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Assessment of Groundwater Pollution In Botlokwa Village In Limpopo Province Of South Africa

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***Abstract* -** Groundwater constituted a critical source of potable water for rural communities in South Africa, including Botlokwa Village under the jurisdiction of Polokwane Municipality. The primary objective of this study was to assess the extent of groundwater contamination in Botlokwa, with specific emphasis on determining the physicochemical characteristics of borehole water and comparing them to the South African National Standards (SANS 241:2015). Additionally, the study aimed to identify potential public health risks associated with groundwater pollution. A total of 107 water samples were collected from randomly selected boreholes situated across residential, public facilities, and commercial zones within the study area. These samples were analysed by a certified independent laboratory to assess concentrations of heavy metals, nitrates, and microbial contaminants. Results indicated elevated levels of aluminium and iron, as well as nitrate concentrations that exceeded the permissible limits stipulated by both SANS 241 and World Health Organization (WHO) guidelines. Although Escherichia coli was not detected in any sample, the elevated chemical parameters posed considerable health risks particularly to infants, the elderly, and immunocompromised individuals. Comparative findings from similar studies conducted in nearby communities such as Mankweng and Ga-Matlala demonstrated consistent patterns of non-compliance, reinforcing the urgent need for proactive water quality monitoring, community-level intervention, and investment in localised treatment technologies.
***Keywords*:** Groundwater, Pollution, Limpopo province, South Africa

1. Introduction

Groundwater has historically served as a fundamental source of drinking water in many rural communities across South Africa [1]. In regions such as Botlokwa Village, located within the Molemole Local Municipality in the Limpopo Province, groundwater remained the primary and often the only source of potable water for domestic, institutional, and agricultural use [2]. Its reliability, affordability, and widespread availability made it a preferred alternative to surface water, particularly in areas lacking centralized municipal water infrastructure [3]. Despite its advantages, groundwater has increasingly been subjected to contamination from various anthropogenic activities [5]. These include improper waste disposal, unregulated agricultural runoff, industrial discharges, and effluent seepage from septic systems [5]. The unconfined nature of many aquifers in rural areas renders them highly vulnerable to pollutant infiltration, especially during rainfall or seasonal flooding events [6]. Inadequate land-use regulation and the absence of coordinated water quality monitoring have further exacerbated this challenge [7].

Over the past decade, numerous studies and government reports have raised concerns regarding deteriorating groundwater quality in Limpopo Province [8]. Elevated concentrations of nitrates, heavy metals (e.g., aluminium, iron, lead), and microbial contaminants have been reported in several communities [9]. This trend, if left unaddressed, poses significant risks to public health, economic productivity, and environmental sustainability [10]. The growing reliance on untreated borehole water in Botlokwa, coupled with increasing land-use pressures, has placed the local aquifer systems under considerable strain [11]. Preliminary observations by environmental officials and local health practitioners have indicated a potential link between contaminated water sources and recurring health complaints, particularly among children and the elderly [12]. However, scientific data to substantiate these claims remained limited or outdated [13]. The central problem addressed in this research is the deterioration of groundwater quality in Botlokwa due to diffuse and point-source pollution

[14]. The lack of timely data on contaminant levels further complicates mitigation efforts and compromises public health [15]. In the absence of systematic water quality testing and municipal oversight, households have continued to consume potentially unsafe water, thereby increasing their vulnerability to long-term health consequences [16].

The aim of this study was to assess the extent of groundwater contamination in Botlokwa Village by evaluating borehole water quality against established drinking water standards and identifying probable sources of pollution. The primary objectives of this study were:

1. To assess the physical, chemical and microbial quality of groundwater (borehole) water in various zones of Botlokwa.
2. To compare observed contaminant concentrations with permissible limits set by SANS 241:2015 and WHO guidelines.
3. To identify spatial patterns of contamination and assess potential sources such as waste disposal sites, agricultural activity, and infrastructure proximity.
4. To propose evidence-based recommendations for community awareness, water treatment, and policy intervention.

This study contributes to filling a significant knowledge gap regarding the status of groundwater quality in Botlokwa. By generating primary data on chemical and microbiological parameters, the research provided a scientific basis for local and provincial authorities to initiate targeted interventions. Furthermore, the findings informed both environmental policy and community-level water management strategies. Ultimately, the study sought to support long-term access to safe and sustainable groundwater resources for all residents of Botlokwa.

2. Literature Review

This section of the paper reviewed relevant scholarly and policy literature related to groundwater pollution, with a particular focus on the sources, mechanisms, and public health implications of groundwater contamination in rural settings. Special attention was given to studies conducted in sub-Saharan Africa and South Africa, including Limpopo Province, to establish the context for the present investigation.

Groundwater constituted one of the most significant sources of fresh water globally, supplying approximately 50% of drinking water and 40% of irrigation water in developing countries [17]. In South Africa, groundwater played an especially vital role in rural and peri-urban areas where surface water infrastructure was limited or non-existent. According to the Department of Water and Sanitation [18], more than 60% of communities in Limpopo Province depended primarily on groundwater for domestic use. The appeal of groundwater as a reliable and naturally filtered resource has, however, led to complacency regarding its vulnerability to contamination. Despite being shielded by geological formations, shallow and unconfined aquifers remained highly susceptible to pollutant infiltration, especially in regions with inadequate sanitation and poor land-use planning [18].

Several studies identified both point and non-point sources of groundwater pollution. Point sources included leaking septic tanks, municipal landfills, and industrial discharge points, while non-point sources comprised widespread agricultural runoff and diffuse domestic waste disposal [19]. Nitrate contamination was frequently attributed to excessive fertilizer application and animal waste, particularly in agricultural regions. Heavy metals such as lead, aluminium, and iron were often introduced into aquifers through leaching from industrial zones, corroding pipes, or natural mineral dissolution. Research conducted by [20] in Gauteng Province revealed that unlined pit latrines posed a significant threat to underlying groundwater quality. Similarly, a study in the Ga-Matlala region by [21] demonstrated elevated nitrate and chloride levels in groundwater samples near informal waste dumping sites.

The consumption of polluted groundwater has been associated with a range of adverse health effects. High nitrate levels, particularly above 10 mg/L, have been linked to methemoglobinemia or “blue baby syndrome” in infants [22].

Long-term exposure to elevated concentrations of aluminium and lead has been correlated with neurological and developmental disorders. Chronic ingestion of water contaminated by heavy metals such as iron and manganese may also also contribute to liver and kidney dysfunctions. According to the South African Bureau of Standards (SANS 241:2015) [23], acceptable water quality parameters are classified into Class 1 (ideal for lifetime consumption) and Class 2 (acceptable (acceptable for short-term use). Exceeding these limits may not only impair health but also reduce the effectiveness of municipal water treatment systems and damage household plumbing infrastructure.

Several studies have reported deteriorating groundwater quality across Limpopo. [24] observed significant microbial and chemical contamination in boreholes in Mankweng Township, primarily due to the proximity of sanitation infrastructure to water sources. In another study, [18] documented high levels of total dissolved solids (TDS) and aluminium in groundwater sampled near old mining areas. Despite these findings, comprehensive data on groundwater pollution in Botlokwa Village remained limited, thus highlighting the importance of the present study. Existing government reports lacked granularity and failed to include seasonal or site-specific contamination profiles.

The paper identified research Gaps with Justification: while national and provincial studies have addressed groundwater contamination in broad terms, there remained a significant gap in localised, community-based assessments. Furthermore, few studies had simultaneously evaluated chemical and microbial contamination using SANS 241 and WHO standards. There was also limited research that explored correlations between borehole contamination levels and land-use practices at the village scale. This study sought to address these gaps by providing an empirical, spatially distributed assessment of groundwater quality in Botlokwa. By identifying pollutants, evaluating compliance, and interpreting potential sources, the research contributed to both academic knowledge and policy development.

3. Methodology

This section of the paper outlines the research design, sampling procedures, analytical methods, and data interpretation techniques used in the study. The methodology included site selection, sample collection, laboratory analysis, and data interpretation using South African National Standards (SANS 241:2015) and World Health Organisation (WHO) guidelines. The study adopted a quantitative, cross-sectional research design to assess groundwater quality in the study area. This approach enabled the collection and analysis of water samples from multiple boreholes within a defined period, allowing for comparative evaluation across different zones of Botlokwa. The research was observational in nature and relied on direct field measurements and laboratory analyses to quantify contamination levels.

In terms of the study area description, Botlokwa Village is situated within the Molemole Local Municipality under the Capricorn District in Limpopo Province, South Africa. The region is characterized by both formal and informal settlements, extensive agricultural activity, and limited municipal water infrastructure (see fig.1). Most residents depend on privately or communally owned boreholes for daily water needs. The area's geology primarily consists of weathered granite and sandstone, both of which are known to influence groundwater chemistry.

Fig. 1: Area of Study, Botlokwa. (Source: Google Maps 2024 https://www.google.com/earth)

In terms of sample size and selection, a total of 107 boreholes were purposively sampled from residential, commercial, and public-use zones within the village. The selection criteria included geographic distribution and proximity to potential pollution sources. Permission was secured from landowners and community representatives before sampling commenced.

Effective sample collection procedures were used in the study. Water samples were collected during the dry season to minimize surface runoff influence. The procedures adhered to accepted groundwater sampling protocols:

1. Each borehole was purged for five minutes to ensure fresh water was obtained.
2. Samples for physical and chemical analysis were collected in 1-litre polyethylene bottles pre-rinsed with sample water.
3. Microbiological samples were collected in sterile 500 mL containers and stored in a cold chain at 4°C during transport.
4. On-site measurements for temperature, pH, and electrical conductivity (EC) were conducted using a calibrated handheld multi-parameter probe.

Regarding laboratory analysis, all water samples were submitted and analysed at a SANAS-accredited laboratory. The results were compared against SANS 241 and WHO permissible limits. Data analysis and interpretation was carried put; the data was captured in Microsoft Excel and statistically analysed using IBM SPSS Statistics (version 25). Key steps included:

- Descriptive statistics: Calculation of mean, standard deviation, and maximum/minimum values for each parameter.
- Compliance assessment: Comparison of test results with SANS 241:2015 Class 1& 2 and WHO guideline values.
- Zonal analysis: Grouping of boreholes based on land use and spatial location to identify contamination patterns.
- Inferential analysis: Correlation assessments were performed to explore potential relationships between chemical parameters and contamination sources.

Certain ethical considerations we taken, such as while no human participants were involved, ethical clearance was obtained, and consent was secured from local authorities and residents where necessary. There were limitations of the Study, Study, such as sampling was limited to a single season and may not reflect year-round variation in groundwater quality. The The study focused primarily on inorganic chemical and microbial parameters and did not include organic pollutants such as as pesticides or hydrocarbons. Some boreholes could not be accessed due to mechanical failure or restricted permissions. In In summary a systematic approach used to collect, test, and analyse groundwater samples across Botlokwa Village. By a combination of analytical methods and benchmark standards, the study aimed to generate valid and actionable data that informed the findings.

4. Results and Discussion

This section presents the results of laboratory analyses conducted on groundwater samples collected from 107 boreholes in Botlokwa Village. The results are interpreted in relation to South African National Standards (SANS 241:2015) and World Health Organization (WHO) guidelines for safe drinking water. Parameters assessed include pH, total dissolved solids (TDS), total hardness, chloride, nitrates/nitrites, aluminium, and microbial contaminants. The discussion highlights the spatial distribution of contamination, likely pollution sources, and potential health risks.

4.1 Physicochemical Characteristics of Groundwater

4.1.1 pH

The pH values of the sampled boreholes ranged from 5.4 to 7.8, with an average of 6.4. Approximately 28% of the boreholes fell below the minimum pH limit (6.5) as per SANS 241:2015 Class 1, indicating mildly acidic water. While not immediately harmful to health, low pH values may enhance the solubility of heavy metals, thus facilitating their mobility in groundwater.

4.1.2 Total Dissolved Solids (TDS)

TDS concentrations ranged from 250 mg/L to 1,820 mg/L. Boreholes located in high-density residential and agricultural zones exhibited values exceeding the 1,000 mg/L limit, with a mean TDS of 1,180 mg/L across all samples. Elevated TDS levels are typically associated with poor taste, scale formation, and long-term appliance degradation.

4.1.3 Total Hardness

Measured total hardness values varied between 180 mg/L and 660 mg/L. Approximately 65% of boreholes exceeded the SANS 241 guideline of 200 mg/L, with some samples classified as "very hard" (>500 mg/L). Hard water, while not a direct health hazard, can lead to increased soap consumption, scale accumulation, and reduced efficiency of heating systems.

4.1.4 Chloride

Chloride concentrations ranged from 25 mg/L to 370 mg/L, with 20% of the samples surpassing the 250 mg/L SANS threshold. Elevated chloride levels were observed predominantly near informal dumping grounds, suggesting leachate infiltration from solid waste or greywater discharge.

4.1.5 Nitrate/Nitrite

Nitrate levels in the groundwater samples were notably high, ranging from 10.2 mg/L to 98.7 mg/L, with a mean value of 42.6 mg/L. Approximately 58% of boreholes exceeded the SANS Class 1 maximum of 11 mg/L. These results indicate widespread nitrate pollution, likely stemming from agricultural fertilizer application and latrine seepage.

4.1.6 Aluminium

Aluminium concentrations ranged from 0.08 mg/L to 0.96 mg/L. Over 70% of boreholes exceeded the SANS 241 limit of 0.3 mg/L. High aluminium levels may originate from soil leaching in acidic environments or industrial waste disposal.

Chronic ingestion of aluminium-contaminated water has been linked to neurological disorders, particularly in vulnerable populations.

4.1.7 Iron and Zinc

Iron levels were generally within acceptable limits, with occasional exceedances (>0.3 mg/L) in older boreholes agricultural zones. Zinc concentrations were well within WHO guidelines, with no sample surpassing the 5 mg/L threshold. These metals, while essential in trace amounts, may cause taste alterations and staining at high concentrations.

4.2 Microbiological Analysis

All borehole samples tested negative for Escherichia coli, indicating an absence of recent faecal contamination. This finding suggested that boreholes were structurally intact and likely protected from surface infiltration. Nevertheless, the presence of high nitrate and chloride concentrations pointed to other contamination vectors that warrant attention.

4.3 Zonal Patterns of Contamination

1. A comparative analysis across land-use zones revealed the following trends:
2. Residential Zones: Boreholes showed elevated levels of TDS, total hardness, and nitrates, likely due to on-site sanitation systems and greywater discharge.
3. Agricultural Areas: High nitrate and chloride levels were prevalent, attributed to the leaching of fertilisers and herbicides.
4. Public Institutions (clinics and schools): Several boreholes used by vulnerable populations exhibited aluminium and nitrate levels above safety thresholds, highlighting the need for urgent mitigation.

4.4 Correlation and Source Attribution

Statistical analysis indicated a positive correlation ($r = 0.74$) between TDS and EC values, supporting the hypothesis that elevated mineral content contributed to conductivity changes. Nitrate levels showed a moderate correlation with chloride concentrations ($r = 0.56$), suggesting a shared pollution pathway from surface activities. These patterns confirmed that groundwater pollution in Botlokwa was primarily anthropogenic, with agricultural runoff, waste seepage, and sanitation practices acting as the dominant contributors.

4.5 Health Implications

The elevated concentrations of nitrates and aluminium posed significant health risks, especially for infants and individuals with compromised immune systems. High nitrate ingestion is associated with methemoglobinemia, while prolonged exposure to aluminium has been linked to Alzheimer's disease and renal dysfunction. While microbial safety was confirmed, the chemical profile of many boreholes rendered them unsuitable for long-term consumption without treatment.

Table 1: Summary of Health and Environmental Impacts (Source: Researchers)

Issue	Health Impact	Infrastructure Impact
Very Hard Water	Can cause skin irritation, kidney stones, and affect detergent effectiveness.	This leads to scaling in pipes and appliances, reducing efficiency.
High TDS & Conductivity	There is a potential for mineral overload, affecting taste and causing digestive discomfort.	This accelerates corrosion of metal pipes and fittings.
High Nitrate Levels	It can cause methemoglobinemia (oxygen deficiency in infants).	No direct infrastructure impact.
Excess Chloride	It may cause dehydration and kidney strain in high doses.	This corrodes metal pipes and storage tanks.

The groundwater in Botlokwa demonstrated varying degrees of chemical contamination across multiple parameters. Most of the boreholes failed to meet SANS Class 1 guidelines, particularly in terms of nitrate, TDS, total hardness, and aluminium levels. Spatial analysis suggested that pollution sources were land-use specific and largely preventable through through improved waste management and agricultural practices.

4. Conclusion

The researchers assessed the quality of groundwater accessed from boreholes in Botlokwa Village, Limpopo Province, with a focus on evaluating compliance with SANS 241:2015 and WHO drinking water standards. A total of 107 samples were analysed for physicochemical and microbiological parameters, including pH, total dissolved solids (TDS), hardness, nitrates, chloride, aluminium, and *Escherichia coli*. The findings revealed widespread chemical contamination, with over half of the boreholes exceeding the permissible limits for nitrates, TDS, total hardness, and aluminium. In contrast, microbial contamination was not detected, suggesting adequate borehole construction and protection from direct surface runoff. However, the presence of high nitrate and aluminium levels, particularly in boreholes near agricultural zones and informal waste sites, underscored the influence of anthropogenic activities on groundwater quality. The analysis indicated that the main sources of pollution were unregulated fertilizer application, leachate from poorly managed waste, and seepage from on-site sanitation systems. Spatial patterns showed that boreholes serving clinics, schools, and densely populated areas were particularly vulnerable, placing at-risk populations in jeopardy of long-term health complications such as methemoglobinemia, neurological disorders, and renal impairment. The study concluded that while groundwater remains a critical resource for Botlokwa residents, its current chemical quality falls short of safe consumption standards in many areas. Immediate intervention is required to safeguard public health and ensure sustainable access to potable groundwater.

Its Recommended that:

1.Water Treatment and Supply Improvement be carried out
- Install point-of-use treatment systems, such as reverse osmosis or activated alumina filters, in boreholes that exhibit elevated levels of nitrates and aluminium.
- Prioritize centralized treatment and reticulation systems in high-risk zones, particularly near clinics, schools, and high-density settlements.

2.Regulatory and Land-Use Controls be put in place
- Enforce buffer zones between boreholes and agricultural plots or sanitation infrastructure to minimize leaching and infiltration risks.
- Implement land-use regulations that prevent informal dumping or the establishment of latrines near known aquifer recharge zones.

3.Monitoring and Early Warning Systems be installed
- Establish a community-based groundwater monitoring program to ensure regular water quality testing and trend analysis.
- Create a real-time data sharing platform through local municipal systems to track borehole compliance with SANS and WHO standards.

4.Community Education and Capacity Building be carried out
- Conduct awareness campaigns to educate residents on the risks of groundwater contamination and the importance of safe hygiene and waste disposal practices.
- Train local borehole users and committees on basic water quality testing techniques and low-cost treatment solutions.

5.Further Research be conducted
- Extend the study to include seasonal sampling (wet vs. dry season) to better understand contamination dynamics throughout the year.
- Investigate the presence of organic pollutants, including pesticides and hydrocarbons, which may also compromise groundwater safety.

The outcomes of this study offer a critical evidence base for policymakers, environmental health officers, and water resource planners. Targeted interventions, informed by scientific data, are essential to mitigate groundwater pollution protect community health in Botlokwa and similar rural settlements. Ensuring the long-term sustainability of this vital resource requires a collaborative approach involving government agencies, researchers, and the affected communities.

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