Effects of Pit Latrines and Poor Design of Sanitary Facilities on Groundwater Quality: A Case study of Minna and Bida, North-Central Nigeria.

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Abstract

A study on the water quality of groundwater in unconfined shallow aquifers was conducted with the aim of assessing physicochemical and bacteriological contamination of groundwater as a result of poor design of water and sanitation facilities in Minna and Bida, Nigeria. The study was conducted using a grid-based approach on wells and boreholes in households. The water has a high Total Dissolved Solids and Electrical Conductivity indicating high concentration of dissolved and suspended materials. The pH is slightly acidic to basic and mean distance of wells to pit latrines, septic tanks and other waste disposal facilities is 12m. Chemical parameters that occur in high concentrations are sulphates, chlorides, nitrates and sodium. Nitrate and chloride are pollution indicators from sewage in groundwater. Total Coliform count, Faecal Coliforms and Faecal Streptococci are very high and far above the maximum permissible limit. Contamination of deeper sources of water from the dug wells is both lateral and vertical with contamination plume spreading to better planned areas. Sanitation facilities in unplanned areas should be upgraded from pit to Ventilated Improved Pit latrines and with adequate provision of water to pour-flush and septic tank system. Septic tanks and soakaways should be designed to protect groundwater from contamination.

Keywords: pit latrines, VIP latrine, poor sanitation, sewage, groundwater quality

Introduction

Groundwater is the water present beneath Earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells. Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water, therefore, it is commonly used for public water supplies.

Polluted groundwater is less visible, but more difficult to clean up, than pollution in rivers and lakes. Groundwater pollution most often results from improper disposal of wastes on land. Major sources include industrial and household chemicals and garbage landfills, excessive fertilizers and pesticides used in agriculture, industrial waste lagoons, tailings and process wastewater from mines, industrial fracking, oil field brine pits, leaking underground oil storage tanks and pipelines, sewage sludge and septic systems.

Groundwater pollution, from pollutants released to the ground that can work their way down into groundwater, can create a contaminant plume within an aquifer. Pollution can occur from landfills, naturally occurring arsenic, on-site sanitation systems or other point sources, such as petrol stations or leaking sewers.

Movement of water and dispersion within the aquifer spreads the pollutant over a wider area, its advancing boundary often called a plume edge, which can then intersect with groundwater wells or daylight into surface water such as seeps and springs, making the water supplies unsafe for humans and wildlife.

A pit latrine is a type of toilet that collects human feces in a hole in the ground. They use either no water or one to three liters per flush with pour-flush pit latrines. When properly built and maintained they can decrease the spread of disease by reducing the amount of human feces in the environment from open defecation. This decreases the transfer of pathogens between feces and food by flies. These pathogens are major causes of infectious diarrhea and intestinal worm infections. Infectious diarrhea resulted in about 700,000 deaths in children under five years old in 2011 and 250 million lost school days (WHO, 2011). Pit latrines are the lowest cost method of separating feces from people.

A pit latrine generally consists of three major parts: a hole in the ground, a slab or floor with a small hole, and a shelter. The shelter is often known as an outhouse. The pit is typically at least 3 meters (10 feet) deep and 1 m (3.2 feet) across. The World Health Organization (2011) recommends they be built a reasonable distance from the house balancing issues of easy access versus that of smell. The distance from groundwater and surface water should be as large as possible to decrease the risk of groundwater pollution. The hole in the slab should not be larger than 25 centimeters (9.8 inches) to prevent children falling in (Reed, 2011). Light should be prevented from entering the pit to reduce access by flies. This may require the use of a lid to cover the hole in the floor when not in use. When the pit fills to within 0.5 meters (1.6 feet) of the top, it should be either emptied or a new pit constructed and the shelter moved or re-built at the new location. Fecal sludge management involves emptying pits as well as transporting, treating and using the collected fecal sludge. If this is not carried out properly, water pollution and public health risks can occur.

Study area

Minna is the capital of Niger State and lies between latitudes $9^o32'$N and $9^o41'$N and longitudes $6^o28'$E and $6^o37'$E, covering an approximate surface total area of $105km^2$. The area is easily accessible through Abuja-Dikko-Lambata-Tegina, Lagos-Mokwa-Bida and Kaduna- Sarkin Pawa roads. It has an annual rainfall of about 2500mm with distinct rainy and dry seasons experienced between April to October and between November to March respectively. It has a mean temperature of 27^oC in the rainy season and 35^oC at the peak of the dry season with a relative humidity of 87% in the rainy season and 35% in the dry season (Idris, 2000). The area is drained mainly by River Chanchaga, which is a tributary of River Niger, as well as other minor seasonal streams. The geology of the area comprises mainly of rocks belonging to the

Precambrian basement complex system of Nigeria (Truswell and Cope, 1963) and is mainly underlain by granites, migmatites, gneisses and schist.

Bida lies on latitude 9°05'08″N and longitude 6°00'36"E at an altitude of 151m with a total surface area of 51 km square. It is located in central Nigeria and is the second largest city in Niger State, one of the 36 federating states in Nigeria, with a population of 224,132 projected to 2015 from the 2006 population census using an annual growth rate of 3.4%. The area is drained mainly by River Landzu which runs in the E-W direction and cuts the town roughly into two. Houses in the area are built close to each other and consist of old buildings that are over 100 years old and more modern ones. The area is underlain by rocks belonging to the Maastrichtian Bida Basin and comprises basically of sandstones, siltstones, mudstones, shale and clay, and is in places capped by the lateritic ironstone.

Groundwater use is mostly restricted to the use of hand dug wells and shallow boreholes all placed within the unconfined aquifer. As a result of the complete failure of the public water supply system attention has turned fully to the use of groundwater as the main source of water supply for the inhabitants (Idris-Nda, 2010).

Sanitary facilities consist of shallow pit latrines and pour flush (locally known as soakaway) and open defecation by children. Waste disposal is by use of open dumps located in open spaces between houses and the drainage systems which have consequently become littered with all kinds of wastes including polythene bags, which are the common packaging materials in the area.

Due to the high population density within a relatively small area, water and sanitation facilities coexist side by side and both are mostly in direct contact with the water table. This situation is likely to have a negative impact on the water quality, owing to the poor design of both water and sanitary facilities.

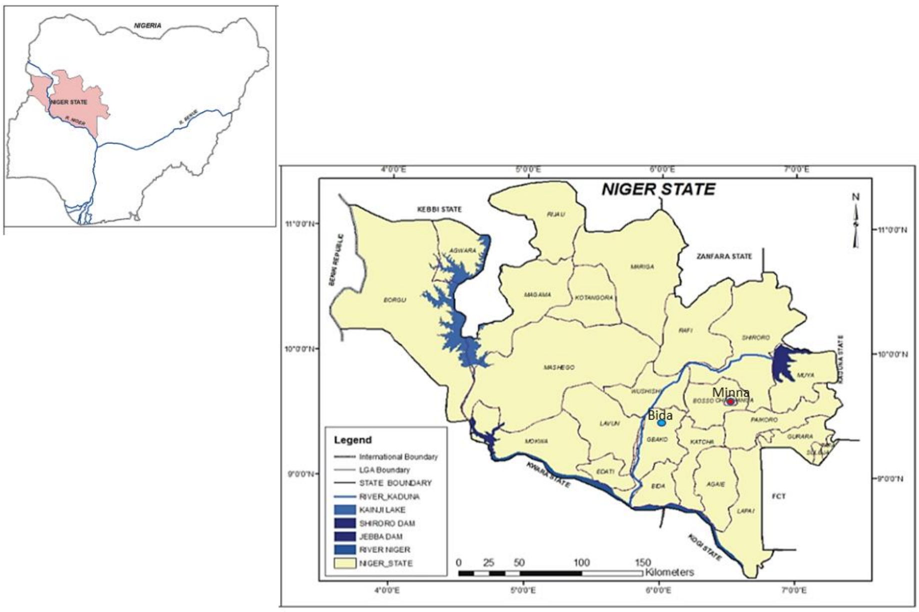

Figure 1: Map of Niger state showing Minna and Bida (inset is map of Nigeria)

Types of Toilets

Off-site sanitation systems

Off-site systems are widely acknowledged as systems that are only suited to developed and affluent areas, whose water resources are plentiful and reliably delivered to household connections in enough quantities. In low income and less developed areas where water is often collected from a stand-post or well, dry (on-site) systems are the only possibilities. Despite this, there are alternatives to conventional sewerage that may sometimes be applicable.

On-site Sanitation Systems

Simple Pit Latrine: On-site sanitation systems are more widely employed in low income and rural areas of the world. Numerous forms have been developed ranging in both price and complexity. A simple pit latrine (figure 2) is perhaps the simplest and the first step among sanitation solution identified by the UN to meet the criteria of the Millennium Development Goals (JMP, 2004). In reality the variance in the standard of these facilities can be great. The JMP distinction is that the latrine should have a superstructure to be acceptable to users. The simplest form of pit latrine is a hand dug pit that is unlined and covered with a series of wooden logs strapped together allowing the user to defecate into the pit. This system can gradually be improved.

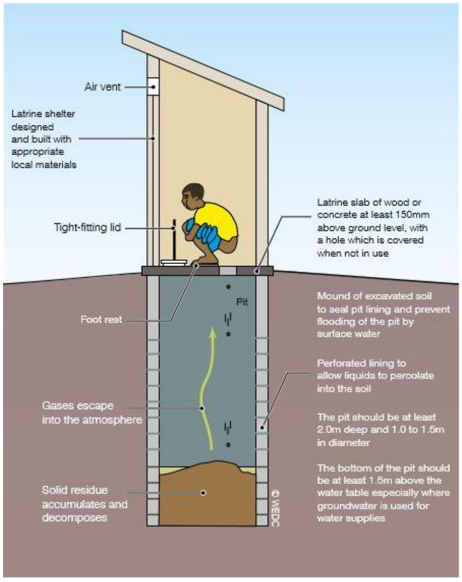

Figure 2: Simple pit latrine (Reed, 2014

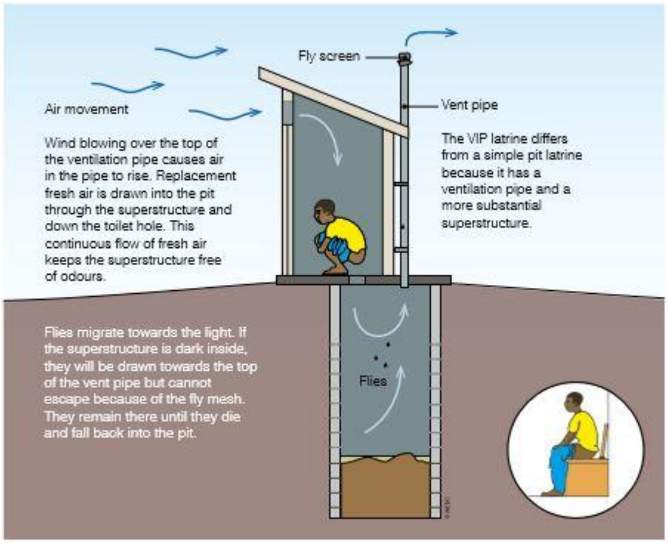

Figure 3: Ventilated improved pit latrine (Reed, 2014)

Raised Latrines: When the groundwater is high or the ground is too rocky to excavate by hand there is a case for using a raised pit latrine (other latrine types can also be raised although it is more common for simple pit latrines to be raised). One major disadvantage is the lack of privacy afforded to the users of the latrines.

Slab type: There are numerous types of slabs that can be used for a latrine, each with different benefits. The purpose of the slab is to hold the weight of the user over the pit, provide a clean surface for the users feet and drain liquids into the squat hole. A variety of materials can be used such as timber, reinforced concrete and un-reinforced concrete slabs in a dome shape to avoid tensile forces. Sanitation platforms (San-plats) are often added onto traditional latrine slabs to provide a clean surface, foot plates and a suitably shaped squat hole.

Ventilated Improved Pit (VIP) Latrine: During the 1980s the VIP latrine (Figure 3) was developed in Zimbabwe. The main drivers for design were to eliminate two unpleasant aspects of using on-site sanitation systems, flies and smell. Furthermore, the reduction of flies can also reduce the transmission of disease. Put simply, the technology facilitates the flow of air through the system. One important aspect is that the inside of the toilet should remain dark as means of attracting flies up a vent pipe where they will eventually die and fall back into the latrine.

Pour-Flush Latrine: Where water is more widely available, or traditionally used for anal cleansing, a pour flush latrine may be appropriate and can bring a number of further benefits on top of simple or VIP latrines. A waterseal is created by a plastic u-bend which prevents bad odour and flies affecting the user (this system is less susceptible to building errors than the VIP system). The system only requires a few litres of water and so should not put a strain on resources.

Offset pits: These are a means of improving the operational nature of a latrine, but may increase the cost of construction and increase the complexity of the system. Two main advantages of employing an offset pit are to make emptying easier without having to disturb the superstructure and they can also enable the toilet to be constructed inside the house.

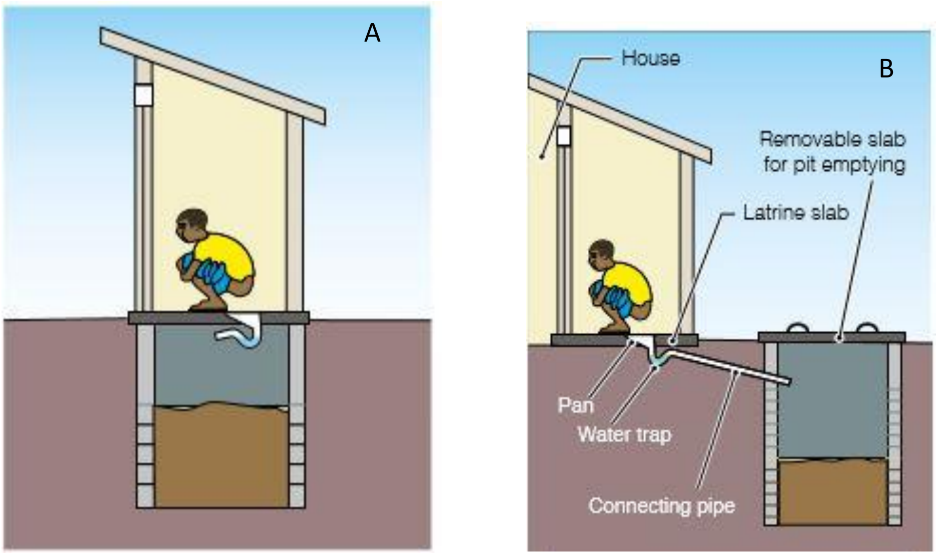

Figure 4: Direct (A) and offset (B) Pour-flush latrine (Reed, 2014)

Single or Double Pit: It is also possible to include a double pit, this involves the need to change the direction of flow between pits. The advantage of a double pit is that the contents of one pit gradually decompose over time whist the other pit used and become safer to remove. The sanitation facility also becomes a more permanent piece of infrastructure as the superstructure never has to be removed. One area for caution is to ensure that the double pits are operated correctly, in some cases it has been observed that incorrect use means the contents of one pit are not safe to remove (Pickford, 1995).

Ecological Sanitation Latrines: Ecological sanitation (ecosan) latrines have been developed employing the concept that human waste contains nutrients that should be returned to the soil and used to grow more food. There are different types of toilet, which treat the waste to some extent prior to using the by-product to increase fertility of land. The types of toilet can be split into dehydrating and composting types with urine diversion often being employed to make the most of the nutrients available.

Aqua-Privy: An aqua-privy function in a similar manner to a septic tank whilst avoiding the need for a consistent water supply to operate a flush toilet. The water will drain off the top and the sludge needs to be emptied on a regular basis. An advantage of the aqua privy is that it reduces odours. However, regular emptying could become an onerous requirement.

Septic Tanks: A septic tank is a water tight tank that typically receives waste from a flush toilet. They are useful in areas with a high water table (due to the sealed nature contamination of the water table is less likely) and when a reliable water supply is present. The system provides some level of treatment to the waste through the separation of solids.

Other Forms of On-Site Sanitation

There are other forms of sanitation which are less used or unsanitary. Borehole latrines are often used in emergency situations but adopted less elsewhere. Unsanitary forms would include overhung latrines which will dispose directly into a watercourse, or bucket latrines where users defecate into a bucket which is routinely emptied.

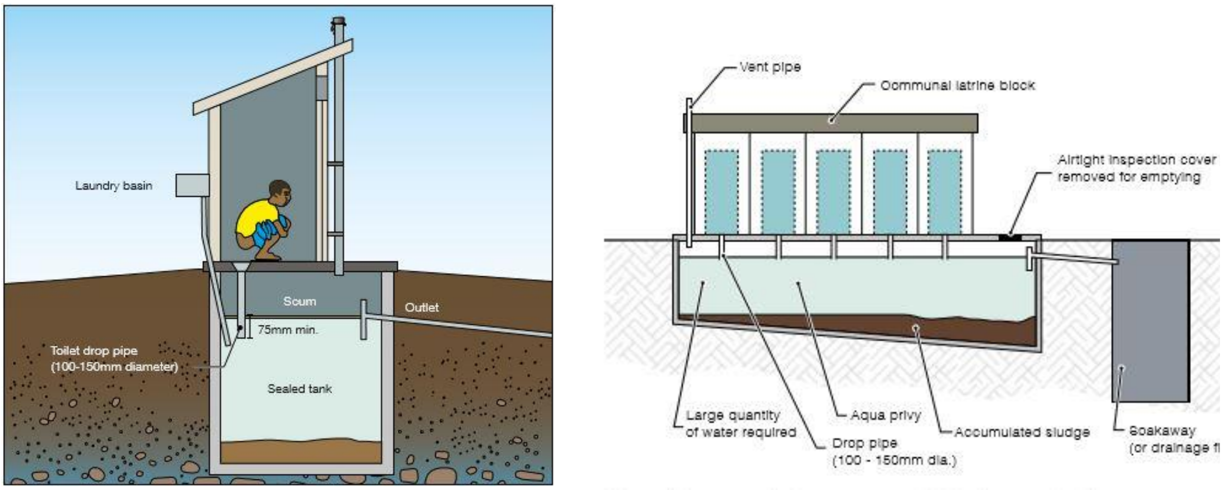

Figure 4: An aqua privy latrine for single and communal uses (Reed, 2014)

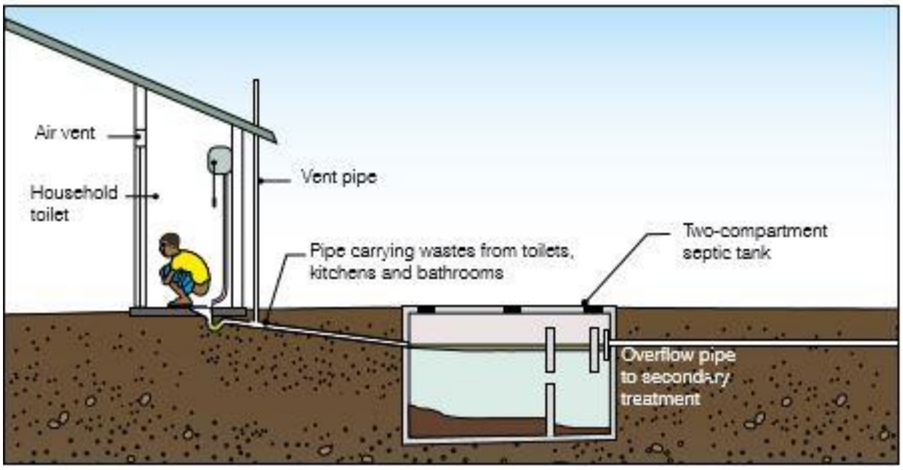

Figure 5: Septic tank system (Reed, 2014)

Groundwater Pollution

An important consideration when employing on-plot sanitation systems is that of groundwater pollution. Due to the nature of on-site systems shallow groundwater can be exposed to the pathogens within faeces and become contaminated. In urban areas this can be particularly problematic especially if shallow groundwater is used for drinking. In general it is possible to reduce this risk by locating a latrine at least 10m horizontally from a groundwater source (Boot, 2008). There is often debate as to the costs associated with alternative sanitation systems as oppose to alternative water sources. An alternative means to reduce the risk of contamination to groundwater is to employ a raised pit latrine.

Aim and objectives

The study is aimed as assessing the effects of poor design and construction of water and sanitation facilities in Minna and Bida, central Nigeria.

The main objectives include:

1. Determine water and sanitation facilities design and proximity in the area
2. Determine the water level and direction of groundwater flow
3. Determine the physicochemical and bacteriological composition of groundwater
4. Propose strategies for effective use and sustainability of water and sanitation facilities

Methodology

In order to meet the objectives of the research work the following methodology was adopted.

- Sampling of wells, boreholes and households in the area was conducted using the grid-based approach. The area was divided into 250m x 250m grids and samples were taken within each alternative grid. Wells, boreholes and sanitary facilities within each grid were carefully recorded and questionnaires administered to respondents within the grid. Coordinates of locations were established using a hand-held Global Positioning System, Etrex Legend H.
- Questionnaires, oral interviews and visual inspection were used to determine water and sanitation facilities in 250 households in each area.
- Depth and water levels of wells and boreholes were determined using a water level dip meter. Some of the installed boreholes were lifted slightly to access the depth and water level.

- 100 water samples were taken in glass and plastic bottles across the area and taken to the laboratory for analysis using standard analytical methods (Atomic Absorption Spectrometry, Titrimetric and Flame Photometry). Physical parameters of pH, Eh, Conductivity, Temperature and Total Dissolved Solids, were taken at the point of sampling. Microbial analysis was conducted using the American Public Health Association (APHA, 2005) standards for the examination of water and wastewater. All other analysis was in conformity with this standard.
- Direction of groundwater flow was determined by using water table elevation contour maps derived from measured results. The differences in water table elevation between wells with the highest and lowest elevations were connected to form a triangle from which the direction of groundwater flow was determined. Vertical flow components were computed from sieved samples using empirical methods. Downward flow component was indicated by the negative hydraulic gradient computed from the water level elevations.

Results and Discussion

Groundwater Occurrence and Use

Groundwater in Minna occurs mostly within the weathered and fractured zones of the rock. Weathering depth ranges mostly between 3 – 10m with most wells relying on this weathered zone for water supplies. Boreholes depend on deeply seated fractures within the rock while well designed boreholes totally exclude water from shallow sources by totally sealing it off. In Bida groundwater occurs in three aquifer levels which are unconfined, semiconfined and confined occurring at 3-60m, 80-150m and >170m respectively (Idris-Nda, 2010). As a result of paucity of water supply from the public service (Niger State Water Board) inhabitants of both areas have turned completely to groundwater as the main source of domestic water supplies for drinking and other utilities. Shallow hand dug wells depend solely on the shallow unconfined aquifers and which tend to dry up in the dry season, for this reason most inhabitants have turned to boreholes as the main source of water supplies. Depth of the boreholes range from 30 to 200m with a mean of 120m. Most of the boreholes have are for commercial activities, selling to water vendors in carts while some are for the production of sachet water commonly called “pure water”. Overdependence on groundwater often leads to over pumping or over drafting resulting into over withdrawal of groundwater and consequent lowering of the water table (dewatering) and pollution from shallow sources of pollutants like pit latrines, septic tanks, wastewater in unlined drains and slaughter houses or abattoirs.

Latrines Types, Design and Use

Common latrines in both areas include; simple pit latrines (both lined and unlined), Ventilated Improved Pit (VIP) latrines, pour flush and septic tanks. Table 1 shows the percentage of the different toilet types in Minna and Bida. The study shows that there are more pit latrines in Bida than in Minna. Pit latrines are found in both areas in older parts of the cities where the houses are older and closer together. The pit latrines have a depth range of 3 – 6m and are mostly in direct contact with the water table especially during rainy season which lasts for about seven months. The septic tank consist of two interconnected chambers, the first chamber is where the waste is first discharged into and the second chamber contains the sewage which is allowed to drain freely into the surrounding rocks through perforations made in it. The first chamber is cemented while the second is not, they are constructed up to depth ranges of 2 – 3m. The average distance of the sanitary facilities to the water facility in the area is 12.2m. If the local hydrogeological conditions are ignored, pit latrines can cause significant public health risks via contaminated groundwater (Buitenkamp and Richert, 2008).

Table 1: Percentage of latrine types in Minna and Bida

	Minna (%)	Bida (%)
Simple pit latrine	10	30
VIP latrine	5	3
Pour-flush latrine	10	20
Aqua privy	-	-
Septic Tank	75	47

Figure 6: Public water supply in Bida with borehole and septic tank in close proximity


Figure 7: Public water supply borehole close to a large open dump.

Groundwater flow and contaminant transport

Generally, groundwater flows from areas of higher hydraulic head to areas of lower head, dissolved and suspended particles, both chemical and bacteriological are carried by the moving water as it tortuously makes its way to a discharge point. The particles it carries are subjected to processes of advection, sorption, advection, degradation, dispersion and attenuation as the water flows, all aimed at removing the particles thereby purifying the water. However due to the proximity of the contributing sources and rapid groundwater withdrawal due to pumping the particles are forced to move faster and to draw from all other sources within the radius of influence of the pumping well. This leads to more sewage from latrines that are not well planned to move into groundwater thereby increasing pollution level. Figure 1 is the graph of mean water level elevation in the area. Groundwater flow is principally in the SE-NW direction with a minor E-W flow component (Figure 6). Determining flow direction is important for mapping recharge areas and contaminant migration path.

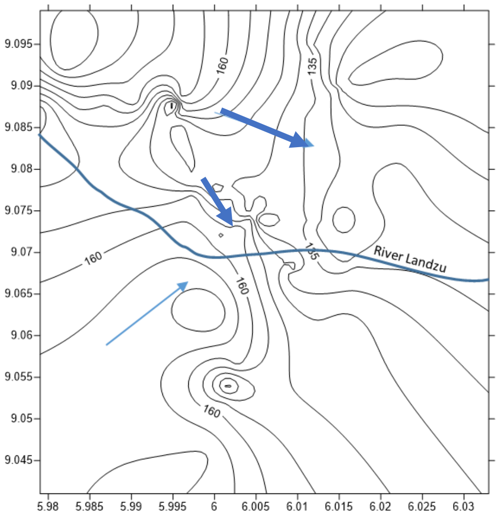

Figure 8: Direction of groundwater flow in Bida (blue arrow).

Physicochemical and bacteriological Composition of Groundwater

Table 2 is the results of the mean values of physical parameters of groundwater in Minna and Bida areas, generally pH is neutral to slightly basic at 6.7 and 8.72 respectively, some areas close to open dumps have pH that trends towards been acidic. Eh (redox potential) which is a measure of the tendency of the solution to either gain or lose electrons and a common measurement for water quality, is -65 and -80 for Minna and Bida respectively, this indicates water that is more in the reduced state with a high tendency to donate electrons. Mean temperature is 29°C, Electrical Conductivity (EC) which is an indication of the dissolved chemical constituents of the water is 905 to 1263µS/cm while Total Dissolved Solids (TDS) which is a measure of the combined content of all inorganic and organic substances contained in the water and is used as an aggregate indicator of the broad presence of a broad array of chemical contaminants, is 458 to 525mg/l. Surface water has the least TDS value of 32mg/l while dug wells have the highest with 385mg/l and boreholes occupy an intermediate position with 148mg/l. Even though the acceptable limits for TDS is 500mg/l some dug wells in the area have concentrations above this limit. Most of the areas have TDS values that exceeds the

NDWQS, this is especially more noticeable in Bida. Figure 9 is the map of Bida and Minna showing TDS concentration in both wells and boreholes. Highest values for TDS (>500) and conductivity (>1000) in Minna include; Limawa, Kongila, Sabon Gari, Mobil, Kpakungu, Paida and Unguwan Kaje areas. In Bida areas with high TDS and have higher nitrate concentration include; Gbangbara, Gbangaie, Basakun, Tutuchiba, Lonchita, Forgun, Lalemi, Kabari Gulu, Efu Madami, Nasarafu, Swatamukun, Masagas, Dokozha, Darachita, Banwuya, Bantigi, Eso, Efu Nakodi and Masaba.

TDS concentration is found to be higher in areas that are unplanned and more densely populated than in better planned areas with low population and better sanitary facilities.

Table 2: Results of physical parameters of groundwater in Minna and Bida

Parameter	**Mean**		**NSDWQ**
	Minna	**Bida**	
TDS	454	525	500
Electrical Conductivity (µS/cm)	905	1263	1000
Dissolved Oxygen (mg/l)	6.97	7	
pH	6.75	8.72	6.5-8.5
Eh (mV)	-65.00	-80	
Temperature (°C)	29.5	29.4	Ambient
Turbidity (NTU)	3.65	3.7	5

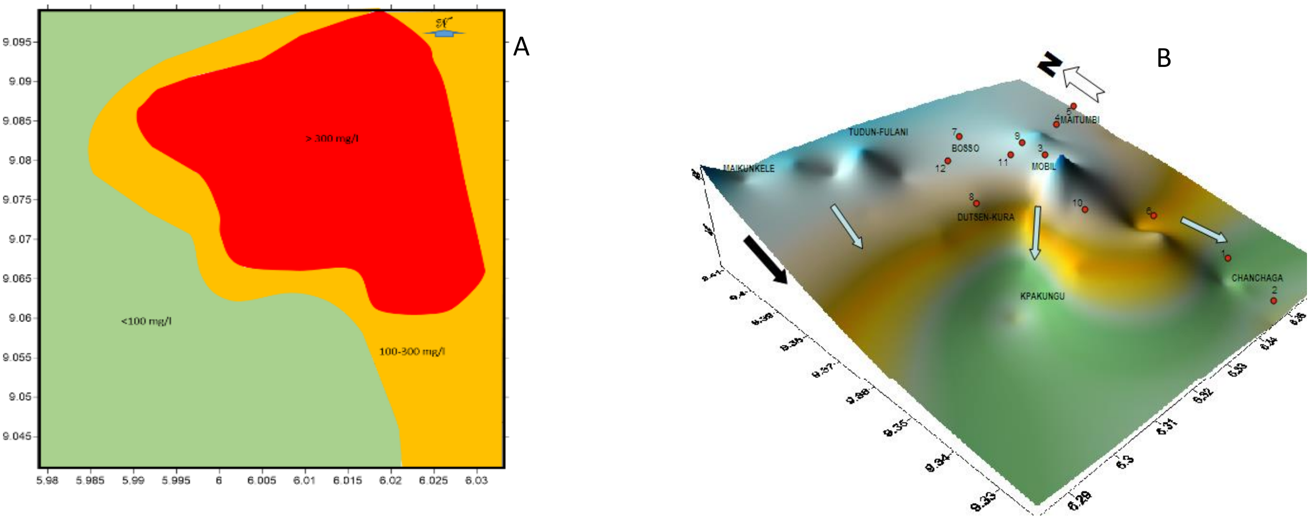

Figure 9: TDS distribution in Bida (A) and Minna (B)

Laboratory analysis of the chemical and bacteriological constituents of the water shows that sulphates, chlorides, nitrates and sodium are the chemical constituents that occur in high concentrations with sulphate and nitrates have values approaching the maximum permissible limits of NDWQS (2007) standards (100 and 50 respectively) for drinking water. Sulphate concentrations range from 230 to 80mg/l while nitrate ranges between 110 and 13mg/l. Chloride concentration ranges between 180 and 20mg/l. Figure 10 shows the major chemical constituents of groundwater while Figure 11 shows the concentrations of heavy metals in the groundwater in parts of Minna and Bida.

Total coliform ranges from 200 to 12cfu/100ml, faecal coliform and faecal streptococci ranges from 80 to 6cfu/100ml and 73 to 1cfu/100ml respectively, NDWQS limit is 0cfu/100ml for all parameters.
Total coliforms count give a general indication of the sanitary condition of a water supply. include bacteria that are found in the soil, in groundwater that has been influenced by surface water, and in human or animal waste. Faecal coliforms are the group of the total coliform that are considered to be present specifically in the gut and faeces of warm-blooded animals. Faecal coliforms are considered an accurate indication of animal or human waste than the total coliforms. Escherichia Coli (E. Coli) is the major species in the faecal coliform group that is generally not found growing and reproducing in the environment. Consequently, E. Coli is is considered to be the species of coliform bacteria that is the best indicator of faecal pollution and the possible presence of pathogens. Water pollution caused by faecal contamination is a serious problem due to the potential for contracting diseases from pathogens.

Table 3: Results of chemical and bacteriological parameters in groundwater of Minna and Bida

Parameter	**Mean**		**NSDWQ**
	Minna	**Bida**	
Chloride	43.0	78.4	250
Sulphate	60.0	85.2	100
Nitrate	48.0	44.7	50
Bicarbonate	10.0	32.6	
Fluoride	0.5	0.5	1.5
Phosphate	2.0	1.3	
Nitrite	0.1	0.0	0.2
Carbonate	0.0	0.0	
Sodium	45.0	64.4	200
Potassium	32.0	22.6	50
Calcium	21.0	33.8	200
Magnesium	27.0	22.6	20
Iron	0.4	0.3	0.3
Manganese	0.1	0.1	0.2
Chromium	0.2	0.6	0.05
Zinc	1.4	0.8	3.0
Copper	0.7	0.3	1.0
Total Coliforms (cfu/100ml)	30.0	54.5	10
Faecal Coliforms	11.0	13.0	0
Faecal Streptococci	8.0	11.0	0

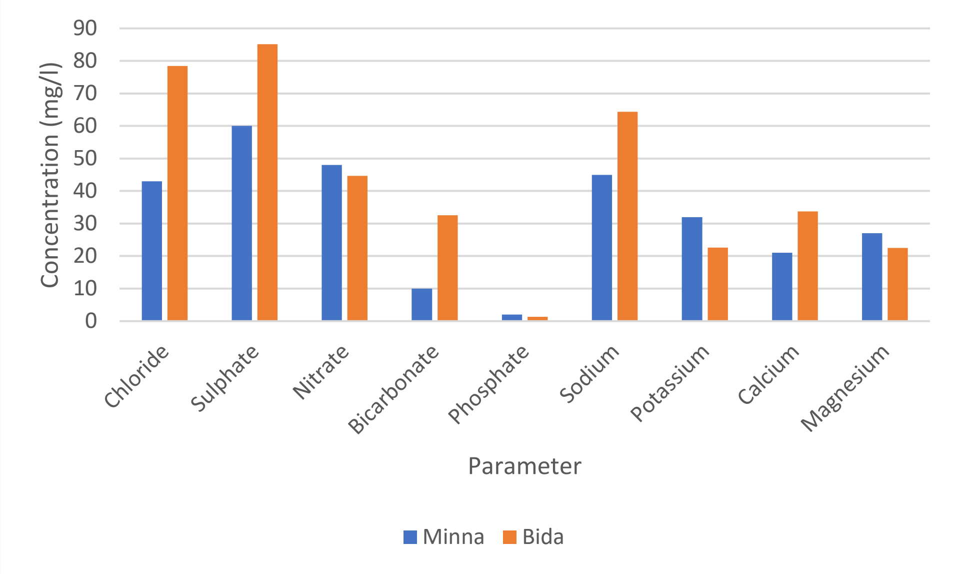

Figure 10: Major chemical constituents in groundwater in parts of Minna and Bida areas

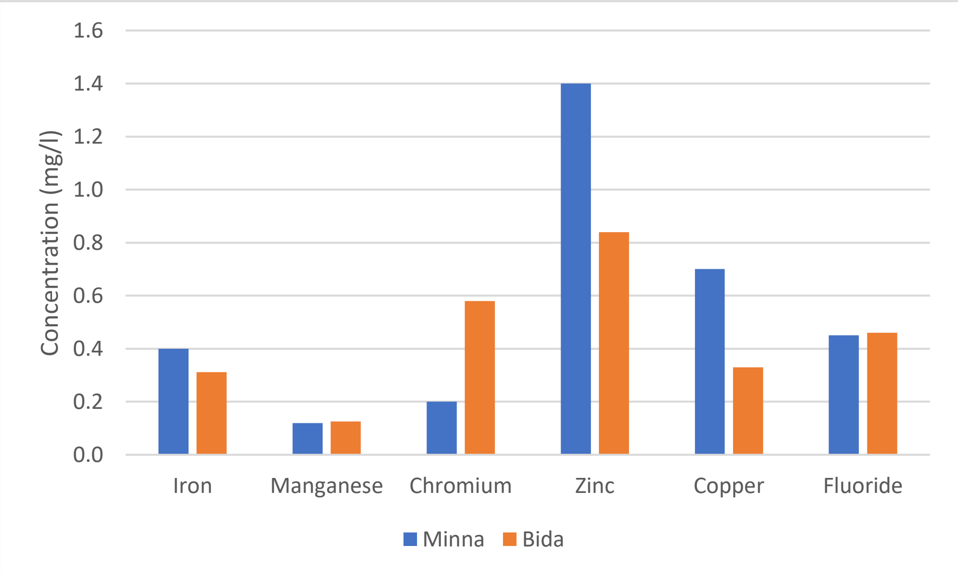

Figure 12: Heavy metal concentration in groundwater of parts of Bida and Minna

Mitigation strategies will involve the following:

i. Upgrading public water supply facilities in Minna and Bida to ensure adequate and sustainable water supply to the teeming populace, this will greatly reduce reliance on groundwater and thereby reducing pollution from sewage.

ii. Improving the present unlined pit latrines by upgrading to the Ventilated Improved Pit (VIP) latrines. As a very general guideline it is recommended that the bottom of the pit latrines should be at least 2 m above groundwater level, and a minimum horizontal distance of 30 m between a pit and a water source is normally recommended to limit exposure to microbial contamination (WEDC, 2012).

iii. Closing down all wells and boreholes placed on shallow aquifer sources and replacing them with well-designed boreholes ones that targets deeper sources of water.
iv. Groundwater development should be monitored and licensed to protect the resource.
v. Routine monitoring of all sources of water in the state should be carried out sustainably in order to identify early on any contaminant(s) that might be potentially detrimental to health.

Conclusions

Common constituents as a result of domestic waste that lead to groundwater contamination and which can be potentially harmful include chloride, copper, nitrate, nitrite and sulphate while bacteriological constituents are mainly coliform bacteria (USGS, 2015). All these parameters are found to be present in concentrations considered above acceptable limits in the groundwater of Minna and Bida. Concentrations are generally higher in hand dug wells than in boreholes but lowest in the surface water, except for turbidity. Bacteriological contamination is found to be particularly high in hand dug wells and poorly designed boreholes. It is therefore advised that secondary treatment with chlorine tablets be carried out on poorly constructed shallow boreholes and hand dug wells before drinking, or such water could be boiled and allowed to cool before using. Transmission of the contaminants was found to be vertically downwards to the deeper water sources and laterally to areas not presently seriously affected. Sanitary systems should be well designed to safeguard groundwater from contamination. The design in Figure 13 is suggested and building supervisors should ensure compliance, present unplanned ones could also be upgraded to comply with the design.

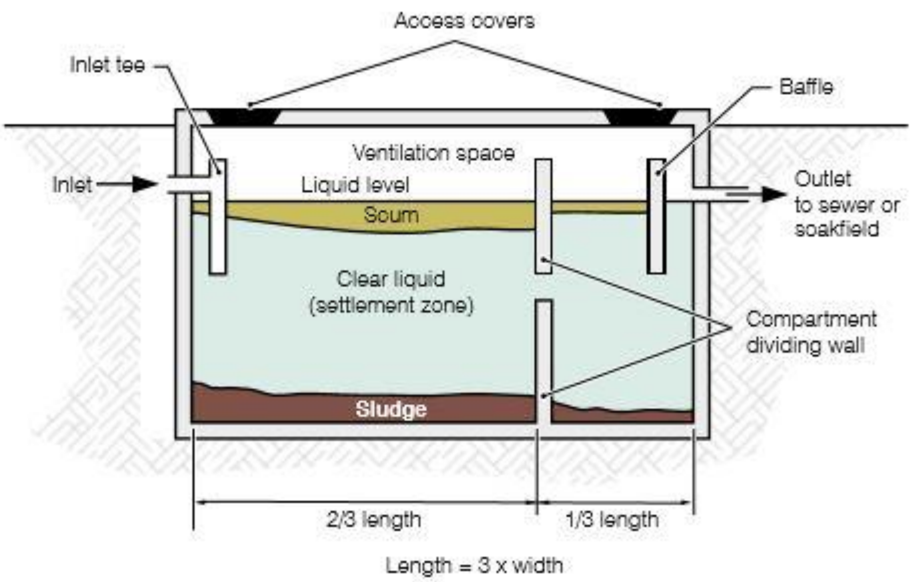

Figure 13: Septic tank design for optimal sanitary condition for groundwater protection (Reed, 2014)

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