GROUNDWATER QUALITY AND ITS DISTRIBUTION IN SILOAM VILLAGE, LIMPOPO PROVINCE, SOUTH AFRICA

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ABSTRACT
Small scale subsistence agriculture aimed at ensuring food security at household level and lack of proper sanitary facilities make groundwater aquifers to be vulnerable to contamination. This is worse in rural communities that reside in semi-arid areas and are dependent on groundwater. Fertilisers from small scale subsistence agriculture and faecal matter from pit latrines contaminate groundwater aquifers. This study assessed the quality of groundwater from selected boreholes in Nzhelele area. A number of residents within Nzhelele area practice small scale subsistence agriculture and lack proper sanitary facilities. EC and pH and turbidity were measured using Cyberscan PC510 benchtop meter and Eutech TN 100 turbidity meter, respectively. 850 Professional Ion Chromatography and atomic absorption spectroscopy were used to analyse non-metals (nitrate, chloride, sulphate) and metals (copper, manganese, zinc, calcium, potassium, magnesium, and iron), respectively. EC, turbidity, chloride, nitrate and iron exceeded the recommended guidelines in some of the boreholes. Turbidity and nitrates had negative effects on human health. A borehole located within the vicinity of a small scale agricultural farm had elevated EC, turbidity, sulphate, magnesium, calcium, and copper. It is therefore crucial to urgently derive solutions aimed at minimising groundwater contamination and treatment of groundwater from the study area as it is the main source of domestic water supply. Spatial distribution maps and water quality classification based on nitrates and fluorides indicated class 4 groundwater quality which is dangerous and totally unsuitable for human consumption. These maps are therefore essential for interactive simple interpretation of water quality status, are useful as decision making tools even at locations where monitoring have not been done, and are useful in advising the residents on water quality parameters which may require treatment.
Keywords: groundwater contamination, pit latrines, subsistence agriculture, water quality.

1 INTRODUCTION

Limpopo is one of the poorest provinces in South Africa where groundwater is mostly used as a source of domestic water supply. This accounts for almost 70% of rural domestic water supply in Limpopo Province [1]. Due to its paramount importance as a source of water supply, there is a need to continuously monitor and know its water quality status. This assists in developing solutions for managing and preventing groundwater contamination and potential health effects. Maherry et al. [2] identified Limpopo Province as one of the areas of priority research and implementation of remediation technologies since communities rely on untested groundwater as the main source of drinking.

Small scale subsistence agriculture is practiced to alleviate poverty and there is wide spread use of pit latrines in rural areas of Limpopo Province. This makes groundwater aquifers to be vulnerable to contamination. The need to increase agricultural productivity to sustain livelihoods in rural areas encourages intensive application of fertilisers in small scale agriculture. Farmers are still encouraged to use fertillisers to increase crop productivity and ensure long term food security [3]. For example, Odiyo et al. [4] found elevated turbidity, nitrate, calcium, magnesium, sulphate and chloride linked to agricultural activities or excessive use of fertilizers in the Soutpansberg area, South Africa. Thus, application of fertilisers need to be managed to avoid environmental problems such as groundwater pollution. Increased use of pit latrines may cause human and ecological health impacts

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associated with microbiological and chemical contamination of groundwater [5]. Lack of safe drinking water and adequate sanitation measures have caused diseases such as cholera, dysentery, salmonellosis and typhoid, claiming millions of lives every year in developing countries [6].

The problem of contaminated groundwater is typical in most developing countries. Jeyaruba and Thushyanthy [7] found that 81% of the wells in a case study area in Sri Lanka were not suited for drinking due to the nitrate-N concentration. Kanyerere et al. [8] reported that most groundwater sources were not potable for domestic use in rural areas of Malawi and identified possible factors that contaminate water at specific sites. This included location of pit latrines upslope from water sources, groundwater-surface water interaction in low-lying areas, distance between water points and pit latrines, depths of water sources and topography. Arsenic and fluoride contamination of groundwater as well as poor sanitation facilities posed high health risks in rural areas of India [9]. Zamxaka et al. [6] considered poor sanitation and hygiene conditions and lack of, or little environmental awareness among the people in rural areas as the major causes of source water contamination in selected rural communities of the Eastern Cape Province, South Africa. Edokpayi et al. [10] reported that 87.5% of boreholes sampled in Limpopo Province, South Africa were not suitable for human consumption and posed carcinogenic risk.

Odiyo and Makungo [11] evaluated the overall quality status of groundwater from private boreholes, implications for domestic use and possible sources of contamination in Siloam Village in Limpopo Province, South Africa. The study only used descriptive statistics (minimum, maximum, mean, and standard deviation) to describe overall water quality status of Siloam Village, and thus did not capture the water quality variation from one borehole to another. Following the latter study, this study conducted a close examination of water quality of each individual borehole to identify their water quality status and specific water quality problems. This assists in identifying boreholes with deviating trends which are likely to be indications of specific water quality problems. In addition, the study generated detailed geographical information system (GIS) maps indicating spatial distribution of groundwater quality in Siloam Village. This was aimed at integrating water quality results to enable simple interpretation of groundwater quality by the community, in addition to prediction of water quality parameters at unmonitored locations. The spatial distribution maps are based on colour coded classification system to enhance interactive and simplified interpretation of water quality status and identification of parameters of concern by communities. Spatial interpolation methods are frequently used to estimate values of physical or chemical constituents in locations where they are not measured [12]. This is because it is practically impossible to sample at all locations due to lack of access or cost implications. Spatial interpolation using GIS assists in ensuring comprehensive monitoring of groundwater quality.

2 STUDY AREA AND METHODS

The study area is located in in the northern region of Limpopo Province in South Africa. Data from 11 boreholes (BH1-BH11) from Odiyo and Makungo [11] were used in this study (Fig. 1). Most residents are dependent on groundwater for domestic uses and small-scale irrigation of crops. Methods for groundwater sampling, quality control and analysis are provided in Odiyo and Makungo [11]. EC and pH, and turbidity were measured using Cyberscan PC510 benchtop meter and Eutech TN 100 turbidity meter, respectively. 850 Professional Ion Chromatography and atomic absorption spectroscopy were used to analyse non-metals (nitrate, fluoride, chloride, sulphate) and metals (copper, manganese, zinc, calcium, potassium, magnesium and iron). The sampling period was from August 2013 to January

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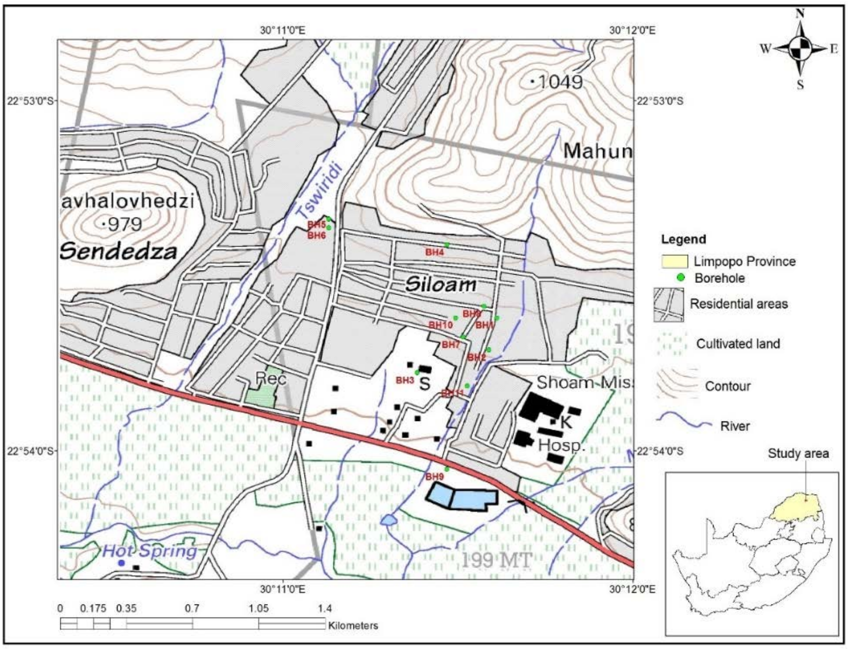

Figure 1: Location of boreholes in the study area. *(Source: modified from Odiyo and Makungo [11].)*

2014. Results on fluoride were not included in this study as they have already been discussed in Odiyo and Makungo [11]. The results were also compared with DWAF [13] guidelines to determine potential health effects and identify boreholes with excessive concentrations of water quality parameters and links to agricultural activities and pit latrines.

Colour coded maps showing spatial distribution of groundwater quality were generated by interpolating mean groundwater quality parameters for the period August 2013 to January 2014 using inverse distance method in Quantum Geographical Information System (QGIS) version 3.0.1 software. The colour coding followed DWAF et al. [14] classification system (Table 1) which was aimed at interactive and simplified identification of groundwater quality and its suitability for domestic use.

Table 1: Water quality classification. *(Source: DWAF et al. [14].)*

Class	Description	Effects
Class 0	Blue (ideal water quality)	Suitable for life time use
Class 1	Green (ideal water quality)	Suitable for use, rare instances of negative effects
Class 2	Yellow (marginal water quality)	Conditionally acceptable. Negative effects may occur in some sensitive groups
Class 3	Red (poor water quality)	Unsuitable for use without treatment, chronic effects may occur
Class 4	Purple (dangerous water quality)	Totally unsuitable for use. Acute effects may occur

3 RESULTS AND DISCUSSION

Figs 2–4 show the water quality parameters in BH1-BH11 throughout the study period. pH values for BH1 were slightly above DWAF [13] recommended guideline of 6–9 in the months of December 2013 and January 2014, with pH values of 9.28 and 9.29, respectively (Fig. 2). DWAF et al. [14] noted that pH values between 9 and 9.5 do not have any potential health effects but only have a slightly soapy taste and insignificant effects on bathing. EC values for most boreholes (BH2, BH4, BH5, BH7, BH9 and BH11) were above the recommended guideline of 70 mS/m. However, it was only BH9 which had extremely high EC values, exceeding 400 mS/m. Water with EC values exceeding 370 mS/m is slightly corrosive, extremely salty and bitter, and has possible health risks [13]. Water from the rest of the boreholes with EC values from 70–150 mS/m had insignificant health effects on sensitive groups. Turbidity values were higher than the recommended guideline of 1 NTU in BH2 (Jan-14), BH4 (Aug-13), BH9 (Aug-13 and Jan-14). Turbidity levels for BH2 and BH4 are associated with slight chance of adverse aesthetic effects and infectious disease transmission exists since they fell in the range of 1–5 NTU. Water in BH9 had turbidity levels >10 NTU, which is associated with severe aesthetic effects and a chance of disease transmission at epidemic level due to infectious disease agents and chemicals adsorbed onto particulate matter as specified in DWAF [13].

BH9 was the only borehole with sulphate concentration above the recommended guideline of 200 mg/L (Fig. 3). Water with sulphate concentration above the guideline has noticeable slight taste and can cause diarrhoea in sensitive and some non-adapted individuals [13].

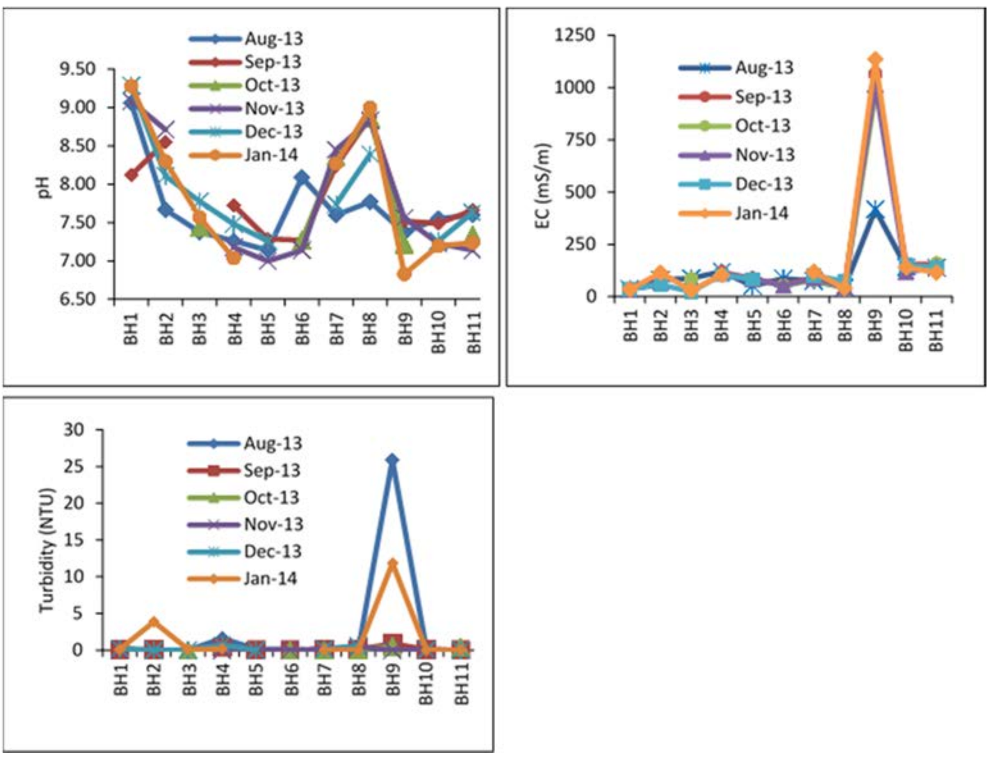

Figure 2: Physical parameters in groundwater.

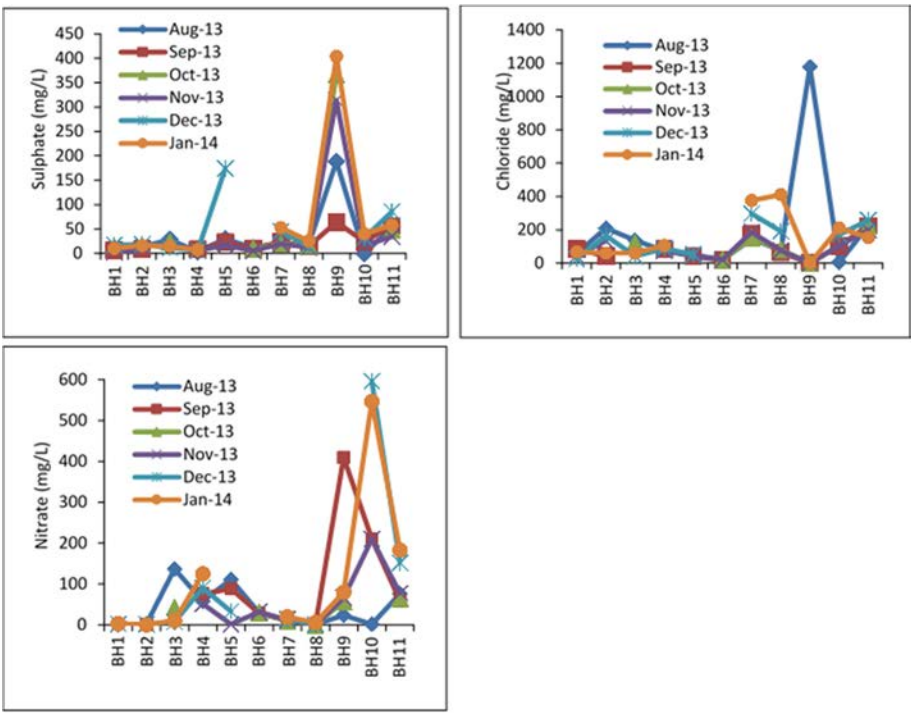

Figure 3: Non-metals in groundwater.

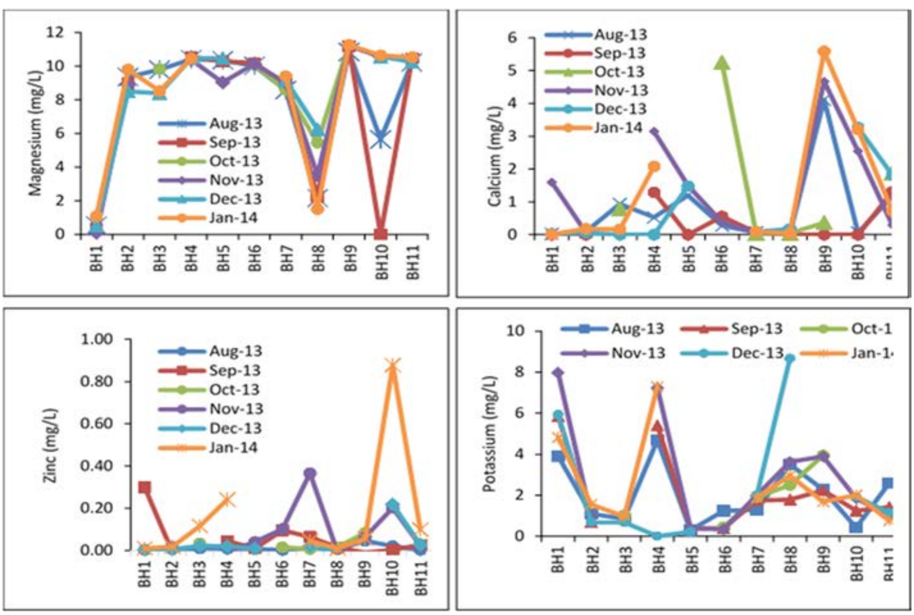

Figure 4: Magnesium, calcium, zinc and potassium in groundwater.

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Chloride concentrations exceeded the recommended guideline of 100 mg/L for more than 3 months of the sampling period in BH2, BH7, BH10 and BH11. Chloride concentration ranging from 100–200 mg/L has no aesthetic or health effects but possibly result in increased corrosion rate in domestic appliances. The highest chloride concentration of 1177.4 mg/L, associated with objectionable salty taste, not slaking thirst and likelihood of rapid corrosion in domestic appliances, was recorded in BH9 in November 2013. BH3, BH4, BH5, BH6, BH7, BH9, BH10 and BH11 had nitrate concentrations that exceeded the recommended limit of 6 mg/L. Most of the concentrations exceeded 20 mg/L which DWAF [13] associates with methaemoglobinaemia and mucous membrane irritation in infants and adults, respectively. Odiyo and Makungo [11] linked high nitrate concentrations in BH3, BH4, BH6, BH7, BH8, and BH11 to groundwater contamination by faecal matter from pit latrines which were within the vicinity of the boreholes. The pit latrines were at maximum distance of 45 m, which was less than the recommended distance of >50m. Studies by Mudau [15] and Odiyo and Makungo [11] found microbial water quality indicators above recommended guidelines indicating high risk of infectious disease transmission in Nzhelele area. This showed that groundwater in most boreholes in Nzhelele area has been contaminated by human waste from pit latrines.

The results show that BH9 dominantly had high EC and turbidity levels, and concentrations of sulphate, magnesium, calcium and copper as compared to the rest of the boreholes, though some of them were within recommended guidelines.

Chloride, copper and zinc are some of the micro-nutrients that are required for plant growth [15]. Sulphate, magnesium and calcium are secondary plant nutrients. This indicates that fertilisers that are applied are likely to contain these parameters which are then leached into groundwater. BH9 is located in a small scale subsistence farm where fertilisers are applied to enhance crop growth. Thus, proper application and management of fertilisers is required to prevent elevated concentrations in groundwater in the future. The physical parameters and concentrations of most of the chemical parameters mostly increased during the rainfall months (Oct-13, Nov-13, Dec-13 and Jan-14) in BH9 while they were mostly comparable for the rest of the boreholes throughout the sampling period. Most crops are planted during the rainfall season and this is an indication that fertilisers contributed to elevated physical and chemical water quality parameters in BH9. Guo et al. [17] also noted that groundwater quality deteriorated in the wet season and this was linked to application of fertilisers in this season.

Magnesium, calcium, zinc, potassium and copper concentrations were within the limits in all boreholes during the sampling period indicating no potential health effects (Figs 4 and 5). Iron concentrations in BH2 and BH8, in Jan-14 and Dec-13, respectively, exceeded 0.1 mg/L. Iron concentration within the range of 0.1-0.3 has very slight effects on taste and marginal other aesthetic effects but does not affect human health as stated in DWAF [13]. The results indicate that turbidity and nitrates had negative effects on human health. Studies by Odiyo and Makungo [11], [18] have already indicated that there is high fluoride in Siloam Village which is likely to originate from the geological formations of the study area. Thus, solutions aimed at minimising or reducing turbidity, nitrates and fluorides in groundwater from the study area are urgently required as groundwater is the main source of domestic water supply.

Examples of spatial distribution maps showing distribution of EC, nitrates and fluorides are shown in Figs 6–8. EC indicated class 4 groundwater quality which is dangerous and totally unsuitable for human consumption around BH9. Nitrates and fluorides also dominantly indicated a similar case as that of EC, though this was throughout most of the study area for these anions. In Siloam Village, drilling of private boreholes is increasing at

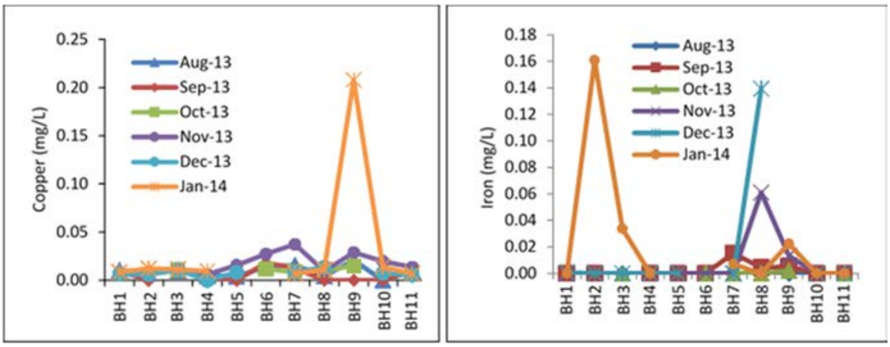

Figure 5: Copper and iron in groundwater.

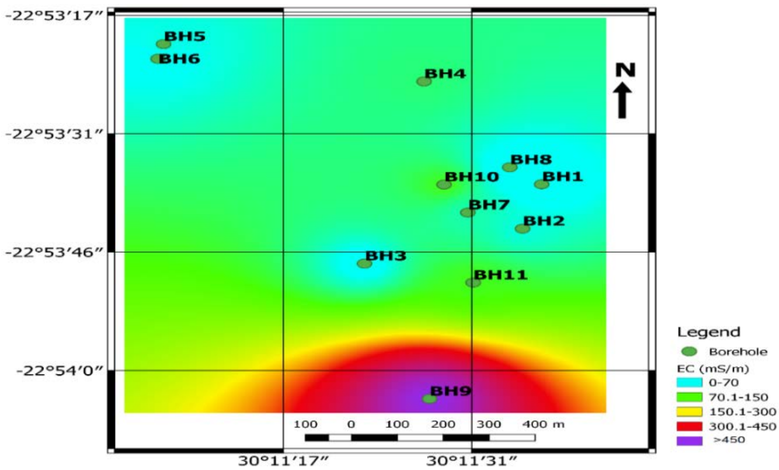

Figure 6: Spatial distribution of EC.

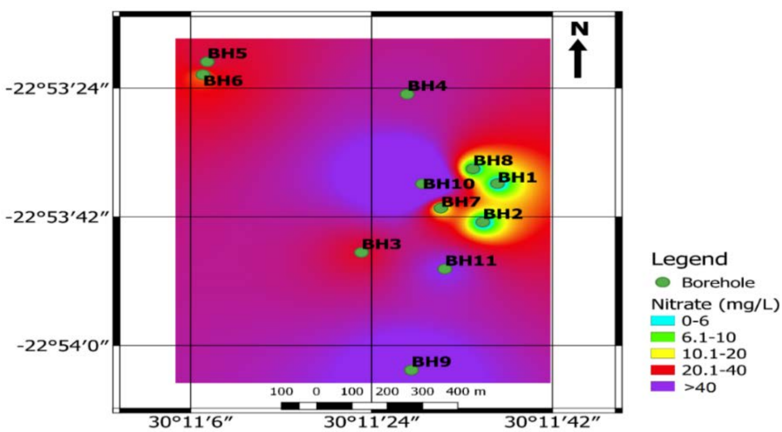

Figure 7: Spatial distribution of nitrates.

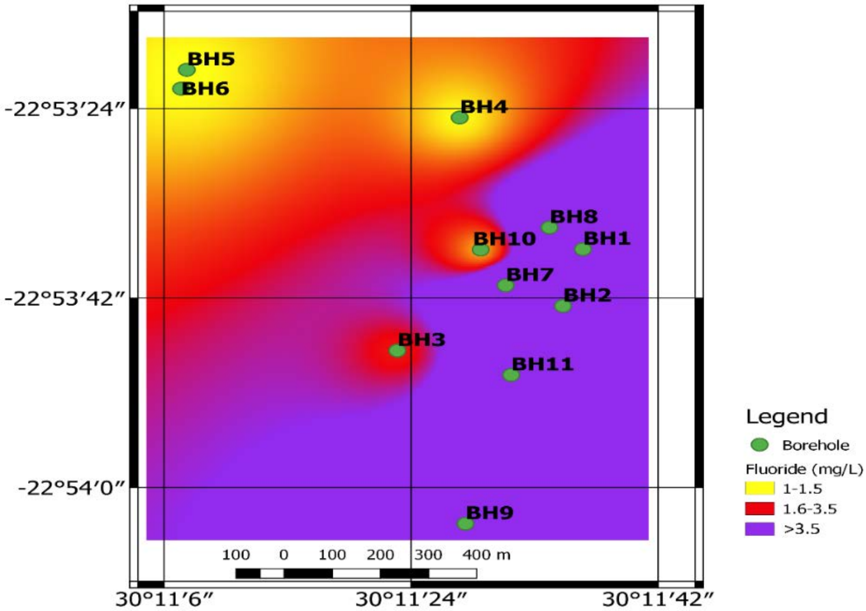

Figure 8: Spatial distribution of fluoride.

an alarming rate as the community copes with water stress which has been exacerbated by the recent drought spells. The maps can therefore aid as decision making tools to assist in determining the status of groundwater quality at locations where monitoring have not been done. They are also useful in advising the residents on water quality parameters which may require treatment, even at unmonitored locations. For example, households where BH1, BH2 and BH8 are located or used can be advised to purchase filters that specifically treat fluoride since it was the only parameter with excessive concentration. In addition, households whose water sources have not been tested will be able to have an idea of specific water quality parameters that require treatment to make water suitable for human consumption.

4 CONCLUSION

The study examined water quality parameters of individual boreholes in Siloam Village to determine their water quality status and identify point specific water quality problems. EC, turbidity, chloride, nitrate and iron exceeded the recommended guidelines in some of the boreholes. Turbidity and nitrates had negative effects on human health. BH9 dominantly had high EC, turbidity, sulphate, magnesium, calcium and copper as compared to the rest of the boreholes. This indicated that fertilisers applied within the vicinity of BH9 are potentially leached into groundwater resulting to contamination. High nitrates were linked to groundwater contamination by faecal matter from pit latrines. This in addition to elevated fluoride concentrations as reported from earlier studies makes residents of Siloam Village vulnerable to potential health risks. It is therefore crucial to urgently derive solutions aimed at minimising contamination and reducing turbidity, nitrates and fluorides in groundwater from the study area as it is the main source of domestic water supply. Spatial distribution maps and water quality classification based on nitrates and fluorides indicated class 4 groundwater quality which is dangerous and totally unsuitable for human consumption.