Evaluation of Microbial Contamination and Groundwater Quality Index in Borehole and Well Water Systems of Sabongida Area, Northwestern Nigeria.

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Abstract- This review focuses on the quality of groundwater in boreholes and well water used as potable water in Sabongida area of Zamfara State, Nigeria. Groundwater, a crucial source of drinking water, is increasingly threatened by microbial contamination which degrades the quality index of the water. This research paper offers a thorough exploration of the sources and pathways through which pathogenic microbial organisms infiltrate groundwater, highlighting key risk factors such as land use, poor sanitation, and climate change. It assesses both traditional and innovative risk management strategies, with more insight on quantitative microbial risk assessment to gauge their effectiveness by simulating microbial behavior under different conditions and predicting the impact of intervention strategies on public health metrics. The review aligns with World Health Organization's (WHO) Guidelines concerning clean water and health, offering emphasis on how microbial contamination can be reduced to meet global targets. The presence of E. coli or thermo tolerant coliform provides strong evidence of recent faecal contamination and is used to estimate disease. The count for E. coli as a microbial water quality indicator should be zero per 100ml water for drinking purpose. Water below ground is mostly safe as long as they are appropriately built and run-in accordance with the recent World Health Organization's Guidelines for potable water, but can be contaminated during collection, transportation, and storage. The increase in drinking water from different sources especially in Sabongida Area of Zamfara state has made it necessary to investigate the microbial content of water.

Index Terms- Ground Water, Coliform, Indicator Organisms

I. INTRODUCTION

Water is a vital, transparent chemical substance that support life, existing as liquid, solid, and vapor, with sources mainly being natural (rain, rivers, lakes, groundwater from springs/wells) and man-made (dams, canals, reservoirs, treated wastewater).

Water is a clear fluid which is known to be odorless and tasteless with a melting point of 0°C and boiling point of 100°C. It covers 70% of the earth. Since water is important for all living organisms for survival there is need to maintain clean and safe water (Ekubo & Abowei, 2011).

Man uses water not only for drinking purposes but also for bathing, washing, laundering, heating, air conditioning, agriculture, stock raising and gardens, Industrial processes and cooling water power and steam power, fire protection, fishing, swimming as well as wild life propagation and navigation.

Natural water contains not only the natural flora but also microorganisms from soil and possibly from animals or sewage. Surface waters in streams or pools and stored waters in lakes and large ponds vary considerably in microbial content (Frazier, 1978). Water quality is degraded by various contaminants such as heavy metals, inorganic materials (Road salt, minerals, and acids from mining). nutrients (nitrogen, phosphorus from fertilizers), pathogens (bacteria, viruses), and chemicals like insecticides, pharmaceuticals, and industrial waste. These substances enter water bodies through industrial discharge, agricultural runoff, sewage, and urban runoff.

Water bodies are living ecosystems filled with many kinds of microorganisms. Some of these microorganisms are indigenous to the natural water while others are transient, entering the water from external environment. The generality of bacteria are mostly commonly found ordinarily in fresh water some of which include: pseudomonas, vibrio, Micrococcus and Actinomycetes etc

Since water is important for all living organisms for survival, there is need to maintain clean and safe water (Ekubo & Abowei, 2011). Potable water is known as drinking water, it is suitable for human and animal consumption. Natural sources of potable water include borehole water, well water etc. Water is known to support the growth of many microorganisms (Chapelle,2000) thus water sources may be contaminated with various enteric pathogens due to natural human activities.

As populations grow, the issue of water contamination becomes more severe. Polluted water, especially when contaminated with fecal matter, can pose serious health risks by serving as a medium for disease-causing microorganisms.

Pathogenic microorganisms that are transmitted by water include bacteria, viruses, and protozoa. Most of the microorganisms transmitted by water usually grow in the human gastrointestinal tract and reach the outside environment through feces. Conventionally, the presence of coliform bacteria in drinking water has been seen as an indicator of fecal contamination through cross connection, inadequate treatment, or inability to maintain a disinfectant residual in the water distribution system (APHA,2005) . Coliform bacteria are regarded as belonging to the genera Escherichia, Citrobacter, Enterobacter and Klebsiella. The presence of E. coli provides strong evidence of recent faecal contamination and is used to estimate disease (WHO, 2017). The count for E. coli as a microbial water quality indicator should be zero per 100ml water for drinking purpose (WHO, 2013).

Contaminated water supply was traditionally treated by chlorination therefore reducing coliform and pathogen population. The presence of pathogens in water can lead to serious diseases in humans (Kurokawa, 2001). Waterborne infections make for about 75% of communicable diseases globally (Karnwal et al,2017) According to the World Health Organization (WHO), using contaminated water causes 80% of all human diseases in developing nations (Tabor et at.,2011). It is required by borehole operators to deliver safe drinking water to their consumers at all times. Contamination of the water supply can be detrimental to consumer's health (Howard et al., 2002). Water below ground is mostly safe as long as they are appropriately built and run-in accordance with the World Health Organization Drinking Water Guidelines (WHO, 2018), but can be contaminated during collection, transportation, and storage. The increase in drinking water from different sources especially in Zamfara state has made it necessary to investigate the microbial content of water. Water is a potential carrier of pathogenic organisms that can endanger human life. Most of drinking water sources are often contaminated with different pollutants like faeces, animal and plant wastes, making such water unfit for drinking, if not treated. The pollution of water with pathogenic organisms and other pollutants can only be detected by carrying out microbiological analyses of such water. Most human disease such as typhoid, paratyphoid, cholera, amoebiasis, Trichinosis, gastroenteritis, salmonellosis, shigellosis, diphtheria, giardia, dracunculus etc. are known to be water borne disease. (Ewington & Westhgoff, 1971). In Sabongida Area of Zamfara State, reliance on borehole and well water is high due to inadequate municipal water supply. However, the extent of microbial contamination and its influence on the groundwater quality index in this area remains inadequately documented. Factors such as population growth, improper waste disposal, shallow well construction, and proximity of water sources to potential pollution points may compromise groundwater quality.

Water-borne diseases which have water as their vehicle of transmission, are capable of destroying a whole community if not checked. Therefore, the quickest way to prevent outbreak of this disease and to determine the portability of such water sources is to determine the microbial load or content. If the microbial content is not within acceptable limit, such water sources should be condemned immediately

II. EMPIRICAL REVIEW

According to Umeh et al (2004) 48 % of the populations in Katsina-Ala Local Government territory of Benue state have urinary schistosomiasis due to consumption of contaminated water. Past study shows that 19 % of the entire Nigerian population is affected, with a few groups having up to half occurrence (Umeh et al,2004). This has made World Health Organization tried to enhance the cultural and socio-economic standards of individuals in the tropical region (Umeh et al, 2004,). Total bacteria and coliform counts were observed to be between 2.86 - 4.45 and 1.62 log cfu/% respectively (Oloaye & Onunide, 2009). Asides microbial contamination, heavy metals, lead, arsenic and other dangerous chemicals injurious to human health have also been identified.

According to Aina et al., (2012), water samples from boreholes gotten in Ogun State from various towns were bacteriologically analyzed using Most Probable Number technique and pour plate method. The results gotten showed that out of the 18 samples 13 were positive for Coliforms and the remaining five weren't. Three (3) water samples satisfied the WHO standard with a coliform count between 1-3/100 ml, 4 water samples were suspected to have a count of 4-8/100 ml and it did not satisfy the WHO standard requirement.

Escherichia coli, Klebsiella sp, Proteus sp, Enterobacter aerogenes, Staphylococcus aureus and Streptococcus sp isolates were gotten from the sample and characterized using Gram staining and biochemical reactions. Gram negative bacilli were more in the water samples (72.22 %) than the Gram-Positive Bacilli (11.11 %) and lastly GramPositive Cocci (16.67 %). E. coli isolates had the highest number of occurrences with a percentage of (33.33 %) and then Klebsiella sp with a percentage of (27.78 %) and lastly the percentage of Proteus sp, S. aureus and E. aerogenes were the least (5.56 %). Streptococcus sp. (11.11 %) and Clostridium sp. (11.11 %) were confirmed in two samples. 50 % of the isolates were positive to acid and gas production.

According to Edessa et al (2017) on the microbiological examination done on drinking water in Ethiopia, using WHO Guidelines for drinking water quality assessment water samples were collected from ground water and surface water sources and then the water samples were analyzed for Total coliform bacteria, E coli, Salmonella, Shigella, and Vibrio cholerae. E. coli was confirmed (APHA, 2005), Salmonella and Shigella were isolated (APHA-AWWA, 1998), and Vibrio cholerae also detected. From the results gotten from the researcher, the bacteriological load in the different water samples was more than the maximum value set for drinking water.

According to Adogo et al., (2016) on the bacteriological examination of the water from a borehole in the Auta Balefi Community, Nassarawa state Nigeria, borehole water samples were gotten from five different locations which were labelled A to D and then analyzed. From the results gotten by the researcher, sample D and C had the lowest total and faecal coliform count while sample B and E had the highest count. Salmonella typhi, Klebsiella pneumonia Staphylococcus aureus, Pseudomonas aeruginosa, Proteus mirabilis and Escherichia coli were also identified.

According to Makhmoor et al (2015) on the evaluation of the microbiological quality of drinking water in the Indian city of Gwalior that has undergone chlorine treatment, different water samples were collected from treatment plants and consumer's household taps, 56 water samples were collected in total and tested for total and faecal coliforms and residual chlorine content. The residual chlorine from all samples were between 0.08 to 0.98 mg/L, total coliforms in all the samples ranges between 0.82 to 7.15 MPN/100 ml and faecal coliforms ranges from 0 to 4.10 MPN/100 ml.

Water contamination has different categories, Surface water and ground water which is known to be from different sources although interrelated, can be contaminated in different ways. Surface water can be contaminated through Point source and non-point source contamination (Ekubo & Abowei, 2011).

III. STATEMENT OF PROBLEM

Groundwater is a major source of drinking and domestic water for many households, particularly in developing areas where access to treated surface water is limited. Despite its natural protection by soil and rock layers, groundwater is increasingly threatened by microbial contamination arising from human activities which are increasingly overcoming this natural protection and contaminating groundwater with microorganisms such as bacteria, viruses, and parasite

However, human activities (anthropogenic activities) are increasingly overcoming this natural protection and contaminating groundwater with microorganisms such as bacteria, viruses, and parasite. These activities introduce pathogenic and indicator microorganisms into groundwater systems, leading to the degradation of water quality. Naturally, the layers of soil and rock act as filters, protecting groundwater from many pollutants by trapping and reducing harmful substances before they reach the water. This is why groundwater is often considered cleaner than surface water

Normally, borehole and well water are considered safe for human and animal consumption but there are doubts about their safety for consumption due to the fact that there could be possible contamination of the water due to poor sanitation practices, indiscriminate waste disposal, agricultural runoff, leakage from septic tanks, and improper siting of boreholes and wells and other points in the infrastructure such as the water storage, pipes used etc.

According to the World Health Organization (WHO), using contaminated water causes 80% of all human diseases in developing nations (Tabor et al, 2011).

IV. JUSTIFICATION

Borehole and well water are continuously being used without treatment which causes a lot of diseases like typhoid, dysentery, cholera, diarrhea among other diseases. The coliform evaluation of borehole and well water in this study will clear the doubts and provide information on the safety of water used within the study area. The results of this study will provide useful information to public health authorities, environmental agencies, water resource managers, and policymakers for formulating measures to safeguard groundwater, enhance water supply safety, and support sustainable groundwater management.

V. AIM AND OBJECTIVES

Aim
The aim of this research is to analyze borehole and well water from sources within student hostels at Sabongida Zamfara to determine their potability.
Objectives
In order to achieve this aim, the set objectives for this research project are:
1. To isolate and enumerate bacteria presence in the water sample.
2. To determine total and faecal coliforms count in borehole and well water sample at student hostel in Sabongida.

Fundamental Concepts

Underground Water
Underground water usage follows in rank to the surface water sources, ground water sources embrace all water sources embrace all water source obtained below the earth surface these include spring well borehole, underground dam (Fair et al, 1971)

Well Water
Wells are constructed for several purposes, including water supply, mineral exploration, drainage, and waste disposal. They may be classified as either shallow or deep depending on their depth. Well water is often relatively stagnant and may contain suspended materials such as clay, dissolved mineral salts, and organic matter, including remains of dead organisms that accidentally enter the well. In many locations, well water is naturally hard due to the dissolution of limestone and other calcium- and magnesium-rich rocks in the aquifer. Consequently, untreated well water is frequently unsuitable for domestic and industrial use and requires appropriate treatment before consumption.

According to (Traral et al, 2006), well water may also contain acidic components and elevated concentrations of trace elements, including potentially toxic metals such as arsenic. Groundwater occurs within saturated geological formations known as aquifers, which are widely distributed across most regions. Despite being underground, wells are often difficult to protect from contamination. Pollution may occur through surface runoff entering poorly sealed wells, seepage from contaminated groundwater, or leakage from nearby sanitation systems (Lay & Mirtarb, 1967).

Proper well maintenance is therefore essential. Sanitary protection measures—including effective sealing of the wellhead, secure casing connections, and diversion of surface drainage away from the well—are critical to preventing contamination. Damage or neglect of these safety components can significantly increase the risk of water pollution (William, 1999).

Groundwater is replenished mainly through the infiltration of rainwater, snowmelt, and water from surface sources such as rivers, lakes, ponds, and reservoirs. Infiltration refers to the downward movement of water through the soil into the zone of saturation (Lay & Mirtarb,1967). The rate and extent of infiltration depend on factors such as soil type, land use, permeability, and water quality (Babor &Lehrman, 1950).

Additionally, Shallow wells are generally more vulnerable to microbial contamination due to their proximity to the surface, especially in areas with poor sanitation, agricultural runoff, or improper waste disposal. Deep wells, although better protected, may still be affected by geochemical contaminants such as fluoride, iron, manganese, or arsenic. Regular monitoring, proper construction standards, and routine disinfection are therefore essential to ensure the safety and sustainability of well water supplies

Boreholes

A borehole is a narrow, deep opening drilled into the ground to access groundwater stored in underground formations known as aquifers. It is typically fitted with a casing and pumping system that enables the abstraction of water for domestic, agricultural, and industrial purposes. Boreholes provide a reliable source of water, particularly in areas where surface water is scarce or unsafe. However, despite drawing water from underground, boreholes are not immune to contamination.

Contamination of borehole water occurs when pollutants from the surface—such as sewage, fertilizers, industrial chemicals, or petroleum products—percolate through the soil and reach the aquifer. This problem is often intensified by human activities and poor environmental management. Boreholes drilled too close to pit latrines, septic tanks, soakaways, refuse dumps, or fuel storage facilities are especially vulnerable, as harmful microorganisms and chemicals can easily leach into the groundwater system.

Structurally, a borehole consists of a vertical casing that prevents the collapse of surrounding soil and rock, as well as a screen that allows water to enter while restricting sediment movement. When boreholes are poorly designed or inadequately sealed, surface runoff and contaminated water can flow directly into the borehole, bypassing the natural filtration capacity of soil layers. Shallow boreholes are particularly susceptible to this risk compared to deeper ones.

Borehole contamination may arise from both natural and anthropogenic sources. Microbial pollutants such as Escherichia coli and total coliform bacteria commonly originate from fecal contamination linked to sewage and sanitation failures. Chemical contaminants, including nitrates from agricultural fertilizers, iron and manganese from geological formations, and toxic heavy metals such as arsenic and lead, may also be present. Environmental factors such as high rainfall, flooding, and highly permeable or sandy soils further increase the likelihood of pollutants migrating into groundwater.

To reduce contamination risks, proper borehole construction and management are essential. This includes adequate grouting and sealing of the borehole casing, siting boreholes at safe distances—typically not less than 30 meters—from potential pollution sources, and ensuring sufficient depth to tap protected aquifers. Routine maintenance, periodic water quality testing, and hygienic handling of storage tanks are also critical to safeguarding water quality. Where contamination is detected, appropriate treatment methods such as chlorination, ultraviolet (UV) disinfection, ozone treatment, or filtration systems should be applied to make the water safe for consumption.

Additionally, although borehole water is often perceived as clean due to its underground origin, studies have shown that increasing urbanization, indiscriminate borehole drilling, and inadequate regulatory oversight have significantly increased groundwater pollution, particularly in developing regions. Sustainable groundwater management, enforcement of drilling standards, and public awareness are therefore crucial to protecting borehole water quality and public health.

Potable water

Potable water refers to water that is safe and suitable for human consumption, particularly for drinking, cooking, and food preparation, without posing any risk to health. It is water that has undergone appropriate treatment processes—such as sedimentation, filtration, disinfection, and sometimes advanced purification—to remove or reduce harmful microorganisms (bacteria, viruses, and parasites), chemical contaminants (heavy metals, pesticides, nitrates), and toxic substances to levels considered safe by public health authorities.

For water to be classified as potable, it must meet established physical, chemical, and microbiological standards set by regulatory bodies such as the World Health Organization (WHO) or national water agencies. Physically, potable water should be clear, colorless, and free from objectionable taste or odor. Chemically, it should not contain harmful concentrations of substances like lead, arsenic, fluoride, or industrial pollutants. Microbiologically, potable water must be free from disease-causing organisms, with indicator organisms such as Escherichia coli absent, signaling that fecal contamination is not present.

Potable water may originate from surface water sources (rivers, lakes, reservoirs) or groundwater sources (wells and boreholes), but regardless of the source, it must be adequately protected and treated before consumption

Potable Water Sources

The main sources of potable water include Surface water, Ground water and Rain water.

a) Surface Water: Surface water is water located above the ground and exposed to the air. Because it receives runoff from the land, it is more likely to contain disease-causing microorganisms. Rivers, lakes, and streams are common examples of surface water. The volume of water is dependent on amount of rainfall, type of soil, type of vegetation, slope of the ground and land use. Surface water such as river is often used to supply water for large urban systems due to the fact that they maintain a large and regular supply of water (Ekiye & Luo, 2010) ... However, surface water is seasonal and as a result would always need treatment to maintain, the cost of treatment and maintenance is usually high therefore is a disadvantage (Ekubo and Abowei, 2011).

b) Ground Water: Groundwater is water located beneath the Earth's surface, filling pores and fractures in soil, sand, and rocks within saturated zones known as aquifers. It requires less treatment than surface water, though it may require disinfection. Examples of ground water include springs, boreholes and wells (Selvinaz et al, 2015).

C. Rainwater: water collected from rooftops or other surfaces, this requires filtration and, at times, disinfection to ensure safety.

D. Desalinated Water: Seawater or brackish water purified through processes like reverse osmosis or distillation, commonly used in coastal regions. After the salt is removed, minerals such as calcium are typically added back into the water to stabilize it and improve taste.

Indicator Organisms

Indicator organisms in water are microorganisms, mainly bacteria such as E. coli, coliforms, and enterococci, that serve as markers for detecting fecal contamination and the possible presence of pathogens. These organisms are typically harmless, occur in greater numbers than actual pathogens, and help assess water safety, the effectiveness of treatment processes, and sewage contamination. They play a vital role in monitoring water quality and protecting public health.

Common Indicator Organisms:

Total Coliforms: General indicators of water's sanitary quality.

Fecal Coliforms: Specifically signal contamination from human or warm-blooded animal feces.

Escherichia coli (E. coli): A precise and widely used indicator of fecal contamination and potential pathogens.

Enterococci: More durable than coliforms, useful for evaluating marine and recreational waters.
Benthic Macroinvertebrates: Help assess long-term biological health and pollution levels in water bodies.

Key Traits of Ideal Indicator Organisms:
Non-pathogenic: They do not cause disease.
Abundant: Found in higher concentrations than pathogens.
Persistent: Survive longer in water than pathogens.
Easily detectable: Can be identified quickly and reliably.

Importance in Water Testing:
Detecting Fecal Contamination: Reveals potential sewage or fecal waste presence.
Monitoring Water Quality: Ensures safety of drinking and recreational water.
Evaluating Treatment Efficiency: Confirms effectiveness of water treatment processes.

Coliforms
The definition of coliforms varies; however, according to APHA (2005), coliform bacteria are aerobic and facultative anaerobic, Gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with the production of acid and gas within 48 hours at 35–37 °C.

According to French Standardization Association (1990), coliforms are rod shaped, non-spore forming, Gram negative, oxidase negative, aerobic or facultative anaerobic bacteria which are able to grow in the presence of bile salts or other surface-active agents having growth inhibitory effects and ferments lactose with acid or aldehyde and gas production within 48 hours at 370 C.

Coliforms are part of the Enterobacteriaceae family and consist of four main genera:
Citrobacter: This genus includes species such as C. amalonaticus, C. freundii, and C. koseri, which can use citrate as their only carbon source. They can be distinguished based on their ability to convert tryptophan to indole and to utilize malonate.
Enterobacter: Members of this genus are oxidase-negative and indole-negative.
Escherichia: These bacteria are commonly found in the intestines of warm-blooded animals.

Klebsiella: Found mainly in soil, about 30% of Klebsiella strains can fix nitrogen under anaerobic conditions. They are often used as indicators of water Pollution, hence classified as indicator organisms.

Coliforms are present in the environment especially in the soil, and in the faeces of warm-blooded animals and humans (faecal coliforms) (Howard et al., 2022). Their detection in drinking water indicates the need for analysis of the water as it means that pathogens or disease-causing organisms are present in the water body posing health risk to the water. Coliform bacteria in water are categorized into three main groups: Total coliforms, Fecal coliforms and Escherichia coli (E. coli).

Total Coliforms: These bacteria are commonly found in the environment and are generally harmless. Their presence in drinking water usually indicates environmental contamination, suggesting that the water may be exposed to pathogens. Total coliforms serve as indicator organisms for assessing water quality. Detection in drinking water implies inadequate treatment, highlighting the need for immediate and proper water treatment. Monitoring coliform levels is therefore an important part of water quality management.

Thermo-tolerant/fecalcoliforms: These bacteria are primarily associated with the intestines and feces of humans and animals, and they thrive at temperatures between 44°C and 45°C. Finding these coliforms in drinking water indicates recent sewage or fecal contamination, signaling a higher risk of pathogenic presence. This group includes Escherichia and certain species of Enterobacter, Citrobacter, and Klebsiella.
c) Escherichia coli (E. coli)
The presence of E. coli in water indicates fecal contamination, showing that sewage or animal waste has entered the water supply and posing a risk of serious illness from other pathogens such as harmful bacteria or viruses. Although most E. coli strains are harmless, finding it in water means the source should not be used for drinking or cooking until it has been

properly treated (e.g., by boiling or disinfection) or replaced with safe water. This is especially important for vulnerable groups like children, the elderly, and immunocompromised individuals. The presence of E. coli in water suggests other disease-causing bacteria, viruses, or parasites might also be present.

Drinking Water Pollution/Contamination

Percy and Frankland (1885) initiated routine bacteriological testing of municipal water supplies through the application of Koch's gelatin culture technique. Identifying organisms associated with sewage contamination is essential for assessing hazardous pollution and determining the potability of water sources. Since pathogenic microorganisms, when present, may be greatly outnumbered by naturally occurring microbial flora, it is crucial to ensure that water is free from disease-causing organisms (Skeat, 1961). Consequently, water quality assessment is more reliably achieved by investigating indicators of potential pathogen presence rather than attempting direct detection of pathogens themselves. As a result, greater attention has been directed toward the detection of fecal contamination as a key indicator of water safety (Gaecdrrch,1972).

Water contamination can be defined as the disintegration of biological, chemical and physical properties of water due to the activities of humans and other sources (Selvinaz et al., 2015). It is impossible to overstate how important water is; if water contamination problem is not controlled appropriately it could result in economic problems, societal problems, and even death (Garba et al, 2010). Water contamination occurs when undesirable substances get into, wells, streams, boreholes and waterways of homes and industries. Nigeria and the third world as a whole have suffered from the effects of water contamination, with 4.6 million deaths from diarrheal disease and a sizable number of ascariasis casualties as a result (Esrey,& Anderson, 2000). Many researches done in Nigeria today indicated that most common fresh water sources are polluted and results in serious outbreaks of diseases.

Groundwater contamination differs from surface water pollution and refers to the degradation of groundwater quality resulting from human activities, rendering the water harmful for use and posing significant public health risks. Chemical spills into the soil—whether arising from point or non-point sources—can infiltrate and contaminate groundwater systems.

Point source refers to the main point the contaminants or the pollutant came from i.e., through a discrete transport e.g., a pipe or a ditch. Common point sources include leaking underground storage tanks, septic tank failures, landfill leachate, industrial discharge pipes, chemical spills, and improperly constructed wells or boreholes. These pollutants percolate through soil and rock layers and eventually reach aquifers, degrading groundwater quality. Point source contamination is usually easier to monitor and regulate, but it can cause severe localized pollution if not properly managed.

The term non-point source describes pollution that does not originate from a single, clearly defined outlet but is instead dispersed over a wide area, commonly through processes such as erosion. Pollutants are transported over large areas and gradually infiltrate the soil into groundwater systems. Typical non-point sources include agricultural runoff containing fertilizers, pesticides, and animal waste, as well as urban runoff from roads, farmlands, and residential areas. These contaminants accumulate in the soil and are leached into groundwater by rainfall or irrigation. Unlike point source pollution, non-point source contamination is more difficult to identify, control, and remediate due to its dispersed nature. Most agricultural pollutants contain chemical substances such as nitrogen compounds and heavy metals which become residues in the soils and are later washed off into nearby water bodies thereby causing water pollution (Hung and Shaw, 2005). Rainwater also washes contaminants from parking garages, roads and highways into nearby water bodies, this is known as urban runoff (Ekubo and Abowei, 2011). The occurrence and extent of groundwater pollution are influenced by factors such as soil characteristics, site topography, hydrogeological conditions, and hydrological processes (Kurokawa, 2021).

Drinking Water Contaminants

Drinking water may be polluted by a wide range of contaminants that reduce its safety and quality. These contaminants can be classified as physical, chemical, biological, and radiological substances, originating from both natural processes and human activities. Biological contaminants include pathogenic microorganisms such as bacteria (Escherichia coli, Salmonella), viruses (hepatitis A, norovirus), protozoa (Giardia, Cryptosporidium), and parasitic worms, which often result from fecal contamination of water sources. Chemical contaminants include heavy metals like lead, arsenic, cadmium, and mercury, commonly released from mining activities, corroded pipes, or industrial discharges; nutrients such as nitrates and phosphates from fertilizers and sewage; pesticides and herbicides from agricultural runoff; and synthetic industrial chemicals such as per- and polyfluoroalkyl substances (PFAS), solvents, and petroleum hydrocarbons. Physical contaminants include suspended solids, sediments, organic matter, and microplastics that increase water turbidity and may harbor harmful microorganisms. Radiological contaminants, such as radon, uranium, and radium, occur naturally in certain geological formations or as a result of mining and nuclear activities. These pollutants enter drinking water through pathways such as agricultural runoff, improper waste disposal, industrial effluents, leaking septic systems, and deteriorating water distribution infrastructure.

Effect of Water Pollution

Water pollution has far-reaching consequences on public health, socioeconomic development, and the environment, particularly in rural and semi-urban communities such as the Sabongida area of Zamfara State. Contaminated water often harbors harmful microorganisms such as bacteria, viruses, and parasites, which are responsible for water-related illnesses including cholera, typhoid fever, dysentery, and diarrhea. Children are particularly vulnerable to these illnesses because their immune systems are not fully developed and are therefore less capable of resisting pathogenic microorganisms. Frequent exposure to contaminated water can lead to malnutrition, stunted growth, and increased child mortality. Although adults generally have more developed immune systems, they are not exempt from the health risks associated with polluted water Prolonged consumption or exposure to water polluted with chemical substances can result in serious health conditions such as damage to vital organs, hormonal imbalance, cancer, and nervous system disorders, particularly when heavy metals like lead, mercury, and arsenic are present. Vulnerable groups, including children, older adults, and individuals with weakened immune systems, are at higher risk.

From a socioeconomic perspective, water pollution imposes substantial financial costs on government authorities and local communities. These costs arise from the need for water treatment, pollution control measures, healthcare services, and environmental remediation. According to Jimoh et al. (2007), governments are increasingly challenged by the high expenses involved in cleaning polluted water bodies, especially those contaminated with sediments, organic waste, and parasitic organisms. These financial burdens can divert funds away from other critical development sectors such as education, infrastructure, and poverty alleviation.

Agriculture depends heavily on water for irrigation, livestock, and aquaculture. When water is polluted, it can harm soil quality, crop health, and farm productivity.

Method of Treatment of Polluted/Contaminated Water

The need for adequate water treatment is critical, as insufficient treatment lowers water quality and poses serious public health risks. The choice of treatment method depends on factors such as the source of water, its intended use, and the size of the population it serves (de Kok et al., 2001). For small-scale use, such as within households, water can be treated through filtration or boiling. Boiling is effective in destroying most disease-causing organisms, particularly non-spore-forming pathogens like coliforms; however, it is unsuitable for water containing chemical pollutants such as lead or nitrates, as boiling may increase their concentration and toxicity.

In centralized water distribution systems, treatment commonly involves four main processes. Flocculation removes suspended particles by adding aluminum or iron salts to form larger, sticky masses. This is followed by sedimentation, where the formed particles settle naturally. Filtration further eliminates fine particles, chemicals, and organic matter, while disinfection uses agents such as chlorine, chlorine dioxide, or chloramines to kill remaining microorganisms (Environmental Protection Agency, 2010).

Control of Water Pollution
Although water pollution cannot be completely eliminated, it can be minimized through effective control measures. These include educating the public on sources, prevention, and treatment of water contamination; establishing environmental monitoring programs; and enforcing environmental laws to curb deliberate pollution of water bodies caused by human activities.

Further control measures include proper waste management, treatment of industrial effluents and sewage before discharge, promotion of environmentally friendly agricultural practices, and protection of water catchment areas. When these strategies are combined and properly enforced, they help to safeguard water resources and protect public health and the environment.

Table 1.1 comparative quality of ground water & Surface

Quality parameter	Ground water	Surface water
1. Coliform bacteria	Low	Moderate high
2. Total bacteria count	Low	High
3. Colour	Low	High/variable
4. Taste	Pleasant	Variable
5. Turbidity	Low	Moderate/ high
6. Temperature	Low	Variable / high
7. Dissolved solids	High	Low/moderate
8. Radio actives	Low	Variable
9. Dissolved oxygen	Low	Variable

Bacterial presence in groundwater is primarily linked to fecal-derived organisms, including Escherichia coli and Streptococcus faecalis. To protect public health, the World Health Organization (WHO) has set forth comprehensive microbiological guidelines for drinking water quality. These guidelines aim to remove all microorganisms originating from human and animal waste, as the majority of waterborne pathogens are transmitted through fecal contamination.

The WHO microbiological guidelines include the following criteria:
No water sample should contain E. coli in 100 ml of the sample.
Over the course of a year, at least 95% of examined samples should show no detectable organisms in any 100 ml volume.
The total coliform count should be fewer than 10 organisms per 100 ml of water
Coliform bacteria should not be detected in two consecutive 100 ml samples.
For water sources serving individuals or small populations—such as wells, springs, and lakes—the permissible level of coliform bacteria is fewer than 10 organisms per 100 ml. Persistent exceedance of this threshold, especially when E. coli is detected repeatedly, signals significant contamination, and such water supplies should be considered unsafe for consumption.

Materials and Method

Study Area
This study was carried out in student hostels at Sabongida a suburb of Gusau Zamfara State. This community is situated along Sokoto-Zaria highway in Gusau Zamfara State, located at the north western region of Nigeria. Zamfara covers a total land area of 3,367km2 with population of 383,162 according to the 2006 census. The city is situated at a latitude 12.820 North, and longitude of 6.66520 East and 450 meters' elevation above the sea level.

Sample Collection

A total of ten (10) water samples were collected from each borehole and well located within the student hostels at Sabon Gida. The samples were collected in sterile bottles and properly labeled. Prior to sampling, the tap nozzles were disinfected using cotton wool soaked in 70% acetone for approximately 10 seconds. The taps were then allowed to run for 2–3 minutes before the water was collected into the sterile bottles. Immediately after collection, the bottles were securely capped and labeled with the date and sample identification number. The samples were promptly conveyed to the laboratory and maintained at 4 °C for subsequent analysis.

Media Preparation

Culture media including Nutrient agar, Eosin Methylene Blue agar, MacConkey broth, and Simmons citrate agar were prepared in accordance with the manufacturers' guidelines. Sterilization of the prepared media was carried out using an autoclave at 121 °C for 15 minutes.

Isolation and Determination of Total Bacterial Count

The total bacterial count of the water samples was determined following the method described by Onilude et al., (2013). From the final dilution of each sample, 0.1 mL was aseptically inoculated onto sterile nutrient agar plates using the spread plate technique with a sterile bent glass rod. The inoculated plates were incubated at 37 °C for 24 hours. After incubation, well-defined colonies were enumerated using a bacterial colony counter (Cheesebrough, 2006). Results were expressed as colony-forming units per milliliter (CFU/mL). Representative colonies were sub-cultured to obtain pure isolates, which were subsequently preserved on agar slants for further analyses.

Presumptive Test

Presumptive Coliform Test

The enumeration of total and faecal coliforms in water samples was carried out using the Most Probable Number (MPN) technique as described by the American Public Health Association (2005). Coliform estimation was performed using the five-tube MPN method. MacConkey broth served as the medium for the presumptive test. The first set of five test tubes contained 10 mL of double-strength broth, while the second and third sets contained 10 mL of single-strength broth. Each tube was fitted with a Durham tube prior to sterilization. Using sterile pipettes, volumes of 10 mL, 1 mL, and 0.1 mL of the water samples were inoculated into the respective sets of tubes. The inoculated tubes were incubated at 37 °C for a period of 24–48 hours for the determination of total and faecal coliforms. Following incubation, the tubes were examined for acid and gas production. Acid production was confirmed by a change in the broth color from reddish-purple to yellow, while gas production was detected by the presence of trapped gas in the Durham tubes. Tubes that showed no evidence of acid or gas production after 48 hours were presumed to be free of coliform organisms and recorded as zero (APHA,2005).

Confirmatory Test

The confirmatory test was performed by aseptically transferring a loopful of broth from each presumptive positive tube onto Eosin Methylene Blue (EMB) agar plates using a sterile wire loop. The inoculated plates were incubated at 37 °C for 24 hours to obtain distinct and pure colonies (Do et al.,2022).

Identification of Isolates (Completed Test)

The isolates obtained were further characterized and identified through Gram staining and a series of biochemical tests, including indole production, methyl red, Voges–Proskauer, and citrate utilization tests collectively referred to as the IMViC tests.

Gram Staining

A representative colony from each isolate was emulsified in a drop of normal saline on a clean, grease-free glass slide using a wire loop to form a thin smear. The smear was heat-fixed by gently passing the slide over a flame and then placed on a staining rack. Crystal violet was applied to the smear for 60 seconds and rinsed off with distilled water. Lugol's iodine was then added for another 60 seconds, followed by rinsing with distilled water. Decolorization was carried out using acetone for 30 seconds, after which the smear was counterstained with safranin for 60 seconds and rinsed again with distilled water. The slide was gently blotted dry with cotton wool and allowed to air-dry on a draining rack. Microscopic examination was conducted using a light microscope under oil immersion at ×100 magnification (Cheesebrough, 2006).

BIOCHEMICAL TESTS

Coagulase Test

A small quantity of plasma was dispensed onto a clean glass slide and mixed thoroughly with the test organism using a sterile wire loop. The slide was gently rocked for approximately 10 seconds. The appearance of visible clumps within this time indicates a positive reaction, whereas the absence of clumping signifies a negative result (Cheesbrough, 2006).

Urease Test

Using a sterile wire loop, bacterial isolates were collected and streaked onto urease agar slants. Care was taken to inoculate only the slanted surface and not the butt of the medium. The inoculated tubes were then incubated at 37 °C for 48 hours. A positive reaction was observed by a color change of the slant from magenta to bright pink, while a negative result showed no color change, with the slant remaining yellow (Davis & Pezzlo ,2016).

Voges–Proskauer Test

The test organism was aseptically transferred into a test tube containing broth using a sterile wire loop and incubated at 37 °C for 48 hours. After incubation, three drops of Barritt's reagent A (5% alpha-naphthol) and one drop of Barritt's reagent B (40% potassium hydroxide) were added to the broth. The tube was shaken vigorously and allowed to stand for a few minutes. The development of a red or pink color at the surface of the broth indicated a positive result, while the absence of color change denoted a negative reaction (Smith & Selby, 2021).

Citrate Utilization Test

The test organism was aseptically transferred into the citrate agar medium using a straight sterile wire loop and incubated at 37 °C for 48 hours. A positive (+) reaction was indicated by a change in the medium color from green to blue, whereas the absence of any color change, with the agar remaining green, was recorded as a negative (–) result (Cheesebrough, 2006).

Methyl Red Test

The isolate was collected using a sterile wire loop and inoculated into test tubes containing the appropriate broth, followed by incubation at 37 °C for 48 hours. After incubation, one to two drops of methyl red indicator were added to the broth and mixed thoroughly. The appearance of a red coloration indicated a positive (+) result, while no change in color signified a negative (–) reaction for the Methyl Red (MR) test (Smith & Selby, 2021).

Indole Test

The test organism was introduced into a test tube containing 5 mL of sterile peptone water supplemented with tryptophan. The inoculated tubes were incubated at 37 °C for 48 hours, after which 0.5 mL of Kovac's reagent was added and gently mixed. The formation of a reddish layer at the surface within 5 minutes indicated a positive (+) reaction, whereas the absence of a red coloration was recorded as a negative (–) result (Cheesebrough, 2006).

Catalase Test

Using a sterile wire loop, four to five drops of 3% hydrogen peroxide were placed on a clean glass slide. A small portion of the bacterial isolate was then mixed with the reagent on the slide. Immediate observation was made for the release of gas bubbles. The presence of bubbles signified a positive reaction, while the absence of bubbling indicated a negative result (Smith & Selby, 2021).

VI. RESULTS

Bacterial Counts of Borehole and Well Water Samples in the Study Area

The findings indicate that all borehole and well water samples analyzed were heavily contaminated with bacterial colonies beyond the (WHO) acceptable limit of "less than 0 Bacteria Colony count/100 ml" for untreated water. Coliform organisms were enumerated using the MPN/100 ml method. Overall, the bacterial loads recorded in the water samples exceeded the WHO recommended standards for drinking water quality, confirming that the water sources were microbiologically unsafe.

Table 1.2 presents the total bacterial counts (CFU/ml) of the isolates obtained from the water samples.

Water sourced from Hostel A recorded the highest bacterial load with 14.7×10^4 cfu/ml, followed by Hostel E with 9.7×10^4 cfu/ml, Hostel D with 8.5×10^4 cfu/ml, and Hostel C with 7.4×10^4 cfu/ml. Hostel B had the lowest bacterial load of 3.5×10^4 cfu/ml. These results show that none of the samples complied with the international standard for potable water safety, which requires "zero coliform per 100 ml of water sample" (WHO). Based on the commonly used WHO risk classification, which categorizes water quality according to the number of organisms per 100 ml sample, samples B, C, D, and E were classified as medium risk, with counts ranging from 10–100/100 ml. In contrast, sample A was categorized as very high risk, having bacterial counts of >100 bacterial colonies (WHO, 2011).

Table 1.3 shows the presumptive coliform counts (MPN/100 ml) of ten (10) water samples collected from student hostels, using five tubes per dilution (five tubes each of 10 ml, 1 ml, and 0.1 ml). Sample A recorded the highest coliform count of 900 MPN/100 ml, followed by sample E with 500 MPN/100 ml, sample C with >300 MPN/100 ml, and sample D with 300 MPN/100 ml. Sample B had the lowest coliform count of 170 MPN/100 ml, as indicated in Table 1.3.

Table 1.4 presents the Gram staining and biochemical test results of bacteria isolated from borehole and well water samples. All isolates were Gram-negative organisms. Some isolates tested positive for Indole, Catalase, Methyl Red, Lactose fermentation, and Hydrogen Sulphide production, and negative for Voges–Proskauer, Citrate, Urease, and Sucrose tests, suggesting they were Escherichia coli. Other isolates showed negative reactions to Indole, Methyl Red, and Catalase tests, indicating the presence of Enterobacter spp. and Klebsiella spp.

Table 1.5 illustrates the frequency of occurrence of bacterial isolates from the ten (10) water samples analyzed. Escherichia coli was the most frequently isolated organism, accounting for 50% of the isolates, followed by Klebsiella pneumoniae with 30%, and Enterobacter spp. with 20%.

Table 1.2: Total bacterial count (CFU/ml) of ten (10) Borehole and Well water samples

S/N	Sample	Total bacterial count per (cfu/ml)	WHO
1	WA	$14.7 \text{ X } 10^4$	0
	BA	$4.5\text{X } 10^4$	0
2	WB	$3.5 \text{ X } 10^4$	0
	BB	$1.6 \text{ X } 10^4$	0
3	WC	$7.4 \text{ X } 10^4$	0
	BC	$1.8 \text{ X } 10^4$	0
4	WD	$8.5 \text{ X } 10^4$	0
	BD	$1.6 \text{ X } 10^4$	0
5	WE	$9.7 \text{ X } 10^4$	0
	BE	$2.5 \text{ X } 10^4$	0

Key:

WA = hostel A well water	BC = hostel C borehole water
BA = hostel A borehole water	WD = hostel D well water
WB = hostel B well water	BD = hostel D borehole water
BB = hostel B borehole water	WE= hostel E well water
WC = hostel C well water	BE = hostel E borehole water
WHO = World Health Organization	CFU = Colony forming Unit

Table 1.3: Presumptive coliform count (MPN/100ml) of ten (10) water sample at student hostel in Sabon Gida

S/N	Water Sample	No. of tubes with positive result			Coliform count (MPN/100ml)	WHO
		10ml	1ml	0.1ml		
1.	WA	5	5	3	900	0
	BA	5	4	4	350	0
2.	WB	5	3	3	170	0
	BB	5	3	2	140	0
3.	WC	5	5	5	>300	0
	BC	5	4	2	220	0
4.	WD	5	5	1	300	0
	BD	5	4	2	220	0
5.	WE	5	5	2	500	0
	BE	5	1	2	280	0

Key:

WA = hostel A well water
BA = hostel A borehole water
WB = hostel B well water
BB = hostel B borehole water
WC = hostel C well water
WHO = World Health Organization
BC = hostel C borehole water
WD = hostel D well water
BD = hostel D borehole water
WE= hostel E well water
BE = hostel E borehole water
MPN = Most Probable Number

Table 1.4: Microscopic and Biochemical characteristics of the bacteria isolated from ten (10) water samples

Sample	Gram Reaction	Indole	MR	VP	Citrate	Suspected organisms
WA	GNR	+	+	-	-	Escherichia coli
BA	GNR	+	+	-	-	Escherichia coli
WB	GNR	-	-	+	+	Klebsiella Pnumoniae
BB	GNR	+	+	-	-	Escherichia coli
WC	GNR	+	+	-	-	Escherichia coli
BC	GNR	-	-	+	+	Enterobacter
WD	GNR	+	+	-	-	Escherichia coli
BD	GNR	-	-	+	+	Klebsiella pneumonia
WE	GNR	-	-	+	+	Klebsiella pneumonia
BE	GNR	-	-	+	+	Enterobacter

Key: (GR- gram reaction, IN-indole MR-methyl red, CIT-citrate, VP-voges-proskauer.
GNR = Gram Negative Rod

Table 1.5**:** Frequency of occurrence on bacterial isolates from ten (10) water sample

S/N	Organisms	Frequency	Percentage
1	Escherichia coli	5	50%
2	Klebsiella spp	3	30%
3	Enterobacter spp	2	20%
Total		10	100%

VII. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

DISCUSSION

Potable water is required to meet internationally accepted quality benchmarks set by the World Health Organization before it can be deemed safe for human consumption. The WHO emphasizes that "parametric limits known to be appropriate for water quality standards have been established" (WHO, 2000), providing measurable indicators for assessing the safety of drinking water. A key microbiological requirement is that "no sample should contain E. coli," as its presence is a direct indicator of faecal contamination and a high risk of waterborne diseases such as cholera, typhoid fever, and diarrheal infections. In situations where E. coli is not detected, total coliform counts must remain below "10 coliforms per 100 ml" to be considered acceptable. Based on WHO classification, water quality is rated as "0/100 ml (excellent), 1–3/100 ml (satisfactory), 4–9/100 ml (suspicious), and 10 and above (unsatisfactory)" (WHO, 2008).

Findings from the present investigation revealed that E. coli was present in five of the ten water samples examined, clearly demonstrating faecal pollution of the borehole and well water sources. Additionally, all water samples recorded coliform counts ranging between 170 and 900 per 100 ml, placing them within the suspicious to unsatisfactory categories (Table 1.5). Such elevated microbial loads suggest inadequate protection of the water sources, possibly due to poor sanitation, seepage from septic systems, surface runoff, or improper borehole construction. These conditions significantly increase the public health risk associated with consuming untreated groundwater.

When compared with earlier studies, the results contrast with those of Aina et al. (2012), who reported the presence of E. coli in some borehole water samples in Zamfara State but observed relatively lower coliform counts. The comparatively higher coliform levels documented in the present study may indicate a progressive decline in groundwater quality over time, increased anthropogenic activities, or differences in sampling locations and environmental conditions. This highlights the urgent need for regular water quality monitoring, improved sanitation practices, and effective water treatment measures to ensure the safety of drinking water in affected communities.

Pollution of well and borehole water is often associated with inadequate construction methods, improper siting of water facilities, the presence of nearby refuse disposal areas, and intensive human activities around water sources. High coliform counts observed in groundwater may be attributed to the close location of boreholes and wells to latrines, septic tanks, soak-away pits, and other sources of waste, as well as poor hygiene and sanitation practices within the surrounding environment. These conditions promote the infiltration of pathogenic microorganisms into groundwater, thereby increasing the likelihood of microbial contamination.

Consequently, water drawn from such wells and boreholes cannot be considered safe for drinking without undergoing suitable treatment processes such as boiling, chlorination, or filtration. The bacteriological analysis summarized in Table 1.3 indicated significant coliform contamination in water samples collected from the study area. All borehole and well samples examined exhibited bacterial colony counts that exceeded the WHO (World Health Organization) recommended limit of "less than 0 Bacteria Colony count/100 ml for untreated water." Coliform bacteria were quantified using the Most Probable Number (MPN/100 ml) technique, and the overall microbial loads were found to be above the WHO permissible standards for potable water.

These results clearly demonstrate the widespread bacterial pollution of borehole and well water sources serving the five hostels in Sabongida, Federal University Gusau, Zamfara State. The detection of both total and faecal coliforms indicates recent faecal contamination, which poses serious public health risks, including the transmission of waterborne diseases. The findings further emphasize the need for improved sanitary infrastructure, proper siting and construction of groundwater sources, routine water quality monitoring, and the implementation of effective water treatment measures to safeguard public health.

Conversely, the findings partially align with Agbabiaka et al (2009), who did not isolate E. coli from water samples analyzed in Ilorin. All tubes that tested positive during the presumptive stage were also positive in the confirmatory test (Table 4.2). The completed test revealed green metallic sheen colonies on EMB agar plates, with some appearing pinkish, further confirming the presence of coliform bacteria in all samples (Table 1.4). Based on Gram staining and biochemical tests, the organisms isolated were suspected to be Escherichia coli, Klebsiella pneumoniae, and Enterobacter spp. (Table 1.5). This outcome is consistent with findings reported by Aina et al., (2012) and Agbabiaka et al., (2009), who also identified Klebsiella pneumoniae and Enterobacter spp. in water samples they examined.

The total bacterial count (TBC) of the analyzed water samples ranged from 1.6×10^4 cfu/ml to 14.7×10^4 cfu/ml (Table 1.2). The Nigerian Standard for Drinking Water Quality specifies an allowable maximum limit of "10 cfu/ml" for potable water. None of the samples met this standard. This observation is partly consistent with Erah et al, 2002), who reported unacceptable groundwater quality in Benin. Similarly, Eniola et al., (2007) recorded bacterial counts ranging from 5.0×10^2 to 7.0×10^2 cfu/ml in stored borehole water samples, further confirming that such water sources were microbiologically unsafe.

CONCLUSION

From the result obtained in this study, three different organisms were identified Escherichia coli, Klebsiella pneumoniae and Enterobacter spp. The detection of indicator organisms, including total bacteria, coliforms, and Escherichia coli, revealed varying levels of microbial contamination, indicating possible faecal pollution and poor sanitary conditions of the water sources. These findings highlight the potential health risks associated with the consumption of untreated water. Therefore, appropriate treatment methods such as boiling, steaming, and filtration are essential to eliminate pathogenic organisms and improve water safety for domestic use. Routine microbiological analysis of drinking water remains crucial to ensuring that water does not serve as a vehicle for disease transmission and is safe for human consumption.

RECOMMENDATIONS

It is strongly recommended that both the Federal and State Governments of Nigeria implement regular public health education programs through environmental health officers and sanitary control inspectors across the country. These programs should focus on raising awareness about proper water quality management, the health risks associated with poor waste disposal practices, and the environmental and public health consequences of water pollution.

To minimize the high rate of contamination observed in well water, wells should be constructed to adequate depths, sited at safe distances from latrines, septic tanks, and refuse dumps, and properly covered to prevent the entry of surface runoff and contaminants. Similarly, borehole facilities must be properly designed and constructed using standard engineering practices to reduce the risk of microbial and chemical contamination. Water storage containers should be cleaned and disinfected regularly, and household water should undergo appropriate treatment methods such as boiling, filtration, or chlorination before use.

Additional recommendations include the routine monitoring and microbiological testing of drinking water sources by relevant regulatory agencies to ensure compliance with national and World Health Organization (WHO) standards. Community-based water management committees should be established to oversee water source maintenance and sanitation practices at the local level. Furthermore, improved waste management systems, including proper sewage disposal and controlled agricultural runoff, should be enforced to protect groundwater sources.

It is also recommended that further research be conducted to determine the antibiotic susceptibility patterns of isolated microorganisms, as this will help assess potential public health risks related to the emergence and spread of antibiotic-resistant bacteria.

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