults and 5 were children. Two adult household members were trained in the use of the Grifaid® filter and the H_2S kit. The village is located in a remote part of Northern Namibia and the GPS coordinates were as follows 17°40'26.74"S and 15°51'20.49"E. The GPS are presented as not to compromise privacy of the study participants. The location of this village points to a gap in the coverage of villages in Africa on Google Maps. This has been reported before for the isolated settlements in Africa before (The Guardian, 2014).

The final filtration system was set up at Nam 3, where the City of Windhoek is responsible for the supply of water to the community. The City of Windhoek has been experiencing large urban migration in recent years. This has contributed to the fact that there are still communities, who live in shanty-towns on the outskirts of the city, who have not gained access to potable water (Lahnsteiner and Lempert, 2007). Communal taps are installed randomly throughout the area where Nam 3 was located, but users are charged for the water (Lahnsteiner and Lempert, 2007). In the Goreangab area, the surrounding community living in this informal settlement uses water from the Goreangab dam for domestic use after boiling it. The site operator's household of the operator consists of 8 people, including one child, with adults two were employed as a taxi driver and the other as a tuck-shop manager. Again to protect that anonymity of the site operator, GPS coordinates of the Goreangab township, as listed on Google Maps, are provided and these were 22°31'07.6"S and 17°01'35.8"E.

The age breakdown of the site operators' household members is summarised in Table 1 below. The age brackets were established at each site through interviews with the site operators only and the age brackets are based on the Namibian Statistics Agency Classification (NSA, 2011).

3.2 Sampling programme results

Angala (2018) reported the results from all samples taken and for all sampling sites. Here the data is analysed per sampling site, i.e. for Nam 1, Nam 2 and Nam 3 separately.

Table 1. ***Age breakdown of the occupants in the households of the site operators'.***

Sampling site	Children[a]	Adults[b]	Elderly[c]
Nam 1	16	8	6
Nam 2	5	2	4
Nam 3	1	2	5

[a] Namibian citizens who are classified as children aged between 0 and 14 years, as defined and reported by Namibian Statistics Agency (2014).
[b] Namibian citizens who are classified as adults aged between 20 and 64 years, as defined and reported by Namibian Statistics Agency (2014).
[c] Namibian citizens who are classified as elderly aged 64 years and above, as defined and reported by Namibian Statistics Agency (2014).

The accuracy/correspondence rate (*CR*) for each site was calculated by taking all the results together from all 180 H_2S kits and the faecal coliform concentrations in control samples. The *CR* values is defined in Equation (1).

$$(CR) = 100^{*} [(TP+TN)/(TNS)] \quad (1)$$

In Equation (1), *TP* is the total number of true positive results in control samples, i.e. this is recorded on occasions when all 5 H_2S kits were positive for faecal contamination and the faecal coliform concentrations were higher than 0 CFUs/100 mL. The term *TN* is the total number of true negative results in control samples, i.e. this is recorded on occasions when all 5 H_2S kits were negative for faecal contamination and the faecal coliform concentrations were below 0 CFUs/100 mL.
Finally, *TNS* in Equation (1) represent the total number control samples.

All control samples contained the *E. coli* concentrations below 0 CFUs/100 mL after filtration (see Tables to 2-4). Therefore, all treated water samples met the *E. coli* criterion for the Class A water as stated in the Namibian water quality guidelines (as summarised in Lewis and Claassen, 2018). This means that based on the concentration of *E. coli* the treated water is safe for human consumption and domestic use. The data on *E. coli* concentrations from this study are lower or comparable to the data of Lewis and Claassen (2018). However, additional criteria must be met and additional indicator microorganisms enumerated to obtain a more complete picture about the microbial water quality after treatment at Nam 1, Nam 2 and Nam 3 sites; and to follow the Namibian water quality guidelines (Lewis and Claassen, 2018).

Data for Nam 1 are shown in Table 2 and all samples taken after treatment with the Grifaid® filter were positive for faecal contamination, as indicated by 5 positive H_2S kits, in all 12 samples taken at Nam 1. Concentrations of faecal coliforms in the control samples ranged from below 0 to 6 CFUs/100 mL, which means that the treated water at Nam 1 can be categorised as Class B and/or Class C (Lewis and Claassen, 2018).

Lewis and Claassen (2018) reported that concentrations of faecal coliforms in groundwater samples from ranged from 0 to 32 CFUs/100 mL in Haardap, Namibia. Boutin et al. (2011) reported concentrations of *E. coli*, which is usually the dominant faecal coliform in the faecally-contaminated water and in the guts of human and the warm-blooded animals such as cattle, ranging from below 0 to 4 MPN/100 mL. Therefore, concentrations of faecal coliforms are comparable or lower than the concentrations reported in literature for faecal indicator microorganisms in Namibia. Based on those results above, the *CR* value was equal to 80 % for Nam 1. This *CR* value is lower than the estimate of Nhokodi et al. (2016), i.e. 99.4 % and *CR* of 88 % measured by Malema (2019, chapter 4 Table 4.2, page 62). The mean *CR* value of around 90 % was reported between the H_2S kit and thermotolerant/faecal coliforms/*E. coli* by Wright et al. (2011). Therefore, the *CR* values reported in this study between the H_2S kit detection of faecal contamination at Nam 1 was lower or comparable to literature values. Data for Nam 2 are shown in Table 3 and all samples taken after treatment with the Grifaid® filter were positive for faecal contamination, as indicated by 5 positive H_2S kits on all sampling occasions.

Table 2. ***Microbial water quality results obtained at sampling site Nam 1.***

Month of sampling	Week of study	# H_2S kits positive	Faecal coliforms (CFUs/100 mL)	*E. coli* (CFUs/100 mL)
June	1	5	NA[a]	NA[a]
June	2	5	NA[a]	NA[a]
June	3	5	NA[a]	NA[a]
June	4	5	6	< 0
July	5	5	NA[a]	NA[a]
July	6	5	7	< 0
July	7	5	NA[a]	NA[a]
July	8	5	4	< 0
August	9	5	2	< 0
August	10	5	NA[a]	NA[a]
August	11	5	< 0	< 0
August	12	5	NA[a]	NA[a]

Concentrations of faecal coliforms were lower than 0 CFUs/100 mL on 80 % of the control samples taken, while one control sample contained 1 CFU/100 mL. As a result, the treated water at Nam 2 can be categorised as Class B, according to the Namibian water quality guidelines (Lewis and Claassen, 2018). Therefore, the *CR* between the results of the faecal coliforms and the H_2S kit results was equal to 20 %. Therefore, results of different tests indicate differences in faecal contamination of the treated water at Nam 2. The *CR* value from Nam 2 was lower than that the values of 88 to 99.4 % reported in previous studies (Wright et al., 2011; Nhokodi et al., 2016; Malema, 2019, chapter 4 Table 4.2, page 62).

Data for Nam 3 are shown in Table 4 and 67 % of the H_2S kit samples taken after treatment with the Grifaid® filter were negative for faecal contamination, as indicated by 0 positive H_2S kits on 8 sampling occasions. One H_2S kit sample, i.e. 8.3 % of all H_2S kit samples, tested positive for faecal contamination, as indicated by 5 positive H_2S kits. Three H_2S kit samples, i.e. 25 % of all H_2S kit samples, were suspected of being faecally contaminated, as indicated by 1-2 positive H_2S kits (Nhokodi et al., 2016). Concentrations of faecal coliforms were lower than 0 CFUs/100 mL on 20 % of the control samples taken, while four control samples contained 1-5 CFUs/100 mL of faecal coliforms.

Table 3. ***Microbial water quality results obtained at sampling site Nam 2.***

Month of sampling	Week of study	# H_2S kits positive	Faecal coliforms (CFUs/100 mL)	*E. coli* (CFUs/100 mL)
June	1	5	NA[a]	NA[a]
June	2	5	NA[a]	NA[a]
June	3	5	NA[a]	NA[a]
June	4	5	< 0	< 0
July	5	5	NA[a]	NA[a]
July	6	5	1	< 0
July	7	5	NA[a]	NA[a]
July	8	5	< 0	< 0
August	9	5	< 0	< 0
August	10	5	NA[a]	NA[a]
August	11	5	< 0	< 0
August	12	5	NA[a]	NA[a]

[a] Not applicable

Table 4. ***Microbial water quality results obtained at sampling site Nam 3.***

Month of sampling	Week of study	# H_2S kits positive	Faecal coliforms (CFUs/100 mL)	*E. coli* (CFUs/100 mL)
June	1	5	NA[a]	NA[a]
June	2	1	NA[a]	NA[a]
June	3	0	NA[a]	NA[a]
June	4	0	2	< 0
July	5	0	NA[a]	NA[a]
July	6	0	5	< 0
July	7	0	NA[a]	NA[a]
July	8	2	3	< 0
August	9	0	1	< 0
August	10	0	NA[a]	NA[a]
August	11	0	< 0	< 0
August	12	1	NA[a]	NA[a]

[a] Not applicable

Based on those figures, the treated water at Nam 3 can be categorised as Class B (Lewis and Claassen, 2018). At the same time, results of different tests indicate differences in the assessment of faecal contamination of the treated water at Nam 2. The *CR* value between the results of the faecal coliforms and the H_2S kit results was equal to 20 %. The *CR* value from Nam 3 was lower than that the values of 88 to 99.4 % reported in previous studies (Wright et al., 2011; Nhokodi et al., 2016; Malema, 2019, chapter 4 Table 4.2, page 62). The observed discrepancies between the results of the faecal coliform enumerations and the H_2S kits, along with reasons for the *CR* values recorded, are discussed below.

At Nam 1, the *CR* value of 80 % was lower, but still comparable to literature data on the correspondence rate between the faecal coliforms and H_2S kits (see above). At the same time, all positive signals in the H_2S kits at all sampling sites were recorded after 48 hours or more (data not shown). If the positive result was detected within several hours of inoculation (< 12 hours of incubations), then false positive results could have been recorded in the samples analysed using in the H_2S kits at Nam 1 (as summarised by Sobsey and Pfaender, 2002). The reason for the false positive results would have been the presence of sulphide anions in the groundwater (as summarised by Sobsey and Pfaender, 2002). As it can be seen from the data in Table 2, this was not the case and so positive signals in the H_2S kits at Nam 1 were recorded due to the presence of faecal contamination of the treated water. This is further supported by review of relevant literature which indicated that false negative results are not common in the H_2S kits (as summarised Sobsey and Pfaender, 2002).

When the new filter was provided to the site operator at Nam 1, the authors tested that efficiency of the treatment by enumeration of faecal coliforms and *E. coli* before and after treatment. The results are shown in Table 5.

Table 5. ***Treatment efficiency performed by authors at Nam 1 after a change of the Grifaid® filter used.***

Sample	Faecal coliform concentration (CFUS/100 mL)	*E. coli* concentration (CFUS/100 mL)
Raw water	12	< 0
Water treated with the old Grifaid® filter	2	< 0
Water treated with the new Grifaid® filter	< 0	< 0

The Grifaid® filters removed 100 % of *E. coli* and faecal coliforms, i.e. the removal and treatment performed as anticipated based on microbial indicators. The lack of *E. coli* detection and the detection of faecal coliforms in the raw groundwater might indicate that cells of *E. coli* might have died-off faster, than other faecal coliforms which have been shown to be detected in the H_2S kits, e.g. *Klebsiella spp.* (as summarised by Sobsey and Pfaender, 2002). Alternatively, faecal coliform strains such as *Klebsiella spp.* could have been of environmental origin. These conclusions can provide an explanation for the indicator microorganism concentrations in both the raw and the treated water. The cell sizes of coliforms, *E. coli* and the H_2S-producing bacteria can be expected to be similar. As a result of this and taking the fact that the Grifaid® filters performed as expected into account, it is clear that the positive signals in the H_2S kits and the faecal coliform concentrations higher than 0 CFUs/100 mL in the treated groundwater at Nam 1 were most likely the result of the recontamination after filtration with the Grifaid® filter. The container into which the raw water was filtered into, could have been contaminated with faecal coliforms after treatment. This must be addressed by modifying the training of site operators in the next instalment of the citizen-science programme applied in this study.

It is more complicated to explain the observations for Nam 2 and Nam 3. What is the same as at Nam 1 are the conclusions about the lack of *E. coli* detection. The *CR* values at both sites were equal to 20 %, but trends in the results from the H_2S kits and the faecal coliform enumeration were different at both sites. Nam 2 had 80 % of samples positive for faecal contamination based on the H_2S kit. On the other hand, Nam 3 had 80 % of samples positive for faecal contamination based on the faecal coliform concentration. The results do point to the need to calibrate *CR* values under local conditions and they also indicate that correspondence rates from literature should not automatically be assumed to be constant among various climatic zones, etc. Further 4research will have to be conducted on the reasons for the *CR* observations at Nam 2 and Nam 3.

3.3 Community perception and feedback on the programme

The monitoring programme was well received by the community members at Nam 1, Nam 2 and Nam 3. All participants in the study committed to monitoring filtered water samples and completed the results chart for the entire three months course, without any missing sampling results. Some logistical challenges arose at Nam 1 where the Grifaid® filter broke down and had to be replaced. Besides this complication, the participants required no additional assistance from the authors throughout the study. The training provided offered sufficient information to the participants to allow them to carry out monitoring water on their own. All participants reported sharing information about the filtration system, as well as water monitoring, with other interested community members in the surrounding areas. Community members can be engaged and equipped to participate in the water supply structure. Therefore, the execution of the study demonstrated that it was carried out as engaged research and in a participatory fashion, as well as with limited logistical support beyond the initial training.

Interviews were conducted with the site operators to collect user-feedback on the Grifaid® filters. All site operators were asked five questions during the interview. The first question looked at the functionality of the filter to determine whether it was user-friendly. Based on the responses obtained, 100 % of the site operators felt that the Grifaid® filter was easy to use. In regards to whether the hand-operated Grifaid® filter was suitable/robust enough for routine use (Question 2), only one site operator (or 25 % of the respondents) felt that it was suitable while others felt it was only suited to short-term use rather than routine use. The problem cited by the site operator at Nam 2 was that it was difficult for the Grifaid® filter to serve the entire community because of the need of prior knowledge and training on how to operate it. The site operator felt that in the absence of trained personnel, other members of the community would not know how to use it, creating the risk of people breaking the filter. The last participant (site operator of Nam 3) felt that a tap would still be a better option.

The third question considered faults in the filter operation that occurred and only one site reported that the filter was not operating effectively. This was due to incorrect management/operation. Question 4 investigated whether the hydrogen-sulphide test kit was easy to use and 100 % of the site operators agreed that the H_2S kit was user-friendly. The interview ended with site operators offering final comments on how to improve the system. The first site operator did not have any additional comments, while the second felt that a bigger system that did not need as much man-power to operate was required for the area. They felt that pumping large volumes of water using the Grifaid® filter was difficult and time consuming. The site operator at Nam 3 also suggested that the design be changed to increase the volume of water filtered at once. All participants expressed their gratitude for being part of the experience and for receiving the filtration systems.

Namibia uses Basin Management Committees (BMC) as a community engagement structure within its water management model (Simataa, 2010). These BMCs consist of interested stakeholders, including members of the public, governed by guidelines from the Ministry of Agriculture, Water and Forestry. There are currently eleven BMCs across the country (Remmert, 2016). These committees advise the Ministry on water issues within their specific area of operation (Remmert, 2016). Similar models are used in Uganda (Terry, et al., 2015) and Malawi (Chowns, 2015), and various countries in Asia (Abdullaev, et al., 2010). Water governance requires a multi-stakeholder approach to ensure successful implementation of management decisions in the different target areas.

Legislated platforms such as the water user associations can be used as channels to provide community members with the tools needed to conduct their own water quality monitoring services. This study shows that community members are willing to participate when provided with the necessary skills and support. Therefore, results from this study and the legislated multi-stakeholder platforms that exist in Namibia can provide a useful tool for wider roll-out of the programme from this study. Scope of such interventions should be widened to include testing for chemical parameters of water (Boutin et al., 2011).

4. CONCLUSIONS

The aim of the monitoring programme was to test the use of the Grifaid® system in a monitoring system using the H_2S kit produced in the laboratory. The H_2S kits were effective in indicating the presence of microbial contamination in all water sources. Although faecal coliforms were detected in filtered samples, there was no *E. coli* present in the water after filtration. Future research will have to focus on the testing of the chemical and physical characteristics of raw and treated water. In addition, the citizen-science strategy will have to be modified to assist the community in preventing re-contamination of the treated water. This study shows that community members are willing to participate when provided with the necessary skills and support.

ACKNOWLEDGEMENTS

The authors would like to thank the German Academic Exchange Service (DAAD) and the Namibia Commission of Science and Technology (NCRST) for their funding the study. The entire Oshakati Basin Management of the Ministry of Agriculture, Water and Forestry, as well as the entire Namibia Water Cooperation (NamWater), Oshakati branch staff, for the technical support during site visits and the laboratory analyses during the study. In addition, the authors would like to thank the Ministry of Agriculture, Water and Forestry (MAWF) of Namibia, through its Directorate of Rural Water Supply as well as under the umbrella of the Namibia University of Science and Technology, in assisting with site visits and for providing gatekeeper permission.

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