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Minimising Groundwater Contamination from Pit Latrines: Lessons from the Global Amphitheatre for South Africa

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Abstract: Pit latrines or toilets are considered to be suitable for the containment of human excreta and they are environment-friendly. Although previous studies have shown that there are some improvements in terms of access to sanitation, the reality is that most South African households still do not have access to sanitation facilities. At least 32.2% of households in South Africa are still using pit latrines. Despite the advantages of pit latrines, the constant outflow from pits could overpercolate the geological strata and contaminate the groundwater. Therefore, the aim of this paper is to reflect on lessons that South Africa can draw from the global arena with regard to reducing groundwater pollution from pit latrines. Concerning the method used to collect data - a review of scholarly peer-reviewed articles and non-scholarly documents such as newspaper reports was used. This paper explains how pit latrines contaminate groundwater as well as discuss the chemical contaminants associated with pit latrines. Importantly, this paper argues that the measures that can be taken to address challenges pertaining to groundwater contamination include operation and maintenance, improved pit and slab design, and setting safe distances between boreholes and pit latrines. Since pit latrines seem to contribute greatly to the contamination of groundwater, transferring bacteria and viruses, it is important for the government (municipalities in particular) to sensitise people about the health hazards associated with the use of pit latrines while also using groundwater for consumption. At the same time, communities who use pit latrines and boreholes for drinking water have to be educated about the need to maintain proper distances between pit latrines and boreholes.

Keywords: Borehole, Chloride, Faecal coliform, Groundwater, Nitrate, Pit latrines

1. Introduction

South Africa is semi-arid country with inadequate water sources and the supply of clean water remains a mammoth task for the government. As a result, the citizenry that do not have access to clean, piped water, rely on water from adjacent rivers, ponds and borehole water (Edokpayi, Rogawski, Kahler, Hill, Reynolds, Nyathi, Smith, Odiyo, Samie, Bessong & Dillingham, 2018). Approximately 40% of the world's population is immensely affected by water scarcity, while 3 out 10 people do not have access to safe drinking water and 6 out of 10 people do not have access to sanitation facilities (United Nations, 2020). Odiyo, Mathoni and Makungo (2020) state that the insufficient or lack of water supply in various municipalities in South Africa has created a situation where most people rely on untreated groundwater for consumption. According to Statistics South Africa (2020), 3.8% of households in South Africa use borehole water for consumption. Provinces with households that are dependent on borehole water are North-West (8.3%), Limpopo (7.7%), Northern Cape (4.5%), KwaZulu-Natal (3.3%), the Free State (2.7%) and Mpumalanga Province (2.1%). While some households are using borehole water for consumption, 32.2% of households in South Africa are still using pit latrines. In fact, most of the households dependent on pit latrines are in Limpopo Province (72.9%), Mpumalanga Province (55%), Eastern Cape Province (48.9%), North-West Province (48.2%) and KwaZulu-Natal Province (46.7%) (Statistics South Africa, 2020). The scenario presented above suggests that some of the households could be at risk of consuming contaminated borehole water due to the seepage of pathogens from pit latrines to groundwater.

Awuah, Abaido, Badu and Appah (2020) argue that the coexistence of pit latrine and boreholes in close proximity can lead to groundwater nitrate contamination. Moreover, Graham and Polizzotto (2013) contend that the number of people dependent on pit latrines is likely to rise from 1.77 billion people globally, while the use of groundwater for consumption by households is also likely to increase exponentially, which necessitates a need to understand how pit latrines can affect the quality of groundwater and human health. In Tillett's (2013:169) view, meanwhile "pit latrines usually lack a physical barrier to keep waste contained in the pit, microbial and chemical contaminants can emanate from them, threatening nearby groundwater sources such as springs, wells, and boreholes."

Odiyo et al. (2020) reveal that school children are the most susceptible groups in areas where schools are dependent on groundwater for consumption. In this regard, Odiyo et al. (2020) mention that groundwater used by school children, particularly in the rural areas of the Giyani district was found to have decreased levels of microbiological quality, while having increased levels of different pathogenic bacterial organisms (*Salmonella, Shigella, Vibrio species, Campylobacteria*), as well as an increased rate of antibiotic-resistant bacteria. Indeed, pathogens such as *Legionella, Giarida, Cryptosporidium, Salmonella, Shigellla* and coliforms are introduced through faecal waste into drinking water, causing gastrointestinal diseases and diarrhoea (Hepp, 2017). In South Africa, "diarrhea is one of the leading causes of death among young children, and this problem is worse in children infected with HIV (Human Immunodeficiency Virus)" (Edokpayi et al., 2018:2). Concerning the antibiotic-resistant bacteria, Serwecinska (2020) postulates that the antibiotic-resistant bacteria pose public health hazards because such bacteria could be infectious and difficult to treat, necessitating the usage of drugs that are more expensive. Furthermore, Serwecinska (2020) points out that antibiotic-resistant bacteria are able to enter water sources via urban wastewater or sewage sludge. This suggests that antibiotic-resistant bacteria leach from pit latrines through the unsaturated zone past the water table towards the saturated zone, thereby contaminating groundwater. In support of this view, Odiyo et al. (2020) note that school children in the Vhembe District experienced incidents of diarrhoea, cholera and dysentery due to the consumption of contaminated groundwater from boreholes located adjacent to the pit latrines. Cholera is a fatal water-borne disease caused by the bacterium Vibrio cholerae. Incidents of cholera among school children in the Vhembe District in Limpopo Province is concerning because the World Health Organisation (WHO) records approximately 1.3 to 4 million incidents of cholera and 21 000 to 143 000 deaths attributed to cholera globally, especially from developing countries (Hepp, 2017).

Still and Nash (2002) point out that the pathogens commonly found in faecal waste include protozoa, helminths (parasitic worms), bacteria and viruses. The protozoa and helminths can be easily filtered through soil, whereas bacteria and viruses are easily transported over a distance due to the seepage of faecal sludge. In line with this view, Tillett (2013) indicates that viruses can be detected in groundwater sources approximately 50 metres away from the pit latrines. This suggests that in cases where pit latrines are located closer to water sources such as boreholes, the likelihood of contamination with bacteria and viruses would increase.

Regulations and policies concerning groundwater in South Africa do permit erection of pit latrines in areas where there are water boreholes for human consumption but the 75 metres distance between pit latrines and the water source must be maintained (Still & Nash, 2002). Hammoud, Leung, Tripathi, Butler, Sule and Templeton (2018) assert that an empirical study undertaken in South Africa shows that there was no correlation between the distance from boreholes and the levels of nitrates. Although the issue of observing a minimum distance between pit latrines and boreholes is emphasised in literature, in some instances there is no compliance with such recommendations.

Chemical pollution in drinking water, groundwater in particular, could be a result of natural factors and anthropogenic processes (human activity), rendering water unsafe for human consumption (Hepp, 2017). For example, Odiyo et al. (2020) highlight that at some schools in Thaba Nchu in South Africa, groundwater was found to contain high levels of nitrate concentration beyond 6 mg/L as per the Department of Water and Sanitation guidelines, suggesting that such groundwater was not suitable for consumption. Similarly, Masindi and Foteinis (2021) note that high concentrations of nitrates (104 mg/L) was detected in drinking water supplied by 22 boreholes in the North-West Province due to faecal contamination. As a result of faecal contamination, the water found was not suitable for human consumption. Still and Nash (2002) postulate that high concentrations of nitrate in water can pose health hazards to breastfeeding infants. In addition, Hepp (2017) highlights that high concentrations of nitrates in drinking water cause an abnormal haemoglobin condition known as methemoglobinemia, which is a health condition commonly referred to as "blue baby syndrome" that may lead to a coma and death if it is not treated properly. Besides its ravaging health impact on infants, increased levels of nitrates (over 10 mg/L) in drinking water heighten the risks of bladder, colon and kidney cancer in adults.

An empirical study conducted in the North-West Province in South Africa, Masindi and Foteinis (2021) found that drinking water from 42 boreholes that formed part of their study contained high concentrations of chloride and fluoride. Similarly, in an empirical study undertaken in the Madibeng Municipality of the North-West Province, Schoeman (2009:97) found that borehole water had high concentrations of flouride that varied between 5 and 6 mg/L, exceeding the 1.5 mg/L mark set in the South African Water Quality Guidelines of 1996. Fluoride in groundwater poses a human health risk because it can cause neurotoxic and fluorosis (dental and skeletal) complications in children (Masindi & Foteinis, 2021). In support of this assertion, Schoeman (2009) emphasises that high levels of flouride in drinking water implies that the water is not suitable for consumption because it could cause "mottling of teeth enamel in children and fluorosis in adults. According to the United States Environmental Protection Agency (2009), fluoride is vital for preventing teeth decay but when it is excessively consumed, it can cause bone disease (painful and delicate bones). High concentrations of chloride >1 mg/L can cause anaemia in young children and foetuses in pregnant women (United States Environmental Protection Agency, 2009). Furthermore, the United States Environmental Protection Agency (2007:2) mentions that high concentrations of chloride in groundwater could be an indication of contamination from sewage sources. In this sense, the proximity of pit latrines to boreholes for drinking water could contribute to an increase in chloride content in groundwater. Masindi and Foteinis (2021) note that unfortunately some members of the community where borehole water was sampled assumed that groundwater was suitable for human consumption without prior treatment. Having stated the challenges associated with the usage of pit latrines and dependence on groundwater for consumption in South Africa, the aim of this paper is to reflect on lessons that South Africa can draw from the global arena concerning the reduction of groundwater contamination from pit latrines.

2. International Perspectives on Groundwater Contamination from Pit Latrines

This section provides the international perspectives on groundwater pollution from on-site sanitation such as pit latrines, particularly in the following countries: Bangladesh, Kenya, Nigeria, Pakistan and Zimbabwe.

2.1 Bangladesh

Bangladesh is among the countries that are struggling to provide citizens with sustained clean water. According to Islam, Rahman, Bodrud-Doza, Muhib, Shammi, Zahid, Akter and Kurasaki (2017), the sources of drinking and irrigation water in Bangladesh are likely to be under tremendous pressure due to the forecasted population growth of 26.6% by 2050. The increased demands for drinking and irrigation water could significantly affect the hydrologic system in such a manner that the water quality could deteriorate and the groundwater table level may start dropping (Islam et al., 2017). Reliance on groundwater could pose some challenges when boreholes or water wells and pit latrines are situated on a homestead that is small. For example, in Bangladesh, "pit latrines are generally constructed close to tube wells, mainly due to space constraints, hygiene and convenience. The widespread use of pit latrines in rural and suburban areas makes them a major source of groundwater contamination. Effluent from pit latrines contains pathogenic bacteria, viruses, protozoa and helminths. The pathogens from the pit latrine may filtrate through the ground (unsaturated and saturated) and ultimately reach the groundwater" (Islam, Mahmud, Islam, Saha, Zahid, Ali, Hassan, Islam, Jahan, Hossain, Hasan, Cairncross, Carter, Luby, Cravioto, Endtz, Faruque & Clemens, 2016:2). Further, Islam et al. (2016) point out that approximately 20 000 children die annually in Bangladesh from diseases such as dysentery, diarrhea, typhoid and cholera.

Islam et al. (2016) report that pit latrines contribute to the microbial contamination of the nearest borehole water, especially where the hydrogeological conditions permit the flow of bacteria. The transportation of bacteria is rare in situations where the unsaturated zone (in terms of lateral and vertical distances) was stable and thick. Ravenscroft et al. (2017:200) propose several ways through which faecal contamination of groundwater can be reduced in Bangladesh, as follows: "replacing cow-dung with bentonite clay as a drilling additive; cement grouting of the borehole annulus after sand packing; overnight shock chlorination on the day of well completion; maintaining a container of chlorinated water for priming purposes; regular removal and cleaning of the pump head with disinfectant and brush; more microbial testing; and, awareness raising in caretake training and water safety plans." Together with these proposals, Clasen, Doza, Titu, Rahman and Unicomb (2018) recommend that pit latrines should be constructed with a sand barrier underneath and all around to reduce the seepage of E. coli and faecal contamination of groundwater.

A study conducted by Islam et al. (2017) in Bangladesh, shows that groundwater had high concentrations of sodium and salinity attributed to natural factors rather than anthropogenic factors. In another study conducted in Bangladesh, Macdonald, Ahmed, Islam, Lawrence and Khandker (1999) found that faecal coliform was detected in water in areas where pit latrines were within a radius of 15 metres from water boreholes, With regard to the chemical contamination of groundwater, Macdonald et al. (1999) note that the concentration of chloride in groundwater was extremely high, exceeding 250mg/L (the World Health Organisation guideline) whereas the nitrogen (nitrate) concentration was significantly lower, particularly in aerobic environments. The low levels of nitrate in groundwater could be an indication of the absence of ammonium in groundwater, since nitrogen is oxidised to nitrate by ammonium.

2.2 Kenya

Most of the peri-urban areas in Kenya do not have piped water and in cases where there is a provision of piped water, reliability is a major problem. This situation impels residents to construct pit latrines inadvertently adjacent to the groundwater wells (Kiptum & Ndambuki, 2012). In a study conducted in Obunga in Kenya, Herman (2017) found that there were approximately 463 pit latrines that were used by 14 747 people. As a matter of concern, most of the pit latrines (45%) were located within a radius of 15 metres from the water wells. Furthermore, Herman (2017) indicates that the analysis results of groundwater reveal that faecal coliform was detected in water, although the contamination could not be fully attributed to the proximity of pit latrines to water wells as other factors such as flooding may have contributed to the contamination. In Kenya, diarrhoea is one of the diseases that have affected about 32% of children who are 5 years old and younger, especially those who live in informal settlements (Kimani-Murage & Ngindu, 2007). About 32.1% of maladies reported in Obunga were mainly diarrhoea and typhoid (Herman, 2017). There is strong evidence that drinking dirty water can cause diseases such as diarrhoea (Herman, 2017).

Kimani-Murage and Ngindu (2007:831) postulate that "where groundwater is used as a source of domestic water, use of pit latrines is not recommended because the two are incompatible unless the water table is extremely low and soil characteristics are not likely to contribute to the contamination of groundwater. Where they coexist, although it is difficult to give a general rule for all soil conditions, the commonly used guideline is that the well should be located in an area higher than and at least 15 metres from the pit latrines and should be at least 2 metres above the water table." In other words, when there is a coexistence of pit latrines and groundwater boreholes, it is imperative to observe the lateral and horizontal distances when positioning each one of them while also ensuring that the soil does not allow seepage into the saturated zone.

An empirical study conducted in the Langas informal settlement of Kenya, Kimani-Murage and Ngindu (2007) found that 38% of pit latrines were located within a distance of less than 15 metres from water wells, while 59% were located within 15 and 30 metres. As a result, the groundwater sample taken from the water wells was found to be contaminated with faecal coliform due to leaching from pit latrines and did not meet the standards for drinking water quality set by the World Health Organisation (WHO). In a similar empirical study conducted in Langas, Kenya, Kiptum and Ndambuki (2012) confirm that the groundwater from the water wells was contaminated with faecal coliform. Moreover, groundwater contained high concentrations of nitrate, which exceeded the 50mg/L for drinking water set by the World Health Organisation (WHO). At the same time, phosphate was detected in all water samples, but the concentration level was below 5.0 mg/L, suggesting that the water was usable for human consumption. Importantly, two factors contribute indirectly to groundwater contamination. Firstly, the type of water well covers, such as timber, contribute highly to water contamination, especially in dry seasons. Secondly, the dimensions of the site can significantly affect the distance between the groundwater well and the pit latrines, particularly when the site or plot is very small (Kiptum & Ndambuki, 2012). To improve the groundwater quality for human consumption, Kimani-Murage and Ngindu (2007) suggest that residents should be advised to disinfect groundwater using chlorine, filter and boiled water consistently. In support of this view, Kiptum and Ndambuki (2012:42) assert that "treatment such as chlorination or boiling should be done before it can be used for domestic purposes." In line with this view, Herman (2017) reports that some of the residents in Obunga, in Kenya treated groundwater through a chlorination process and boiling it. Moreover, Herman (2017) points out that treating groundwater decreases the possibility of diseases such as diarrhoea.

2.3 Nigeria

The provision of clean potable water in rural areas and informal settlements of Nigeria is a major challenge that impels households to consume polluted water. Moreover, approximately 65 million people in Nigeria do not have access to clean potable water while only 24% of the rural population has access to clean water (Ahaneku & Adeoye, 2014). In an empirical study conducted in Abeokuta in Nigeria to examine the pollution effect of pit latrine on groundwater wells, Adejuwon and Adeneyi (2011) found that the distance between the pit latrines and groundwater wells ranged from 1.7 metres to 23.9 metres. Notably, the study found that the groundwater sample presented some chemical contaminations such as nitrate and chloride, but their concentration levels did not exceed 50 mg/L. At the same time, the bacteriological analysis of sampled groundwater tested positive for faecal coliform, meaning that the water was not suitable for human consumption. A significant positive correlation between nitrate and faecal contamination was reported in the study because this signified seepage from pit latrines into the groundwater (Adejuwon & Adeneyi, 2011). This important finding on bacteriological contamination is consistent with the study that was carried out to investigate the impact of pit latrines on groundwater quality in the Nguru town of Yobe State, Nigeria, where Faruk and Babale (2020) discovered that groundwater did not meet the standards for human consumption mainly because it tested positive for high levels of coliform and escherichia coli (*E. coli)* bacteria counts (458 and 388 respectively) as a result of faecal contamination from pit latrine seepage.

In a separate study conducted in Benin City, Nigeria, Okhuebor and Izevbuwa (2020) found that there is an increased reliance on the usage of groundwater for human consumption due to a lack of potable water supply. While people rely heavily on groundwater for survival, pit latrines are situated indiscriminately in the area. For this reason, the groundwater was found to be contaminated. Specifically, the pathogenic micro-organisms (e.g. faecal streptococci, aerobic bacteria, coliform) and fungi were detected in borehole water, which raises a public health concern for the residents. In other words, the quality of the groundwater implied that the water was not appropriate for consumption. Based on the groundwater analysis from a study undertaken in the Foko informal settlement in Ibadan South-West Local Government Area of Oyo State, Nigeria, Ahaneku and Adeoye (2014) discovered there was strong evidence that indicated that the proximity of boreholes to pit latrines contributed to an increased bacteriological pollution of groundwater. Similarly, high chemical contamination was reported in Benin City because the groundwater tested positive for high concentrations of inorganic chemicals such as chromium (Cr), Lead (Pb), Zinc (Zn) and Cadmium (Cd), which could be attributed to heavy metals from boreholes in southern Nigeria (Okhuebor & Izevbuwa, 2020). This implies that the chemical contamination could not be linked to the leachate from pit latrines.

According to Okhuebor and Izevbuwa (2020), groundwater contamination in Nigeria could also be attributed to anthropogenic factors because some drilling artisans do not follow basic standards relating to the installation of boreholes. Based on this and other issues raised above, it is important for drilling artisans to ensure that geological surveys are undertaken before installing water boreholes. Equally important, the government in Nigeria needs to ensure that the installation of water boreholes is regulated and make sure that only knowledgeable, qualified and experienced professionals undertake installations (Okhuebor & Izevbuwa, 2020). Ahaneku and Adeoye (2014) recommend that water boreholes should be located in areas that are topographically higher than the pit latrines and more than 15 metres away from pit latrines while also ensuring that the pit latrines are 2 metres above the water table. This is in line with a view that lateral separation between the point of contamination and point of groundwater abstraction could minimise pollution from pit latrines. Nevertheless, Faruk and Babale (2020:224) suggest that the "Water and Sanitation Board in the community should ensure that the distance of pit latrines to water sources meet the recommended distance of 30 metres by the World Health Organisation (WHO)." Additionally, members of the community need to be sensitised and educated about the installation, positioning and maintenance of latrines, boreholes, water pumps and wells.

2.4 Pakistan

Pakistan is one of the top ten countries where people are living without access to clean drinking water. As a result, most people living in urban and rural areas depend on groundwater for consumption, in which case over 50% of households in rural areas make use of hand pumps to draw groundwater (Cooper, 2018). According to Nawab. Esser and Baig (2017:296-297), "groundwater supplies nearly 93% of the drinking water of people living in a northwestern province (i.e., Khyber Pakh [KP]) of Pakistan. Less than 10% of the population is connected to sewer systems; the rest use flushed pit latrines." Cooper (2018) reports that there are some disparities between the urban and rural areas of Pakistan with regard to access to clean drinking water. This is evidenced by 35% of people who have access to clean drinking water in Khyber Pakhtunkhwa and 18% in Punjab respectively. The use of pit latrines for on-site sanitation combined with the usage of hand pumps to draw groundwater in most disadvantaged areas increase the likelihood of groundwater pollution due to the leaching of human excreta into the water table (Cooper, 2018). Nawab et al. (2017) point out that in some instances pit latrines were situated less that 10 metres away from a groundwater source, exacerbating groundwater contamination. Pit latrines were located close to the water sources to ensure that water was accessible for bathing and ablution purposes (Khan, Baig, Nawab, Mahmood & Nyborg, 2016).

In Khyber Pakhtunkhwa, the groundwater was found nearly 500 feet making it difficult for abstraction while the water also extremely salty (Cooper, 2018). Moreover, samples of groundwater from Kot and Takht-e-nasrati villages tested positive for coliform bacteria. The contamination of groundwater could be attributed to seepage from pit latrines. Although some households were compliant in terms of the location of pit latrines away from their water sources, the challenge was that in most cases their pit latrines would be close to their neighbour's source of groundwater (Nawab et al., 2017; Cooper, 2018). In the Tank District, the water quality was found to be poor and diseases such as diarrhoea, cholera, dysentery, typhoid and hepatitis were reported predominantly among children (Cooper, 2018). As a way of preventing groundwater contamination, "the depth of groundwater sources, the permeability of subsurface soil, and the design of pits and water wells could play a crucial role in assessing the risk of groundwater contamination" (Nawab et al., 2017:304). In addition, Khan et al. (2016) state that the installation of water sources should be upstream while pit latrines must be situated downstream in order to prevent seepage from pit latrines. In other words, households need to be aware of the direction of groundwater flow before situating pit latrines and boreholes.

2.5 Zimbabwe

In an empirical study conducted in the Marondera district in Zimbabwe, Dzwairo, Hoko, Love and Guzha (2006:780) note that approximately 70% of the rural population depend on groundwater for consumption. Ndoziya, Hoko and Gumindoga (2019) highlight that rapid urbanisation in Harare City overwhelmed the water and sanitation infrastructure and this has created a situation where people live without access to basic sanitation and clean drinking water. For instance, most of the households in the Hopley settlement on the southern part of Harare CBD rely on boreholes and hand-dug water wells for drinking water while pit latrines are used for on-site sanitation. Unfortunately, most of the pit latrines are not lined and it is also extremely difficult to desludge the latrines that are filled up (Ndoziya et al., 2019). At the same time, Chidavaenzi, Jere and Bradley (1997) note that most of the pit latrines in Zimbabwe are installed without prior survey to determine the direction of groundwater flow.

The chemical analysis has shown that nitrate and ammonium were at 10 mg/L and 1.5 mg/L respectively as per World Health Organisation (WHO) guidelines for drinking water (Dzwairo et al., 2006). On the one hand, 41% of the analysis results indicated that the turbidity of groundwater exceeded 1.5 NTU, suggesting that the water was not fit for human consumption. Loosened soil and excavation of pit latrines were mainly attributed to high turbidity levels of groundwater (Dzwairo et al., 2006). On the other hand, faecal coliform also rendered groundwater unfit for drinking. Ndoziya et al. (2019) found that the chloride concentration for groundwater in Harare City were within the acceptable levels of 250 mg/L as per the World Health Organisation (WHO) standards for drinking water. Nevertheless, the sampled groundwater results from the wells had a high concentration of nitrate, thus exceeding 10 mg/L, implying that the water was not safe for drinking. Dzwairo et al. (2006) suggest that constructing raised or lined pit latrines could minimise seepage of latrine effluent into the saturated zone or water table. Equally important, the on-site sanitation practices must be monitored to determine the extent of groundwater source pollution (Chidavaenzi et al., 1997). Specifically, Tillett (2013:169) emphasises that "clear standards need to be established for the placement of pit latrines in relation to groundwater supplies."

3. Conclusion and Recommendations

Based on the preceding discussion, numerous lessons can be drawn from international experiences in terms of reducing groundwater contamination by pit latrines. The Bangladesh experiences reveal that pit latrines are indeed the main source of groundwater contamination because they are situated approximately 15 metres from the groundwater sources. Proper materials must be used to seal water wells or boreholes. It is important for the government in South Africa, especially the municipalities, to raise community awareness of water safety plans. Similarly, the Kenyan experience indicates that pit latrines contributed to the contamination of groundwater, in which case faecal coliform was detected. Disinfecting groundwater using chlorine, filtering and boiling it appears to be effective in removing microbials. In Kenya, the emphasis is placed on ensuring that pit latrines are not less than 15 metres away from groundwater sources and that the pit latrines are 2 metres above the water table. However, this means that the unsaturated zone must be thick and stable. In other words, the type of soil strata must not be permeable since this could allow transportation of viruses and bacteria from pit latrines to the water table.

In Nigeria, faecal and nitrate contamination were frequently reported as main contaminants of groundwater. This could be attributed to the indiscriminate placing of pit latrines. Other challenges are that some of the borehole drilling artisans in Nigeria did not follow basic guidelines for installing boreholes. At the same time, regulating borehole installations by the Nigerian government was poor. Therefore, South Africa will need to ensure that horizontal and vertical distances between pit latrines and groundwater sources are observed when installations of pit latrines and boreholes are undertaken. Additionally, municipalities may need to ensure that the indiscriminate placing of pit latrines by individual households is avoided. The South African government will need to maximise monitoring of borehole installations to prevent inappropriate installations that may result in groundwater pollution. Nevertheless, Nigeria's experience shows that boreholes need to be located in areas topographically higher than pit latrines.

The Pakistan practices regarding the placing of pit latrines reveals that most groundwater sources were within a radius of 10 metres from pit latrines, suggesting that the risks of groundwater contamination were high. In some instances, individual households that complied with the minimum distance of 30 metres from pit latrines found themselves in a situation where their neighbours' pit latrines were close to their groundwater sources. To avoid a similar situation in South Africa, it would be imperative for the government to monitor and regulate distances between water sources and latrines within homesteads and between multiple homesteads. Another important issue is the design and construction of pit latrines for on-site sanitation. In this regard, the Zimbabwe experience shows that most of the pit latrines were not lined and allowed quick seepage of effluent from pit latrines into the groundwater table. Due to the magnitude of groundwater contamination, it is recommended that if the unsaturated zone is permeable and unstable, raised pit latrines must be constructed to prevent seepage of effluent to the saturated zone. Importantly, this suggests that land surveyors need to be involved to assist communities who rely on pit latrines for on-site sanitation. In this sense, municipalities should play a leading role in the safeguarding of groundwater against contamination by pit latrines.

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