Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2022, 10, 159-185
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

# Sanitary Surveys and Hydrochemistry of Groundwater in Two Urban Towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria

**Abel Ojo Talabi*, Lekan Olatayo Afolagboye, Christopher Ayodele Ajayi, Olufunke Kolawole**

Department of Geology, Ekiti State University, Ado-Ekiti, Nigeria
Email: *abel.talabi@eksu.edu, lekan.afolagboye@eksu.edu.ng, christopher.ajayi@eksu.edu.ng, olufunkekolawole22@gmail.com

**How to cite this paper:** Talabi, A. O., Afolagboye, L. O., Ajayi, C. A., & Kolawole, O. (2022). Sanitary Surveys and Hydrochemistry of Groundwater in Two Urban Towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria. *Journal of Geoscience and Environment Protection, 10,* 159-185.
https://doi.org/10.4236/gep.2022.107011

**Received:** May 23, 2022
**Accepted:** July 19, 2022
**Published:** July 22, 2022



## Abstract

Groundwater contamination in urban cities is imminent in the phase of increased anthropogenic activities apart from the contribution of geogenic contaminants. This study examined the sanitary surveys and hydrochemistry of groundwater in Ado-Ekiti and Ijero-Ekiti to establish the contaminants' sources, decipher the effects of urbanization on population and explain any relationship between the surveys and the groundwater chemistry. Sanitary surveys of 30 randomly selected wells each from Ado-Ekiti and Ijero-Ekiti were executed by administering and processing appropriately designed questionnaires that addressed salient problems of hygiene and sanitation. The results of the surveys were grouped into very high risk, high risk, intermediate risk, and low risk classes. Subsequently, at each location, *in situ* parameters (temperature (˚C), pH and EC (μS/cm)) were measured using a portable Multi-parameter TestrTM 35 Series S/N: 1382654. At each well, water samples were collected into clean polyethylene bottles in triplicates for cation, anions and e-coli evaluations, respectively. Water samples for cations were acidified by adding two drops of concentrated nitric acid. All samples were kept in a refrigerator at a low temperature of about 4˚C before being taken to the Federal University of Technology, Akure, for analyses. Ion chromatography was employed for the anions analysis while the cations were determined using an Atomic Absorption Spectrophotometer Buck 210 model. Membrane filter technique was employed for the e-coli estimation. From the results of the hydrochemistry, the Nitrate Pollution Index (NPI) and Modified Nitrate Pollution Index (MNPI) were estimated and classified into; clean unpolluted, light pollution, moderate pollution, significant pollution, very significant pollution waters. Sanitary surveys in the two cities showed that in the very low risk, intermediate and high-risk categories, Ado-Ekiti had 33.33%, 56.67% and 10% representations, while Ijero-Ekiti had 50%, 23.33% and 26.67% representations, respectively. This observation showed that Ado-Ekiti with higher population and humans' activities compared to Ijero-Ekiti was less susceptible to pollution. Urbanization has no direct effects on sanitary surveys. The pH of wells' water in Ado-Ekiti ranged from 4.8 - 8.2, EC (μS/cm) from 101 - 1008, while at Ijero-Ekiti, the pH and EC (μS/cm) varied from 2.1 - 13.8 and 80 - 1008 respectively. Ado-Ekiti wells' water was more acidic than that of Ijero-Ekiti. Chemical concentrations (mg/L) of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^-$, $SO_4^{2-}$ and $Cl^-$ of the wells' water in both cities were within WHO-approved standards for drinking water. However, $NO_3^-$ with average concentrations of 142.17 (mg/L) and 252.71 (mg/L) at Ado-Ekiti and Ijero-Ekiti, respectively, exceeded the standard in many locations. Susceptibility to pollution classification employing TDS, NPI and MNPI showed that Ijero-Ekiti was more susceptible to pollution compared to Ado-Ekiti. This assertion was supported by statistical analysis employing correlation, cluster analysis, and principal component analysis. This study showed that urbanization had no direct effects on sanitary surveys and groundwater quality. Pollution of wells' water in the two cities was, mainly from anthropogenic activities. However, Ijero-Ekiti, with significant anthropogenic activities, had its wells' water more susceptible to pollution. Sanitary surveys are a complementary method to water quality monitoring.

## Keywords

Urbanization, Groundwater Quality, Geogenic Contaminants, Sanitary Surveys, Hydrochemistry, Nitrate Pollution Index

## 1. Introduction

Urbanization is considered to be the agglomeration of individuals in relatively sizable amount at a selected spot of the globe (Oyeleye, 2013). Population is one in all the foremost significant factors controlling urbanization and it varies amongst countries. An urban city in Japan has a minimum of 30,000 people, a minimum of 50,000 people in the US, in Greece a minimum of 10,000 people, in Australia a minimum of 1000 people and a minimum of 250 people in Denmark (Aluko, 2010). Based on the Nigerian census, an urban centre should have 20,000 people and above. Going by this standard, the 2 towns; Ado-Ekiti and Ijero-Ekiti (study areas) have a population of 308,621 and 147,300 respectively, (NPC, 2006) and are urban cities. Urbanization denotes a place both with a high density and a large number of people.

Urbanization plays an important role in the development and progress of Humans. It is also responsible for the inequalities and health issues in the society (Kuddus et al., 2020). Urban cities are the prime mover of technology, economic advancement but is also the driver of poverty, disparity, environmental problems and the spread of communicable diseases (McMichael, 2000). The poor people are more adversely affected during the migration of people from rural settlement to urban cities. The migration of humans along with their belongings leads to unavoidable interactions causing pollution, malnutrition, traffic congestions and transmission/spread of communicable diseases (Moore et al., 2003; Alirol et al., 2011).

There is no doubt that urbanization has effects on the problem of water supply and the local hydrologic cycle. More storm runoff and erosion ensue due to less vegetation. Amount of water recharging the groundwater is reduced while there is an increase in groundwater depletion due to over exploitation (Odeloui et al., 2016). Dhania and Rani (2014) on "impact of urbanization on groundwater pollution—an emerging problem" show that millions of people all over the world are deprived of fresh and clean drinking water. In addition, groundwater quality is worsening due to infiltration of the discharge of effluent from septic tanks; soak pits and pit latrines. Humans' health issues including cholera, dysentery, diarrhea, jaundice and other water related gastrointestinal diseases are the outcome of continuous consumption of contaminated groundwater.

Sources of groundwater pollution can be geogenic or anthropogenic. Rise in population may cause increased anthropogenic activities, which might aggravate groundwater supply problem and will impact the groundwater resources negatively. Over exploitation and increased human activities may lead to pollution of groundwater. Urbanization may have devastating consequences on sanitation, groundwater quantity and quality. Current water resources are stressed by urbanization and cause a rise in pollution.

Sanitation and hygiene are essential to healthiness, survival and development. In many countries, provision of adequate sanitation constitutes great challenges, leaving people in danger of contacting diseases associated with water, sanitation, and hygiene. Basic sanitation indicates access to facilities for the safe disposal of body waste (feces and urine), as well as having the power to keep up hygienic conditions, through services like pickup, industrial/hazardous waste management and wastewater treatment and disposal. Hygiene represents set of personal practices including washing hands, cutting hair/nails periodically, bathing, etc. Both hygiene and sanitation require safe water for their operations. Water, sanitation and hygiene services (WASH) are employed in combating one of the neglected tropical diseases, as for buruli ulcer, in Benin (West Africa) particularly in the district of Lalo (Johnson et al., 2015).

Poor quality water supply cuts across the globe. However, children in developing countries are worst hit by the diseases arising from poor quality water and hygiene (Prüss et al., 2002; WHO, 2000). Report has it that globally; about 1.1 billion people still lack access to safe water, while 2.4 billion do not have the right to improved sanitation (WHO, 2010).

Safe water constitutes major resources to fulfill the wants of basic hygiene that are necessary in curtailing water related diseases. Water is needed in all life activities, especially for domestic and agricultural activities. Safe water represents water that is affordable, available at required quantity as beverage, for food preparation and for private hygiene and washing (Bos et al., 2016). It also signifies water that doesn't pose any significant health risk. Though safe water is key to human existence, unfortunately, its availability is restricted (United Nations Committee on Economic, Social and Cultural Rights, 2002). About, 2.7% of the whole globe water is fresh. The supply and distribution of the planet freshwater worldwide is lopsided. The chunk of the water isn't available to be used because it is locked up in icecaps and glaciers. Even the fresh water in form of surface water and groundwater has associated problems that make them not to be readily available as safe water. Though access to safe water is most important to human existence and continuity of ecosystem (Samra & Fawzi, 2011), its availability and affordability worldwide amidst continual increase in world population and industrialization remains a mirage and deserves special attention.

Groundwater is a major source of fresh water for the world and is employed in carrying out some of the humans' activities apart from industrial applications. Approximately one third of the worldwide population depends on groundwater for drinking usage (International Association of Hydrogeologists, 2020). Water is crucial for sustenance of life as every human's interactions involve using water. Urban areas have high anthropogenic activities and consequently possibility of a high risk of groundwater pollution. Research by (Lü et al., 2022), revealed that urbanization has negative impacts on groundwater quality. The research showed that 96% of groundwater in the study area (Lanzhou city in China) did not meet the quality standard for drinking water in China.

Inadequate access to safe water and sanitation services, coupled with poor hygiene practices, kill and sicken thousands of children every day, and leads to impoverishment and diminished opportunities for thousands more (Allen et al., 2006; WHO, 2010). High population density, which results in overcrowding, inadequate planning and poor governance, exacerbates this problem. In view of the importance of water in our daily life and the unknown state of sanitation of the sources of water wells supply in the two urban cities (Ado-Ekiti and Ijero-Ekiti Southwestern Nigeria), it becomes necessary to conduct sanitary surveys and groundwater chemistry of randomly selected wells and their water samples, respectively. This will provide clues to the source of pollutants of the groundwater and the effects of urbanization on sanitary surveys and hydrochemistry. The study will also elucidate any possible relationship between sanitary survey and groundwater chemistry.

**Location and Geology of the study Areas**

The locations of study consist of Ado-Ekiti and Ijero-Ekiti in southwestern Nigeria. Ado-Ekiti lies within Latitudes 7˚35'N and 7˚44.3'N, Longitudes 5˚7'E and 5˚20'E while that of Ijero-Ekiti is within latitudes 7˚48'59"N and 7˚49'30"N and Longitudes 5˚02'50"E, 5˚5'30"E (**Figure 1**). Both areas of study have rugged terrains with two distinct seasons (rainy and dry seasons). The rainy season spans from April to October each year, while the dry season is from November to April. Little variation is possible in these settings because of climate change.

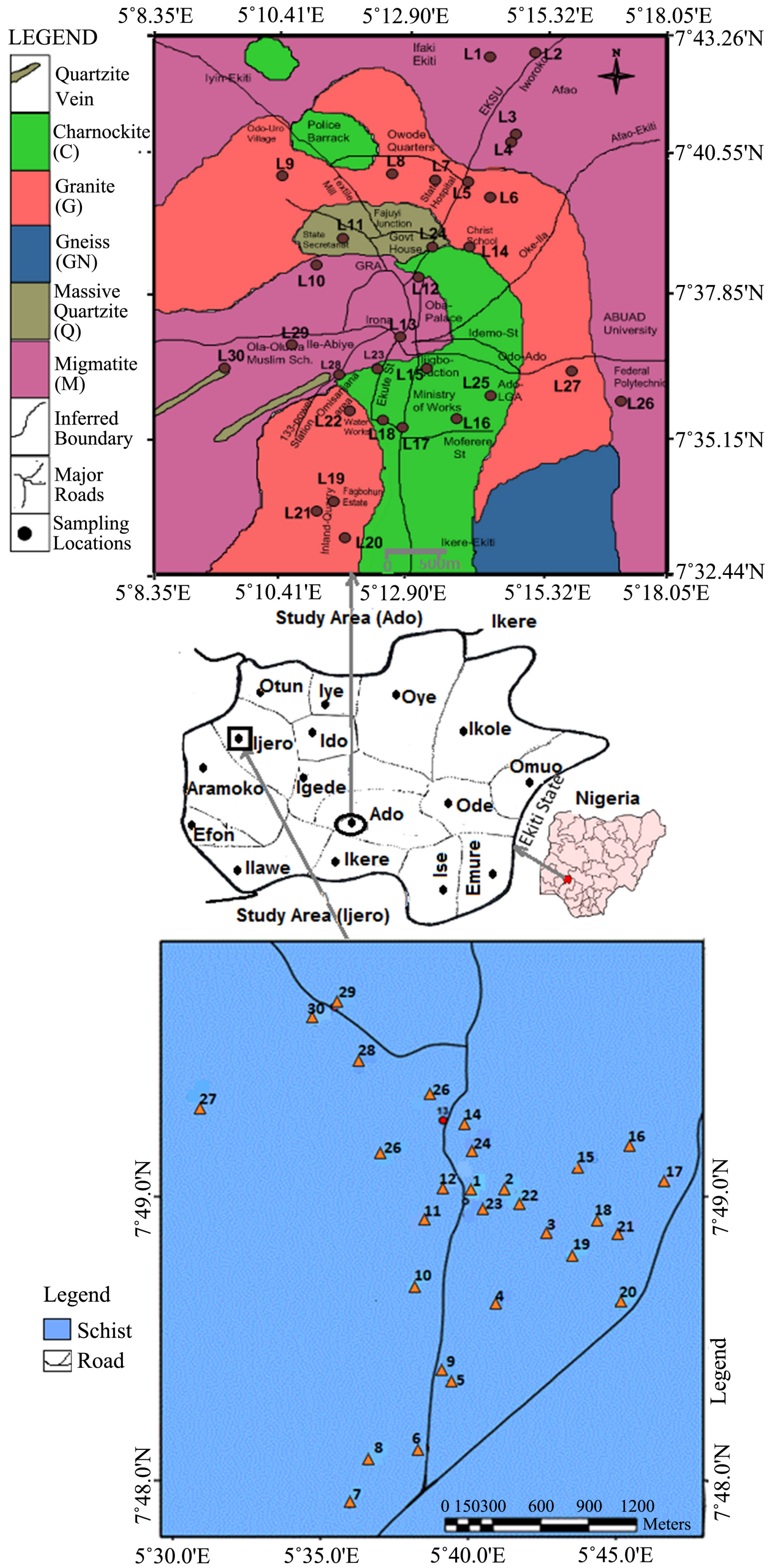


**Figure 1.** Locations of study indicating sampled wells.

There is no difference in terms of rainy and dry seasons in the two areas. The annual rainfall ranges between 1200 mm and 1400 mm. The mean monthly temperature is 27˚C (Adebayo & Arohunsoro, 2014).

The study areas belong to the basement complex area of southwestern Nigeria. However, both areas differ significantly in terms of lithological composition. The geology of Ado-Ekiti revealed presence of migmatites, quartzites, granite and charnockites. The granites and charnockites constitute the late intrusive phase that intruded into the pre-existing migmatites and quartzites during the Pan-African orogeny. Ijero-Ekiti has different lithologic units as it is underlain mostly by schist trending in the N - S direction. Mineralized pegmatite intruded into the schist in places. Minerals such as feldspar, sheet mica, tantalum-niobium, lithium have been found in the area (Ale et al., 2014). Ijero-Ekiti schist is part of the Ilesha schist belt representing infolded Upper Proterozoic supracrustal rocks into the migmatite-gneiss-quartzite complex. The lithological assemblages of the schist belts include coarse to fine grained clastics, pelitic schists, phyllites, banded iron formation, carbonate rocks (marbles/dolomitic marbles) and mafic metavolcanics (amphibolites).

## 2. Methods

The two towns selected for this study were considered because both towns have a population that qualified them as urban centres. Ado-Ekiti had a population of 308,621 while Ijero-Ekiti's population was 147,300, respectively (NPC, 2006). Anthropogenic activities that normally increase with increased population are known to contribute significantly to groundwater pollution. Thus, the effects of urbanization on the quality of groundwater and sanitation in the two areas can be established through a sanitary survey and hydrochemical characterization of the groundwater. In line with sanitary survey guidelines (WHO, 1997; Colorado Department of Public Health and Environment—Water Quality Control Division Engineering Section, 2010; USEPA, 2019), thirty (30) wells were randomly selected and subjected to sanitary survey procedures employing designed questionnaires for each of the two cities. At each well, locations were captured and recorded employing etrex 12 Channel Geographical Position System (GPS) (**Figure 1**, **Table 1(a)**). The questionnaires were prepared to address the salient problems of hygiene and sanitation. Questions designed include, amongst others; standard distance of well to latrine (≥10 m), well established on concrete cement base or marshy environment, using unpolluted bucket and rope to fetch water, covering and lining of wells, well close to animal breeding, $NO_3^-$ polluted well water with measured concentration > 50 mg/L and wells with presence of e-coli. The questions are essential to hygiene and sanitation practices and water quality. Response to each question was in the form of yes or no and each response was accorded ten (10) marks. The answers that constitute risk were summed up to arrive at a final risk score of each well in percentage, since the total designed questions summed up to 100. The results were subsequently categorized

**Table 1.** (a) Results of sanitary survey of thirty randomly selected wells from Ado-Ekiti; (b) Results of sanitary survey of thirty randomly selected wells from Ijero-Ekiti.

(a)

| Code | Distance to latrine < 10 m | Well covered | Bucket & rope | Animal breeding close to well | Damage apron | Well not lined | Conta. rope/bucket | Marshy area | $NO_3$ > 50 mg/L | E-coli present | Total Risk score (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | No | No | Yes | No | Yes | No | No | No | No | No | 40 |
| S2 | No | No | Yes | No | Yes | No | No | No | Yes | No | 40 |
| S3 | Yes | Yes | Yes | Yes | No | No | Yes | No | No | No | 40 |
| S4 | Yes | Yes | Yes | Yes | No | No | Yes | No | No | No | 40 |
| S5 | Yes | Yes | No | No | No | No | No | No | Yes | No | 20 |
| S6 | No | No | Yes | No | No | No | No | No | Yes | No | 30 |
| S7 | Yes | Yes | Yes | No | No | No | No | No | No | No | 20 |
| S8 | No | No | Yes | No | No | No | No | Yes | No | Yes | 40 |
| S9 | No | Yes | Yes | No | No | No | No | No | No | Yes | 20 |
| S10 | No | Yes | Yes | Yes | No | No | No | No | No | No | 20 |
| S11 | No | No | Yes | No | No | No | No | No | Yes | No | 30 |
| S12 | Yes | Yes | Yes | Yes | No | Yes | Yes | No | No | Yes | 50 |
| S13 | Yes | Yes | Yes | No | Yes | No | No | No | Yes | No | 40 |
| S14 | Yes | Yes | Yes | No | No | No | Yes | No | Yes | Yes | 50 |
| S15 | Yes | No | Yes | Yes | No | No | No | No | Yes | No | 50 |
| S16 | Yes | Yes | Yes | No | No | No | No | Yes | Yes | No | 40 |
| S17 | No | Yes | Yes | Yes | No | Yes | No | No | Yes | No | 40 |
| S18 | Yes | Yes | Yes | No | Yes | No | No | No | No | Yes | 40 |
| S19 | No | No | Yes | Yes | Yes | No | No | No | No | No | 40 |
| S20 | Yes | Yes | Yes | No | No | No | No | No | Yes | No | 30 |
| S21 | Yes | Yes | No | No | No | No | Yes | No | No | No | 20 |
| S22 | Yes | Yes | Yes | No | No | Yes | Yes | No | Yes | No | 50 |
| S23 | Yes | Yes | Yes | No | No | No | Yes | No | No | Yes | 40 |
| S24 | No | No | Yes | No | No | No | Yes | Yes | Yes | Yes | 60 |
| S25 | Yes | No | Yes | Yes | Yes | No | No | No | Yes | Yes | 60 |
| S26 | Yes | Yes | Yes | Yes | No | Yes | Yes | No | No | No | 50 |
| S27 | No | Yes | Yes | Yes | No | Yes | No | No | No | Yes | 40 |
| S28 | No | No | Yes | Yes | No | Yes | No | Yes | No | Yes | 60 |
| S29 | Yes | Yes | No | No | No | No | No | Yes | Yes | No | 30 |
| S30 | Yes | Yes | Yes | No | Yes | Yes | No | No | No | Yes | 20 |
| | | | | | | | | | | Min | 20 |
| | | | | | | | | | | Max | 60 |
| | | | | | | | | | | Mean | 38.33 |
| | | | | | | | | | | Stdev | 12.34 |

(b)

| Code | Distance to latrine < 10 m | Well covered | Bucket & rope | Animal breeding close to well | Damage apron | Well not lined | Conta. rope/bucket | Marshy area | $NO_3$ > 50 mg/L | E-coli present | Total Risk score (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | No | No | No | No | Yes | No | No | No | No | No | 20 |
| S2 | No | Yes | Yes | No | Yes | Yes | Yes | No | No | Yes | 50 |
| S3 | Yes | Yes | Yes | No | Yes | Yes | Yes | No | No | Yes | 60 |
| S4 | No | No | Yes | No | Yes | Yes | No | No | No | No | 40 |
| S5 | No | Yes | Yes | No | Yes | Yes | Yes | yes | No | Yes | 60 |
| S6 | No | No | No | No | No | No | No | No | No | No | 10 |
| S7 | Yes | No | Yes | No | Yes | No | No | No | No | No | 40 |
| S8 | No | No | Yes | No | Yes | No | No | No | No | No | 30 |
| S9 | Yes | No | Yes | No | No | No | No | yes | No | No | 30 |
| S10 | Yes | No | Yes | No | No | No | No | No | No | No | 30 |
| S11 | No | No | No | No | No | No | No | No | No | No | 10 |
| S12 | No | No | No | No | No | No | No | no | No | Yes | 10 |
| S13 | Yes | No | Yes | No | No | Yes | No | No | No | No | 40 |
| S14 | No | Yes | No | No | Yes | No | No | No | No | No | 10 |
| S15 | No | Yes | Yes | No | Yes | Yes | Yes | yes | No | No | 50 |
| S16 | Yes | Yes | Yes | No | Yes | No | Yes | Yes | No | Yes | 60 |
| S17 | Yes | No | Yes | No | Yes | No | Yes | yes | No | Yes | 70 |
| S18 | No | Yes | No | No | Yes | Yes | No | No | No | No | 20 |
| S19 | No | Yes | Yes | No | Yes | Yes | Yes | No | No | No | 40 |
| S20 | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | No | No | 60 |
| S21 | Yes | No | Yes | No | Yes | Yes | Yes | No | No | No | 60 |
| S22 | Yes | No | Yes | No | No | Yes | Yes | No | No | Yes | 60 |
| S23 | Yes | No | Yes | No | Yes | Yes | No | No | No | Yes | 60 |
| S24 | No | Yes | Yes | No | Yes | No | No | No | No | Yes | 30 |
| S25 | No | No | No | No | No | No | No | No | No | No | 10 |
| S26 | Yes | No | Yes | No | No | No | No | Yes | No | Yes | 50 |
| S27 | Yes | No | No | No | No | No | No | No | No | No | 20 |
| S28 | No | No | Yes | No | Yes | No | No | No | No | No | 30 |
| S29 | No | No | No | No | No | No | No | No | No | No | 10 |
| S30 | No | No | Yes | No | No | No | Yes | No | No | No | 20 |
| | | | | | | | | | | Min | 10 |
| | | | | | | | | | | Max | 70 |
| | | | | | | | | | | Mean | 36.33 |
| | | | | | | | | | | Stdev | 19.56 |

after modification (Talabi, 2022) to very high risk (R > 80%), high risk (50 < R ≤ 80%), intermediate risk (30 < R ≤ 50%) and low risk (0 ≤ R ≤ 30%). Subsequently, groundwater sampling exercise in line with APHA (2012) standard was embarked upon.

At each location, in situ parameters (temperature (˚C), pH and EC (μS/cm)) were measured using a portable Multi-parameter TestrTM 35 Series S/N: 1382654. In natural water, EC and TDS are related approximately by: TDS (mg/L) - 0.75EC (μS/cm) (Raghunath, 1987). TDS in this study was estimated using this relationship. At each well, water samples were collected into clean polyethylene bottles in triplicate copies for cation, anion and e-coli evaluations, respectively. Water samples for cations were acidified by adding two drops of concentrated nitric acid already stored in clean medical syringe.

All samples were kept in refrigerator at low temperature of about 4˚C before being taken to the central research laboratory, Federal University of Technology, Akure for analyses. Ion chromatography was employed for the anions analysis while the cations were determined using an Atomic Absorption Spectrophotometer Buck 210 model. Membrane filter technique was employed for the e-coli estimation. Obtained data from the in situ and chemical analyses were evaluated employing descriptive statistics; correlation, cluster analysis (CA) and principal component analysis (PCA) (Ghodbane et al., 2015; Athamena & Menani, 2018).

Furthermore, Nitrate pollution Index (NPI) and modified Nitrate Pollution Index (MNPI) were estimated. The NPI is a single water quality parameter index (Obeidat et al., 2012). Nitrate pollution of water is a common global problem associated with anthropogenic activities (McLay et al., 2001). Currently, there is increasing apprehension about the presence of nitrates ( $NO_3^-$ ) in groundwater due to the intensive use of fertilizers and other anthropogenic sources (sewage or industrial wastewater discharge) (Abascal et al., 2022).

Nitrate pollution has inflicted severe health problems on humans. Among the health related problems are colon and rectum cancers, methemoglobinemia in infants, and non-Hodgkin's lymphoma (Knobeloch et al., 2000; De Roos et al., 2003; Ward et al., 2018; Sehlaoui et al., 2022). The NPI was estimated using:

$$\text{NPI} = \frac{\text{Cs} - \text{HAV}}{\text{HAV}}$$

where Cs = the analytical nitrate concentration value in the groundwater sample,

HAV = the threshold value of anthropogenic source (human affected value = 20 mg/L).

The threshold value of 20 mg/L was in line with Spalding and Exner (1993) in which groundwater with $NO_3^-$ concentration > 20 mg/L is considered to have been contaminated due to human activities (Human Affected Value-HAV). Thus, the NPI value was employed to unravel nitrate pollution due to human activities. Subsequently, obtained NPI values were employed to classify the groundwater into five classes (NPI < 0 = Clean unpolluted water, 0 < NPI ≤ 1 = Light pollution, $1 < NPI \leq 2$ = Moderate pollution, $2 < NPI \leq 3$ = Significant pollution, $NPI > 3$ = Very significant pollution) of groundwater quality. Generally, $NO_3^-$ concentration < 50 mg/L is the maximum acceptable value for humans' consumption (WHO, 2010). Therefore, a modify Nitrate Pollution Index (MNPI) was calculated using the maximum acceptable nitrate concentration of 50 mg/L in which;

$$MNPI = \frac{Cs - NSV}{NSV}$$

where, MNPI = Modified Nitrate Pollution index, Cs = concentration of groundwater sample, NSV = Nitrate Standard Value (50 mg/L) (WHO, 2010).

To obtain the classes of the modified NPI, the classes of NPI were multiplied by a multiplication factor of 2.5 (50/20). Hence, the modified NPI was classified into $MNPI < 0$ = Clean unpolluted water, $0 < MNPI \leq 2.5$ = Light pollution, $2.5 < MNPI \leq 5$ = Moderate pollution, $5 < MNPI \leq 7.5$ = Significant pollution, $MNPI > 7.5$ = Very significant pollution.

## 3. Results and Discussion

The results of the sanitary surveys are presented in **Table 1(a)** and **Table 1(b)** for Ado-Ekiti and Ijero-Ekiti, respectively. The results in **Table 1(a)** revealed a minimum sanitary survey value of 20, maximum of 60 and an average of 38.33 in wells at Ado-Ekiti while at Ijero-Ekiti (**Table 1(b)**), the minimum value was 10, maximum 70, and average of 36.33. The standard deviations were 12.34 and 19.56 for Ado-Ekiti and Ijero-Ekiti wells, respectively. Judging by the average values of sanitary surveys in the two areas, Ijero-Ekiti was less susceptible to contamination. Standard deviation measures the dispersion of data around the mean, showing that the sanitary survey result of Ijero-Ekiti was more spread out from the mean than that of Ado-Ekiti (**Figure 2**). A critical view of the tables further revealed that 15 wells from Ijero-Ekiti were in the very low-risk category compare to Ado-Ekiti with ten, though in the intermediate class, Ijero-Ekiti had 7 wells while that of Ado-Ekiti were 17 wells.

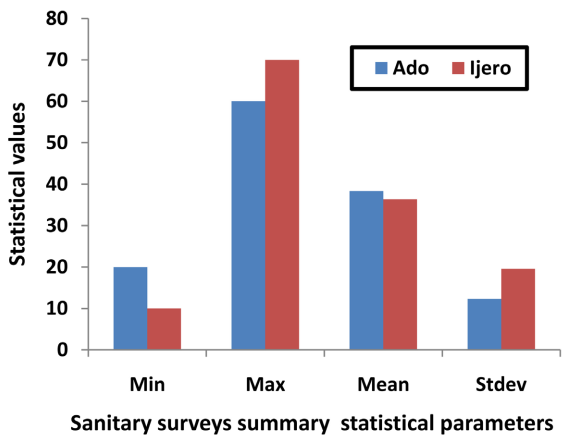


**Figure 2.** Comparison of estimated sanitary surveys' statistical parameters.

However, in the high class of risk classification, Ijero-Ekiti and Ado-Ekiti had 8 wells and 3 wells respectively (Figure 3 and Figure 4). These trends are not diagnostic enough to show which area was more pruned to risk of contamination. However, Ijero-Ekiti had more wells (50%) in the very low-risk category signified that Ado-Ekiti with 10 wells (33.33%) was more pruned to contamination. The high value of wells in Ijero-Ekiti (8 wells representing 26%) in the high-risk category with that of Ado-Ekiti (3 wells representing 10%) signified

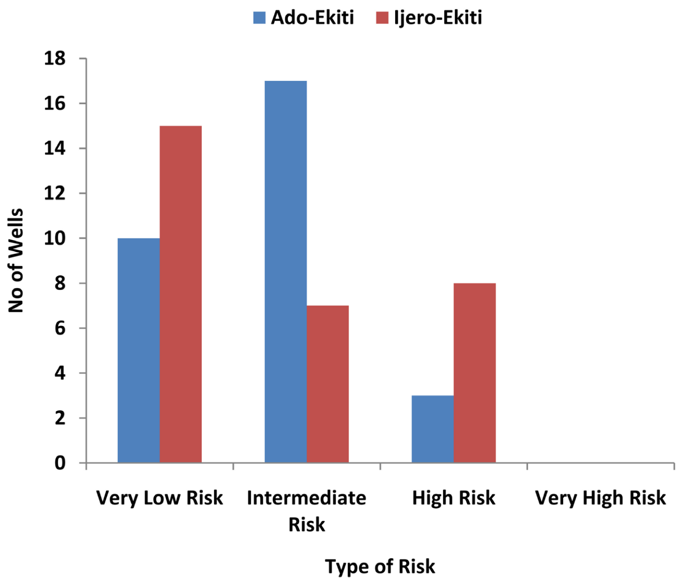


Figure 3. Risk classification.

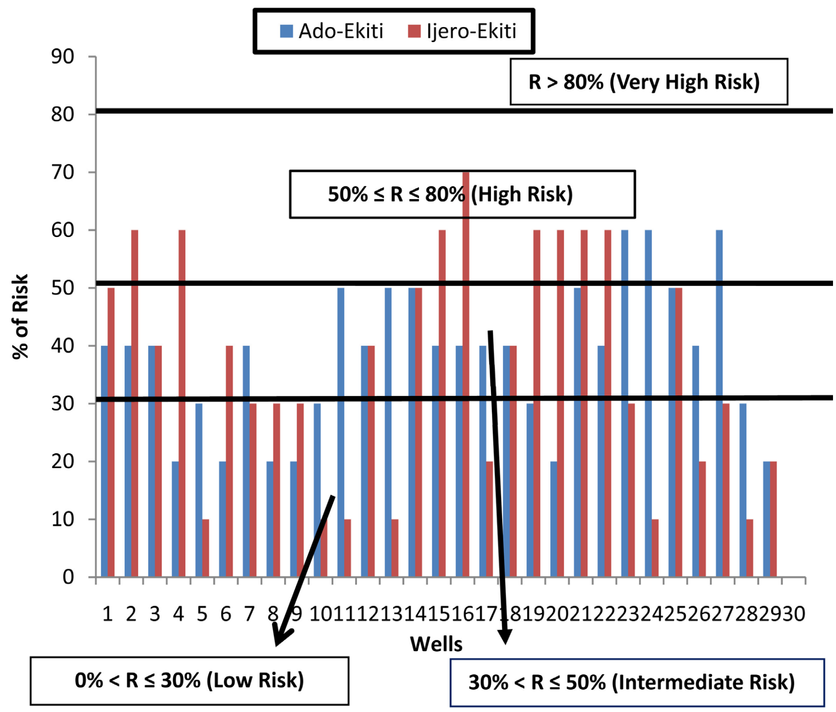


Figure 4. Comparison of the sanitary survey results of the study area.

presence of more localized anthropogenic contaminants at Ijero-Ekiti. There are concerted efforts by the government to reduce indiscriminate dumping of wastes and open defecation at Ado-Ekiti. In addition, there are intensive health education/activities by the Health workers at Ado-Ekiti (the capital of Ekiti State). The government efforts and intensive health activities at Ado-Ekiti may be responsible for the lack of clear-cut dichotomy in the evaluation of the sanitary surveys of Ado-Ekiti and Ijero-Ekiti, as Ijero-Ekiti groundwater appeared to be more susceptible to contamination. The low sanitary risk observed in Ado-Ekiti despite the high population, is in line with the research findings of Adeniyi and Odogiyon (2018) that there are high number of households in Ado-Ekiti using improved sanitation facilities.

The results of physical and chemical parameters of water in the wells of the areas are presented in **Table 2(a)** and **Table 2(b)**, respectively. The pH in Ado-Ekiti groundwater ranged from 4.8 - 8.2 (av. 7.07), EC (μS/cm) from 101 - 1008 (av.410) while at Ijero-Ekiti, the pH and EC (μS/cm) varied from 2.1 - 13.8 (av. 9.88) and 80 - 1008 (av. 366) respectively. The pH of water in the study areas showed that Ado-Ekiti groundwater was more acidic compared to Ijero-Ekiti. Waters in 12 wells were acidic, with the remaining 18 alkaline in Ado-Ekiti while at Ijero-Ekiti, waters in only 5 wells were acidic with the remaining ones alkaline. The variations in pH were a consequence of differences in the lithology and in adherence to standard sanitation and hygiene practices of the two areas. Approved standard pH values for drinking water range from 6.5 - 8.5 (NSDWQ, 2007; USEPA, 2019). In Ado-Ekiti, 13% and 77% of the wells' waters had pH < 6.5 and pH > 8.5 respectively. As for the Ijero-Ekiti, only 10% of the wells' water had pH < 6.5 and none with pH > 8.5. According to the USEPA (2019) and Cotruvo (2017), the pH of water usually has no direct impact on the health and safety of consumers. However, since pH initiates interactions of groundwater with the environment, it is monitored periodically. Groundwater that doesn't fall in the "safe" pH range of 6.5 to 8.5, may be suitable for drinking. Though, such water can have an unpleasant smell or taste, and it can also damage pipes and water-carrying appliances. Acidic water may be useful in eliminating inflammatory skin conditions like atomic dermatitis, hair health, and growing plants. However, drinking acidic water is not recommended, it can corrode humans' teeth/pipes and may lead to heavy metal poison (Proksch, 2018).

All other physicochemical parameters had values within approved WHO standards for drinking water except for the $NO_3^-$ (mg/L) concentrations that exceeded the standard (50 mg/L) in many locations. In Ado-Ekiti, the concentrations (mg/L) range from 13.47 - 382.49 (av. 142.17) while that of Ijero-Ekiti is from 95.62 - 405.39 (av. 252.71).

It is globally accepted that nitrate is among the most common groundwater contaminants (Rajmohan & Elango, 2005). The work of Adeyemi et al. (2003) revealed that pollution of wells' water at Ikire, southwestern Nigeria was mostly from, or due to, near surface activities. The concentrations of $NO_3^-$ in all the waters in wells at Ijero-Ekiti fell outside the WHO (2004) approved standard of

Table 2. (a) Physical characteristics of groundwater in wells at Ijero-Ekiti and Ado-Ekiti; (b) Chemical characteristics of groundwater in wells at Ijero-Ekiti and Ado-Ekiti.

(a)

| Ijero-Ekiti Wells | | | | | | | | | Ado-Ekiti Wells | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Northing | Easting | Elev (m) | Temp (˚C) | pH | EC (μS/cm) | TDS (mg/l) | E-coli (cfu/100 ml) | Location | Northing | Easting | Elev (m) | Temp (˚C) | pH | EC (μS/cm) | TDS (mg/l) | E-coli (cfu/100 ml) |
| 1 | 7.81944 | 5.06944 | 490 | 31.9 | 7.2 | 1008 | 756.0 | NIL | 1 | 7.71169 | 5.25127 | 320 | 26.7 | 10.2 | 80 | 60 | NIL |
| 2 | 7.81944 | 5.08889 | 485 | 31.0 | 6.5 | 457 | 342.8 | 15 | 2 | 7.71295 | 5.26356 | 400 | 27.6 | 10.2 | 529 | 396.75 | NIL |
| 3 | 7.94444 | 5.11111 | 465 | 33.0 | 6.9 | 790 | 592.5 | 3 | 3 | 7.68794 | 5.25830 | 397 | 27.8 | 9.6 | 260 | 195 | NIL |
| 4 | 7.90278 | 5.08333 | 443 | 31.7 | 8.1 | 312 | 234.0 | NIL | 4 | 7.68547 | 5.25702 | 396 | 28.6 | 9.8 | 274 | 205.5 | NIL |
| 5 | 7.86111 | 5.20556 | 435 | 32.2 | 5.3 | 440 | 330.0 | 2 | 5 | 7.67327 | 5.24531 | 379 | 286 | 11.6 | 380 | 285 | NIL |
| 6 | 7.81944 | 5.19167 | 440 | 30.8 | 6.7 | 135 | 101.3 | NIL | 6 | 7.66852 | 5.25131 | 379 | 29.9 | 9.4 | 239 | 172.08 | NIL |
| 7 | 7.93611 | 5.15000 | 420 | 31.2 | 7.5 | 226 | 169.5 | NIL | 7 | 7.67381 | 5.23639 | 373 | 38.7 | 11.8 | 306 | 229.5 | NIL |
| 8 | 7.81389 | 5.16389 | 440 | 31.7 | 8.1 | 162 | 121.5 | NIL | 8 | 7.67571 | 5.22470 | 388 | 29.2 | 11.8 | 237 | 170.64 | 1 |
| 9 | 7.86389 | 5.20278 | 450 | 30.6 | 4.8 | 232 | 174.0 | NIL | 9 | 7.67515 | 5.19487 | 436 | 28.4 | 11.4 | 397 | 297.75 | 4 |
| 10 | 7.91389 | 5.18611 | 460 | 31.6 | 5.9 | 308 | 231.0 | NIL | 10 | 7.64771 | 5.20415 | 413 | 28.7 | 11.5 | 363 | 272.25 | NIL |
| 11 | 7.95000 | 5.18611 | 490 | 30.0 | 6.8 | 392 | 294.0 | NIL | 11 | 7.65589 | 5.21132 | 406 | 28.8 | 9.6 | 287 | 204.64 | NIL |
| 12 | 7.82778 | 5.20833 | 500 | 32.2 | 7.7 | 790 | 592.5 | 5 | 12 | 7.64394 | 5.23188 | 405 | 31.0 | 7.8 | 206 | 154.5 | 58 |
| 13 | 7.86111 | 5.20278 | 520 | 31.0 | 8.1 | 701 | 525.8 | NIL | 13 | 7.62560 | 5.22689 | 456 | 30.4 | 12.3 | 882 | 661.50 | NIL |
| 14 | 7.85833 | 5.21389 | 520 | 32.2 | 7.6 | 532 | 399.0 | NIL | 14 | 7.61760 | 5.22691 | 427 | 29.0 | 11.6 | 1008 | 725.76 | 2 |
| 15 | 7.83333 | 5.13056 | 480 | 33.6 | 6.5 | 402 | 301.5 | NIL | 15 | 7.61590 | 5.23406 | 430 | 31.0 | 13.2 | 525 | 393.75 | NIL |
| 16 | 7.84722 | 5.16111 | 470 | 31.5 | 7.0 | 315 | 236.3 | 33 | 16 | 7.60045 | 5.24220 | 395 | 30.0 | 12.1 | 195 | 140.40 | NIL |
| 17 | 7.82500 | 5.17778 | 470 | 31.7 | 7.5 | 367 | 275.3 | 4 | 17 | 7.59777 | 5.22750 | 419 | 28.2 | 9.5 | 502 | 376.50 | NIL |
| 18 | 7.94167 | 5.13889 | 470 | 32.7 | 6.2 | 261 | 195.8 | NIL | 18 | 7.60001 | 5.22217 | 427 | 30.0 | 9.5 | 533 | 399.75 | 3 |
| 19 | 7.93056 | 5.12500 | 480 | 31.3 | 6.3 | 419 | 314.3 | NIL | 19 | 7.57497 | 5.20882 | 431 | 28.4 | 10.8 | 267 | 200.25 | NIL |
| 20 | 7.90278 | 5.15278 | 470 | 30.9 | 6.8 | 124 | 93.0 | NIL | 20 | 7.56385 | 5.21187 | 420 | 28.4 | 11.3 | 367 | 264.24 | NIL |
| 21 | 7.94444 | 5.15278 | 460 | 31.5 | 7.8 | 292 | 219.0 | NIL | 21 | 7.57202 | 5.2042 | 425 | 30.3 | 10.5 | 158 | 118.50 | NIL |
| 22 | 7.96389 | 5.09167 | 480 | 31.8 | 7.9 | 894 | 670.5 | 41 | 22 | 7.60285 | 5.21316 | 420 | 29.1 | 11.6 | 120 | 90.00 | NIL |
| 23 | 7.95556 | 5.21667 | 506 | 32.1 | 8.2 | 1001 | 750.8 | 4 | 23 | 7.61575 | 5.22071 | 432 | 28.5 | 13.8 | 349 | 261.75 | 4 |
| 24 | 7.84722 | 5.06944 | 520 | 30.1 | 6.2 | 765 | 573.8 | 4 | 24 | 7.61436 | 5.22084 | | 26.9 | 11 | 106 | 79.50 | 4 |
| 25 | 7.87222 | 5.18889 | 520 | 31.4 | 7.3 | 165 | 123.8 | NIL | 25 | 7.60753 | 5.25143 | 391 | 24.5 | 2.1 | 194 | 145.50 | 21 |
| 26 | 7.83889 | 5.16944 | 490 | 31.3 | 7.5 | 333 | 249.8 | 3 | 26 | 7.60582 | 5.28680 | 380 | 23.5 | 6.70 | 766 | 514.50 | NIL |
| 27 | 7.87500 | 5.16389 | 510 | 30.2 | 8.2 | 151 | 113.3 | NIL | 27 | 7.61507 | 5.27342 | 367 | 25.4 | 7.20 | 718 | 538.50 | 23 |
| 28 | 7.89167 | 5.15556 | 520 | 30.6 | 6.9 | 108 | 81.0 | NIL | 28 | 7.61399 | 5.21031 | 432 | 36.6 | 5.70 | 295 | 221.25 | 3 |
| 29 | 7.92778 | 5.14167 | 540 | 31.6 | 7.1 | 117 | 87.8 | NIL | 29 | 7.62320 | 5.19744 | 449 | 27.8 | 6.30 | 136 | 102.00 | NIL |
| 30 | 7.91944 | 5.13056 | 530 | 30.0 | 7.5 | 101 | 75.8 | NIL | 30 | 7.61601 | 5.17918 | 477 | 26.2 | 6.40 | 299 | 215.28 | 3 |

(b)

| | Ijero-Ekiti Wells | | | | | | | | | Ado-Ekiti Wells | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | K (mg/L) | $HCO_3$ (mg/L) | $Cl^-$ (mg/L) | $SO_4$ (mg/L) | $NO_3$ (mg/L) | **Location** | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | K (mg/L) | $HCO_3$ (mg/L) | $Cl^-$ (mg/L) | $SO_4$ (mg/L) | $NO_3$ (mg/L) |
| 1 | 67.33 | 11.67 | 64.50 | 185.50 | 5.00 | 116.62 | 885.33 | 356.90 | 1 | 12.83 | 2.92 | 5.42 | 2.32 | 3.00 | 10.98 | 26.67 | 37.71 |
| 2 | 52.91 | 18.48 | 23.00 | 26.00 | 3.30 | 47.38 | 208.00 | 338.05 | 2 | 28.86 | 9.73 | 69.50 | 8.40 | 5.00 | 84.14 | 32.00 | 285.52 |
| 3 | 88.81 | 2.92 | 46.50 | 91.00 | 3.20 | 91.11 | 357.37 | 323.23 | 3 | 25.65 | 8.76 | 41.00 | 4.98 | 5.40 | 18.29 | 117.33 | 242.42 |
| 4 | 27.25 | 8.76 | 25.50 | 16.00 | 2.10 | 58.31 | 106.67 | 250.51 | 4 | 32.06 | 3.00 | 19.00 | 7.06 | 4.90 | 21.95 | 21.33 | 18.86 |
| 5 | 44.89 | 1.95 | 28.00 | 40.00 | 7.00 | 61.95 | 90.66 | 389.23 | 5 | 31.50 | 17.51 | 13.00 | 3.07 | 1.70 | 32.93 | 10.67 | 193.94 |
| 6 | 14.43 | 2.91 | 7.00 | 40.00 | 2.00 | 18.22 | 85.33 | 153.54 | 6 | 31.90 | 1.95 | 29.00 | 2.58 | 2.00 | 18.55 | 32.00 | 71.38 |
| 7 | 24.05 | 2.68 | 21.00 | 30.00 | 3.10 | 7.29 | 80.00 | 278.79 | 7 | 19.24 | 4.86 | 49.00 | 9.01 | 2.10 | 43.90 | 277.33 | 51.18 |
| 8 | 16.03 | 6.81 | 25.00 | 60.50 | 4.50 | 3.64 | 101.33 | 160.27 | 8 | 27.25 | 2.90 | 30.50 | 5.26 | 1.90 | 21.26 | 545.33 | 141.41 |
| 9 | 19.24 | 6.88 | 34.00 | 62.00 | 3.40 | 25.51 | 378.67 | 153.54 | 9 | 36.87 | 5.84 | 43.50 | 32.50 | 2.30 | 36.58 | 106.67 | 253.20 |
| 10 | 24.05 | 0.97 | 28.50 | 62.50 | 2.20 | 40.09 | 128.00 | 390.57 | 10 | 30.46 | 6.02 | 8.44 | 67.50 | 1.50 | 29.27 | 288.00 | 250.51 |
| 11 | 32.06 | 3.89 | 33.00 | 44.50 | 2.60 | 47.38 | 379.00 | 281.48 | 11 | 22.44 | 1.68 | 43.00 | 6.62 | 1.20 | 32.90 | 37.30 | 202.02 |
| 12 | 60.92 | 1.94 | 68.00 | 158.00 | 2.10 | 98.40 | 170.66 | 280.13 | 12 | 20.84 | 4.96 | 30.50 | 2.56 | 1.10 | 25.61 | 64.00 | 88.89 |
| 13 | 66.34 | 5.84 | 58.50 | 66.00 | 2.50 | 91.10 | 309.33 | 405.39 | 13 | 64.13 | 32.10 | 102.00 | 2.98 | 3.20 | 131.70 | 794.67 | 180.47 |
| 14 | 51.30 | 9.73 | 57.50 | 79.00 | 3.00 | 99.50 | 373.33 | 331.31 | 14 | 67.33 | 21.40 | 129.00 | 51.50 | 3.00 | 147.99 | 426.66 | 202.02 |
| 15 | 41.68 | 3.80 | 25.50 | 34.50 | 2.40 | 21.87 | 549.30 | 266.67 | 15 | 52.91 | 7.78 | 53.00 | 5.44 | 0.80 | 76.83 | 16.00 | 296.30 |
| 16 | 33.67 | 10.71 | 48.00 | 34.50 | 2.30 | 14.58 | 96.00 | 257.24 | 16 | 17.64 | 1.94 | 47.00 | 2.79 | 1.50 | 29.26 | 138.67 | 102.36 |
| 17 | 22.44 | 8.75 | 62.00 | 31.00 | 2.00 | 47.30 | 16.00 | 188.55 | 17 | 41.68 | 2.98 | 72.50 | 8.01 | 1.20 | 62.19 | 250.67 | 142.76 |
| 18 | 16.10 | 9.72 | 45.00 | 41.50 | 1.60 | 36.44 | 106.66 | 276.09 | 18 | 44.89 | 6.81 | 69.00 | 51.50 | 1.10 | 51.22 | 506.00 | 118.52 |
| 19 | 33.80 | 2.92 | 44.50 | 115.50 | 2.30 | 32.80 | 352.00 | 298.99 | 19 | 24.05 | 2.91 | 44.00 | 8.18 | 2.00 | 32.96 | 37.33 | 153.54 |
| 20 | 16.30 | 2.90 | 46.50 | 31.50 | 1.50 | 10.93 | 229.33 | 191.25 | 20 | 20.60 | 3.89 | 56.00 | 70.00 | 3.50 | 36.60 | 112.00 | 21.55 |
| 21 | 16.03 | 4.86 | 44.00 | 31.00 | 2.50 | 47.30 | 256.00 | 164.31 | 21 | 16.03 | 5.80 | 7.69 | 43.00 | 1.00 | 10.96 | 74.67 | 13.47 |
| 22 | 68.94 | 17.59 | 47.00 | 131.50 | 3.20 | 51.02 | 101.30 | 351.52 | 22 | 9.62 | 3.68 | 40.00 | 1.06 | 1.50 | 14.63 | 31.00 | 36.36 |
| 23 | 72.14 | 2.92 | 63.50 | 146.00 | 2.90 | 102.04 | 506.66 | 261.28 | 23 | 24.08 | 4.94 | 55.50 | 0.59 | 1.60 | 43.90 | 234.67 | 145.45 |
| 24 | 64.12 | 23.35 | 74.50 | 54.00 | 4.80 | 112.97 | 448.67 | 354.21 | 24 | 16.80 | 4.86 | 6.98 | 4.12 | 2.50 | 7.32 | 165.33 | 60.60 |
| 25 | 14.43 | 7.78 | 36.50 | 25.50 | 2.40 | 29.15 | 149.33 | 145.45 | 25 | 18.00 | 3.80 | 30.50 | 2.43 | 2.00 | 18.20 | 75.00 | 107.74 |
| 26 | 33.06 | 9.73 | 33.00 | 25.50 | 2.80 | 18.22 | 16.22 | 272.05 | 26 | 70.54 | 9.92 | 77.00 | 20.00 | 1.00 | 120.73 | 32.60 | 382.49 |
| 27 | 9.62 | 3.87 | 48.00 | 23.50 | 2.00 | 21.87 | 37.33 | 95.62 | 27 | 48.10 | 14.59 | 128.00 | 6.11 | 9.90 | 25.61 | 36.67 | 25.59 |
| 28 | 17.64 | 3.98 | 33.00 | 21.00 | 2.20 | 10.93 | 21.30 | 111.78 | 28 | 19.58 | 1.92 | 57.50 | 8.03 | 2.10 | 44.90 | 28.00 | 193.94 |
| 29 | 16.00 | 1.94 | 23.50 | 21.00 | 2.50 | 14.58 | 10.67 | 107.74 | 29 | 11.22 | 0.97 | 27.00 | 8.39 | 2.00 | 7.68 | 34.33 | 71.30 |
| 30 | 16.02 | 3.85 | 37.50 | 30.50 | 1.70 | 7.29 | 58.66 | 145.54 | 30 | 32.66 | 2.98 | 31.00 | 4.45 | 1.80 | 29.67 | 42.67 | 173.74 |

50 mg/L whereas in Ado-Ekiti, water in 7 wells was within the standard (**Figure 5**). The $NO_3^-$ concentrations in both cities call for attention because of the health implications of excess $NO_3^-$ in groundwater. The adverse health effects of high dose of nitrate on humans' health range from infant methemoglobinemia (Blue Baby Syndrome), cancers, the hot dog headache, and hypertension; the other adverse effects include birth defects (congenital malformations) and spontaneous abortions.

Nitrate can be reduced or removed entirely from drinking water by employing ion exchange resins, reverse osmosis, electrodialysis and either biological or chemical denitrification. In situation, where treatment is impossible, developing a different water source, blending with a different source or connecting to another safe water source in the area becomes necessary (Edet, 2000; Adelana & Olasehinde, 2003).

***Classification of Groundwater based on TDS***

To further categorize the two cities into ease of contamination, TDS values were evaluated (**Figure 6**). TDS measures the total number of dissolved ions in the groundwater of an area and provides information about the general quality of the groundwater. According to the WHO (2004), water with TDS ≤ 500 mg/L is suitable for consumption. Water with TDS < 300 mg/L is in the excellent category, 300 mg/L < TDS ≤ 600 mg/L in the good class, 600 mg/L < TDS ≤ 900 mg/L fair class, 900 mg/L < TDS ≤ 1200 mg/L in poor category while TDS > 1200 mg/L is in the unacceptable zone (**Figure 6**). The TDS classification of groundwater in this study showed that Ijero-Ekiti groundwater was more pruned to contamination with 3 wells, 8 wells and 19 wells in the fair, good and excellent classes, respectively, while that of Ado-Ekiti following the same order were 2 wells, 6 wells and 22 wells (**Figure 7**). Several factors are responsible for contaminants in groundwater. Among these factors, human activities play a

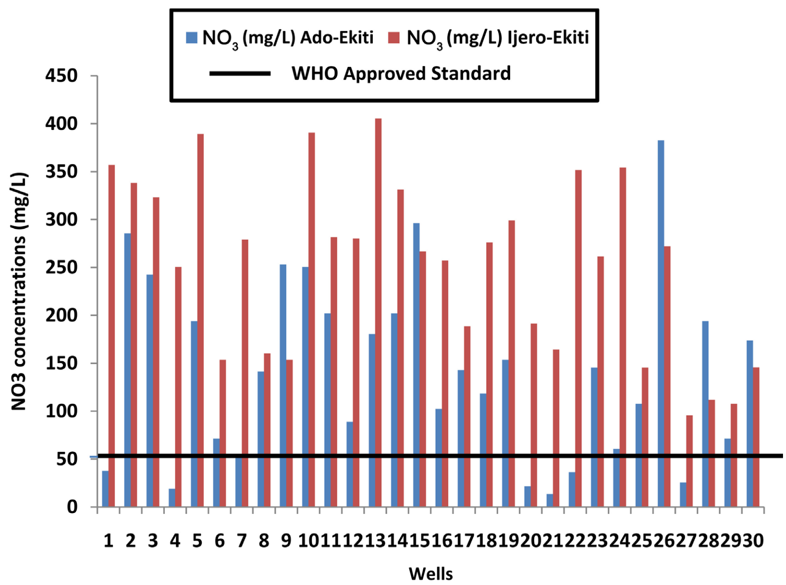


**Figure 5.** Nitrate concentrations in Wells at Ado-Ekiti and Ijero-Ekiti.

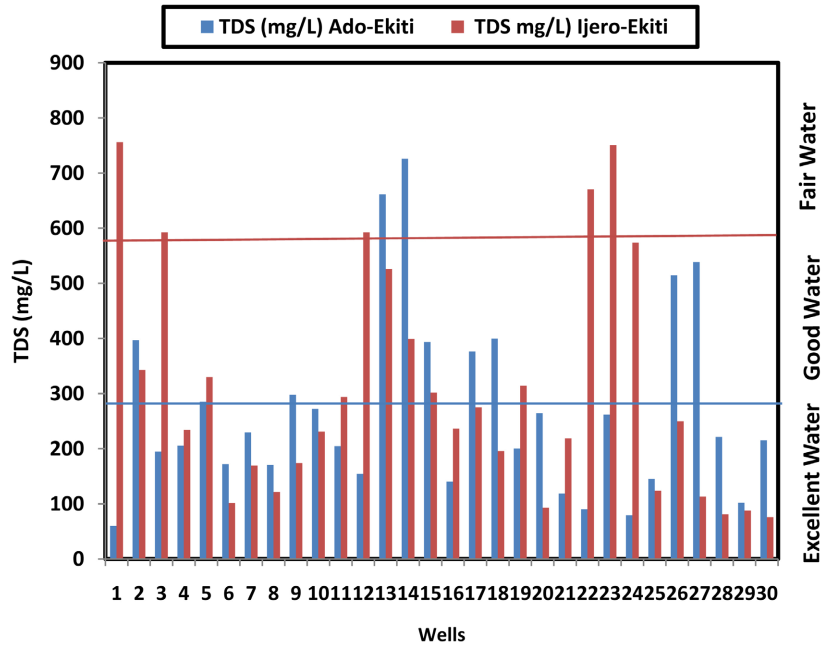


**Figure 6.** Classification of groundwater in Ado-Ekiti and Ijero-Ekiti using TDS.

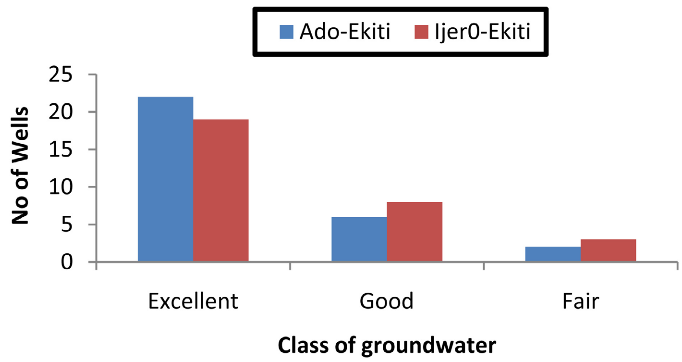


**Figure 7.** Bar Chart indicating categories of wells in the two cities.

significant role in groundwater deterioration (Dragon, 2008). Groundwater contaminants include excessive solutes or heavy metals toxicants arising from rock-water interactions, seepages from polluted rivers' water, saline water intrusion and anthropogenic activities (Umar et al., 2006; Giridharan et al., 2008).

***Nitrate and Modified Nitrate Pollution Index***

Result of the Nitrate Pollution Index (**Figure 8**) showed that only water from one well and four wells in Ado-Ekiti were in the classes of clean unpolluted and light polluted waters respectively while none fell within these categories at Ijero-Ekiti. Water from 2 wells in Ado-Ekiti was in both the moderate and significant pollution classes and none from Ijero-Ekiti.

As for the very significant category, water in all wells from Ijero-Ekiti fell into this class, while waters in 20 wells from Ado-Ekiti were represented. Ijero-Ekiti groundwater was more polluted than that of Ado-Ekiti, though nitrate pollution issue is common to both cities.

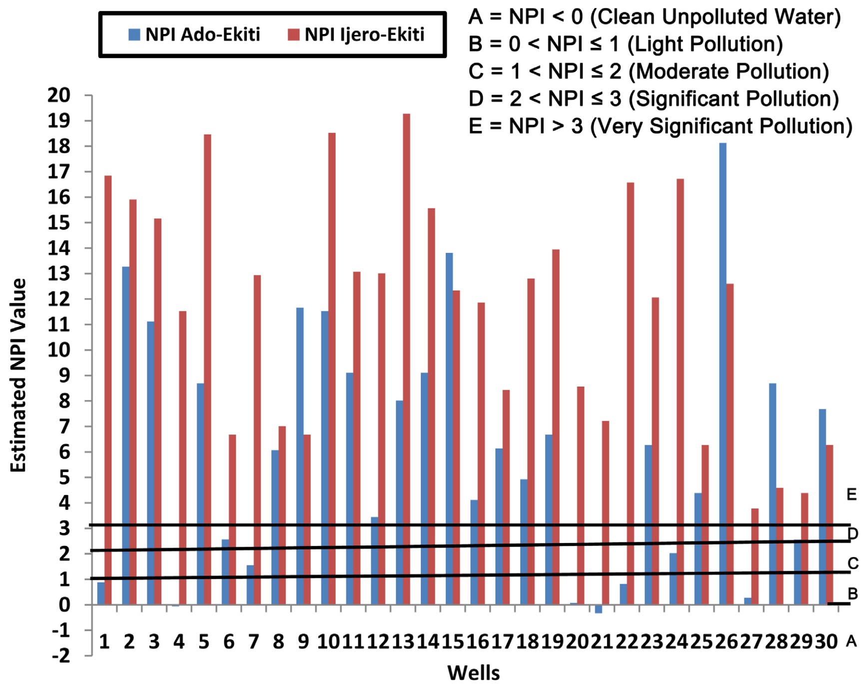


**Figure 8.** NPI values for Ado-Ekiti and Ijero-Ekiti.

The WHO approved standard for nitrate concentration in water is 50 mg/L, hence, modified nitrate pollution index was estimated for water in each well of the study areas (**Figure 9**). The result revealed a fair and realistic pollution index than the index in which 20 mg/L was adopted for its calculation. In the present result, water from 6 wells in Ado-Ekiti fell into the clean unpolluted water category, with none from Ijero-Ekiti. Water from 13 wells, 10 wells and 1 well from Ado-Ekiti fell into light pollution, moderate pollution and significant pollution classes, respectively. At Ijero-Ekiti, water from 9 wells, 12 wells and 9 wells were in light pollution, moderate pollution and significant pollution classes, respectively. In both cities, no water was in the very significant category (**Figure 10**).

The trends portrayed by the groundwater in the two cities employing MNPI clearly revealed that Ado-Ekiti, with a higher population, is less prune to pollution compared to Ijero-Ekiti. Obviously, there have been intensive hygiene education/practices at Ado-Ekiti. The Health Workers and Government Law Enforcement Agents are working assiduously to ensure that Ado-Ekiti is reed off indiscriminate wastes dumps and open defecation.

The State Ministry of Environment and Natural Resources provides Dino Bins placed at strategic places for wastes dumps. Designated government Agent clears regularly the dumped wastes.

***Statisical Analysis***

Data obtained in this study was subjected to correlation analysis, cluster analysis and principal component analysis to gain better understanding of the groundwater quality and the main controlling variables (Guezgouz et al., 2017).

*Correlation Analysis*

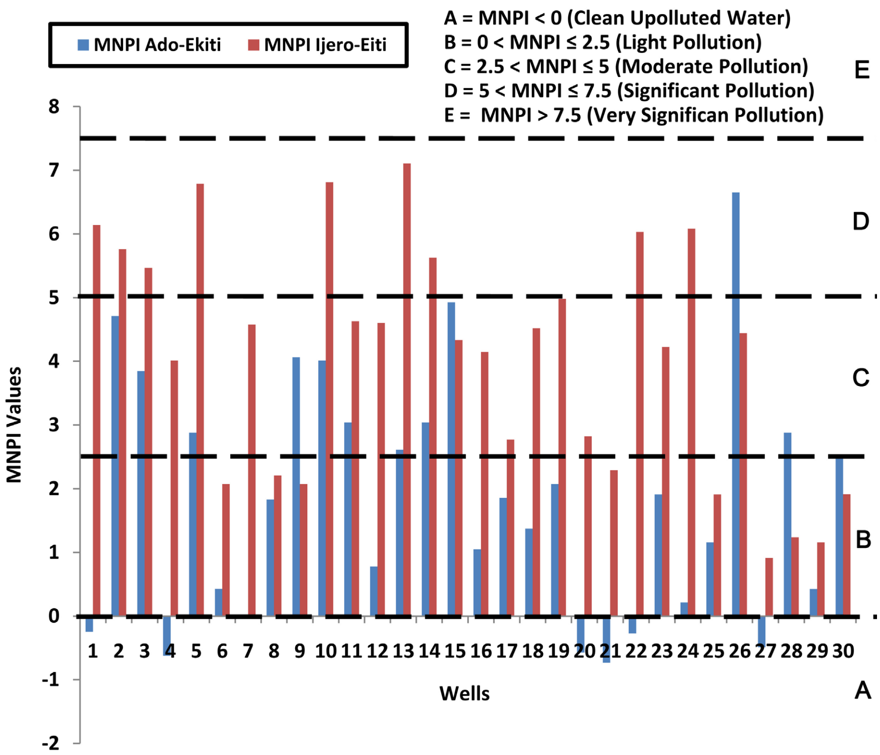


**Figure 9.** Bar Chart indicating MNPI values for Ado-Ekiti and Ijero-Ekiti.

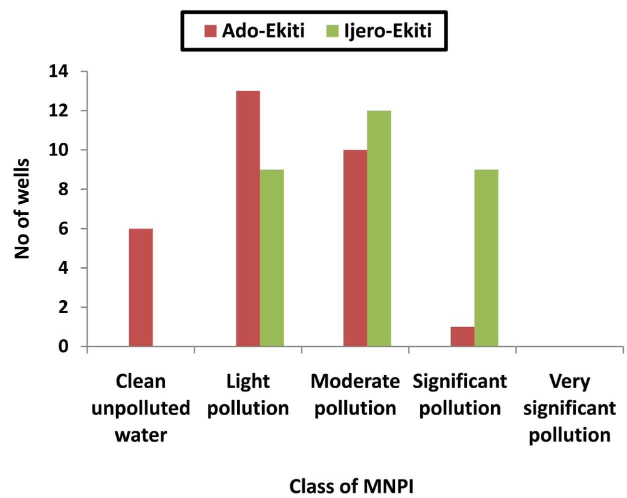


**Figure 10.** Classification of MNPI in Ado-Ekiti and Ijero-Ekiti.

Correlation analysis provides quick and straight forward means to establish relationship among variables and is useful in understanding the geochemical processes involved in the groundwater evolution (Priya & Arulraj, 2011). The result of the correlation analysis in this study is presented in Table 3(a) and Table 3(b). Table 3(a) shows the correlation in respect of wells' water at Ijero-Ekiti while Table 3(b) is for Ado-Ekiti. At Ijero-Ekiti, $Ca^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^-$, $SO_4^{2-}$, $Cl^-$ and $NO_3^-$ contributed significantly to EC since they all have correlation coefficient (r) > 0.5. However, $Ca^{2+}$, $K^{+}$ and $SO_4^{2-}$ correlate with $NO_3^-$

**Table 3.** (a) Correlation of Ijero-Ekiti wells' water parameters; (b) Correlation of Ado-Ekiti wells' water parameters.

(a)

| Designation | EC (μS/cm) | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | $K^+$ | $HCO_3^-$ | $SO_4^{2-}$ | $Cl^-$ | $NO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|
| EC (μS/cm) | 1.00 | | | | | | | | |
| $Ca^{2+}$ | 0.93 | | | | | | | | |
| $Mg^{2+}$ | 0.29 | 0.23 | | | | | | | |
| $Na^+$ | 0.54 | 0.45 | 0.29 | | | | | | |
| $K^+$ | 0.70 | 0.64 | −0.02 | 0.52 | | | | | |
| $HCO_3^-$ | 0.52 | 0.54 | 0.29 | −0.03 | 0.35 | | | | |
| $SO_4^{2-}$ | 0.86 | 0.74 | 0.25 | 0.57 | 0.58 | 0.39 | | | |
| $Cl^-$ | 0.60 | 0.55 | 0.15 | 0.35 | 0.63 | 0.38 | 0.60 | | |
| $NO_3^-$ | 0.78 | 0.80 | 0.15 | 0.26 | 0.61 | 0.47 | 0.66 | 0.46 | 1.00 |

(b)

| | EC (μS/cm) | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | $K^+$ | $HCO_3^-$ | $SO_4^{2-}$ | $Cl^-$ | $NO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|
| EC (μS/cm) | 1.00 | | | | | | | | |
| $Ca^{2+}$ | 0.86 | | | | | | | | |
| $Mg^{2+}$ | 0.66 | 0.58 | | | | | | | |
| $Na^+$ | 0.78 | 0.56 | 0.37 | | | | | | |
| $K^+$ | 0.47 | 0.28 | 0.21 | 0.29 | | | | | |
| $HCO_3^-$ | 0.07 | 0.00 | 0.13 | 0.11 | 0.03 | | | | |
| $SO_4^{2-}$ | 0.88 | 0.68 | 0.44 | 0.81 | 0.39 | −0.07 | | | |
| $Cl^-$ | 0.20 | 0.14 | 0.17 | 0.26 | 0.23 | 0.01 | 0.19 | | |
| $NO_3^-$ | 0.54 | 0.54 | 0.34 | 0.35 | 0.19 | −0.16 | 0.60 | 0.03 | 1.00 |

significantly while the correlation of $NO_3^-$ with $Cl^-$ is very low (r = 0.03). This observation shows that most of $Ca^{2+}$, $K^+$ and $SO_4^{2-}$ ions in the wells' water at Ijero-Ekiti are from anthropogenic activities in agreement with Adeyemi et al. (2003). In case of Ado-Ekiti, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $SO_4^{2-}$ and $NO_3^-$ contribute significantly to EC (r > 0.5). Nitrate has significant correlation with $Ca^{2+}$ and $SO_4^{2-}$. Both $NO_3^-$ and $SO_4^{2-}$ have negative correlation with $HCO_3^-$. Contributions of $Ca^{2+}$, $NO_3^-$ and $SO_4^{2-}$ to the wells' water at Ado-Ekiti are equally mainly from anthropogenic sources. Generally, $NO_3^-$ shows higher positive correlation with other ions in Ijero-Ekiti wells' water compare to the ones at Ado-Ekiti. The correlation analysis shows that ions input into the groundwater of Ijero-Ekiti are mostly from anthropogenic activities compared to Ado-Ekiti.

*Cluster analysis*

Cluster analysis (CA) is a group of multivariate technique whose primary purpose is to group objects based on the similarity of their characteristics (Setyaningsih, 2012). In this study CA is carried out employing both the R- and Q-modes so that interactions among water quality parameters and the study samples can be revealed respectively. Eight measured hydrochemical variables considered in this study are; $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^-$, $SO_4^{2-}$, $Cl^-$ and $NO_3^-$. The chemical data were log—transformed to assume almost normal distribution characteristics and subsequently standardize to standard Z scores (Güler et al., 2002). Selection of groups in the dendogram was by virtual inspection (**Figure 11**). Results of the CA indicate that both cities are categorized into three groups (**Figure 11**). As for Ijero-Ekiti, the first cluster group (GIJ1) (**Figure 11**) comprises $Mg^{2+}$ and $HCO_3^-$ and the second group (GIJ2) in close association with the first group is made up of $Na^{+}$, $K^{+}$ and $SO_4^{2-}$. GIJ1 and GIJ2 have 23.33% and 33.33% representations respectively (**Figure 12**).

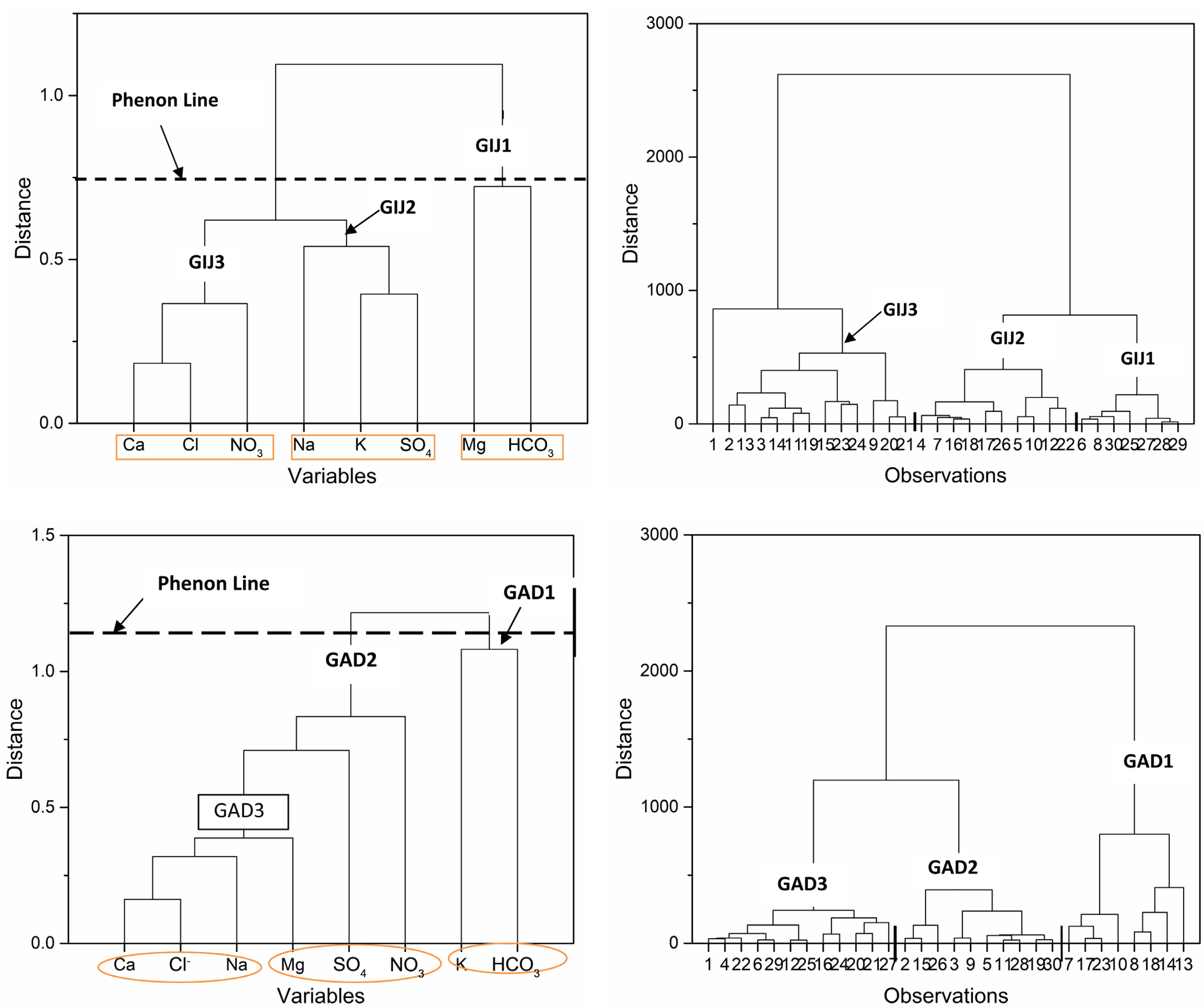


**Figure 11.** Dendrogram resulted from cluster analysis based on correlation coefficient of similarity.

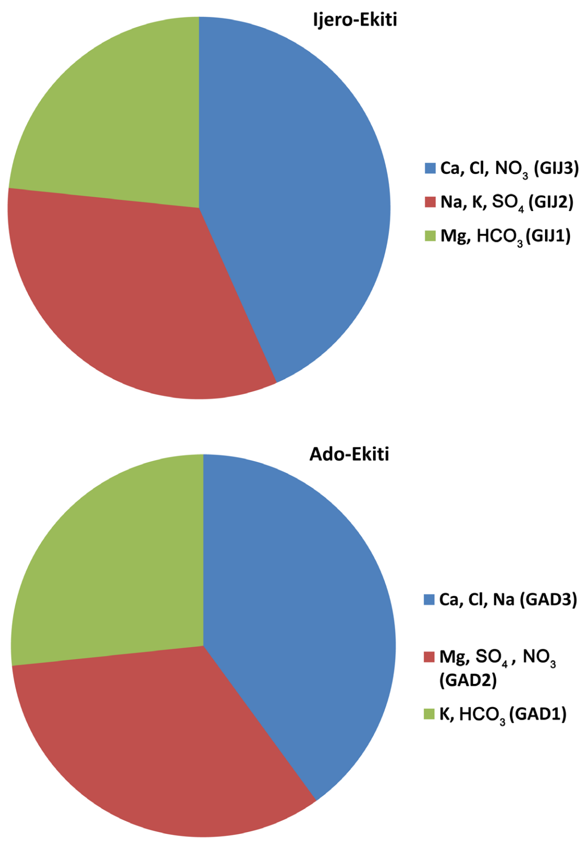


**Figure 12.** Percentage coverage of wells in the cluster analysis.

These two groups represent the main source of solute contribution to groundwater through rock-water interactions. The third group (GIJ3) with 43.34% representation has $Ca^{2+}$, $Cl^{-}$ and $NO_3^-$ as main chemical constituents. This group represents solute contribution to the groundwater through anthropogenic sources. This observation is in tandem with the correlation analysis (Table 3) as $Ca^{2+}$ and $NO_3^-$ have significant correlation values > 0.50 with $Cl^{-}$ having correlation of 0.46 with $NO_3^-$. In case of Ado-Ekiti, the first group (GAD1) has 40% representation with $K^{+}$ and $HCO_3^-$ being the main chemical constituents (Figure 11). The second group (GAD2) (33.33% representation) (Figure 12), has $Mg^{2+}$, $SO_4^{2-}$ and $NO_3^-$ as constituents while the third group (GAD3) with 26.67% coverage (Figure 12), has $Ca^{2+}$, $Cl^{-}$ and $Na^{+}$ as chemical constituents. Both GAD1 and GAD3 are indicative of solute contributions into the groundwater of the study area vide rock-water interactions while GAD2 represents anthropogenic sources. This result is in agreement with the correlation analysis (Table 3(a) and Table 3(b)) with $SO_4^{2-}$ and $NO_3^-$ having correlation coefficient of 0.6. A critical view of the results of this study shows that anthropogenic sources of solutes contributions into groundwater are more prevalent at Ijero-Ekiti compared to Ado-Ekiti. This justifies the findings from sanitary surveys that indicate Ijero-Ekiti to be more susceptible to pollution compared to Ado-Ekiti.

*Principal component analysis*

Principal component analysis is a variable reduction procedure useful when data are obtained on a large number of variables and there is possibility of some redundancy in those variables. In this case, redundancy means that some of the variables are correlated with one another, possibly because they are measuring the same construct. Because of this redundancy, it should be possible to reduce the observed variables into a smaller number of principal components that will account for most of the variance in the observed variables.

Principal component analysis was performed on the data of wells' water in the study area to foster a better understanding of their interrelationships and to explore the reduction of the experimental variables. PCA was carried out on the standardized data (cations and anions) to establish the relationships among the variables used and factors contributing to the water contamination/source apportionment. The PCA was carried out for all the groundwater wells (Ijero-Ekiti and Ado-Ekiti groundwater wells samples combined) and for the different groundwater wells separately. The results of PCA on the chemical characteristics of Ijero-Ekiti and Ado-Ekiti groundwater wells samples (separately) are shown in **Table 4**.

The PCA (**Table 4**) revealed two Principal Components (PCs) with standard deviation (eigenvalues) greater than one that accounted for 67.37% of total cumulative variances in the chemical characteristics of Ijero-Ekiti groundwater data. As for the wells' water at Ado-Ekiti, the PCA (**Table 4**) revealed three Principal

**Table 4.** Result of principal component analysis.

| | Ijero Water Well | | Ado Water Well | | |
|---|---|---|---|---|---|
| | Coefficients of PC 1 | Coefficients of PC 2 | Coefficients of PC 1 | Coefficients of PC 2 | Coefficients of PC 3 |
| $Ca^{2+}$ | −0.438 | 0.028 | 0.469 | −0.053 | −0.124 |
| $Mg^{2+}$ | −0.200 | 0.519 | 0.427 | 0.185 | 0.055 |
| $Na^{+}$ | −0.337 | −0.361 | 0.421 | 0.298 | −0.027 |
| $K^{+}$ | −0.377 | −0.360 | 0.130 | −0.262 | 0.644 |
| $HCO_3^-$ | −0.242 | 0.586 | 0.098 | 0.765 | −0.046 |
| $Cl^-$ | −0.444 | −0.099 | 0.476 | −0.158 | −0.110 |
| $SO_4^{2-}$ | −0.355 | −0.178 | 0.303 | −0.087 | 0.534 |
| $NO_3^-$ | −0.362 | 0.294 | 0.274 | −0.434 | −0.517 |
| Standard deviation | 2.064 | 1.064 | 1.945 | 1.175 | 1.045 |
| Proportion of Variance | 53.226 | 14.140 | 47.286 | 17.244 | 13.661 |
| Cumulative Proportion | 53.226 | 67.366 | 47.286 | 64.531 | 78.191 |

Components (PCs) with standard deviation (eigenvalues) greater than one that accounted for 78.19% of total cumulative variances in the chemical characteristics.

The statiscal analysis indicates that, ions contribution into Ijero-Ekiti wells' water is mostly from anthropogenic activities compared to Ado-Ekiti wells' water.

## 4. Conclusion

The study investigated sanitary surveys and hydrochemistry of wells' water at Ado-Ekiti and Ijero-Ekiti, Southwestern, Nigeria. Results of the sanitary surveys showed that Ado-Ekiti had 33.33%, 56.67% and 10% representations in the very low-risk, intermediate and high-risk categories while Ijero-Ekiti had 50%, 23.33% and 26.67% representations, respectively. There was no direct effect of urbanization on the sanitary surveys as Ado-Ekiti with higher population and humans' activities compared to Ijero-Ekiti was less susceptible to pollution. Results of hydrochemistry showed that the pH of the wells' water in the two cities in many locations is not within the approved standards (6.5 - 8.5) for drinking water. Ado-Ekiti wells' water was more acidic than that of Ijero-Ekiti. Other parameters (EC, $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^-$, $SO_4^{2-}$ and $Cl^-$) were within national and international approved standards for drinking water. However, $NO_3^-$ (mg/L) concentrations exceeded the standards in many locations in both cities. Susceptibility to pollution classification employing TDS, NPI and MNPI showed that Ijero-Ekiti was more susceptible to pollution compared to Ado-Ekiti. This assertion was corroborated by statistical analysis employing correlation, cluster analysis and principal component analysis. High $NO_3^-$ concentrations in water can adversely affect humans' health as it can result in diseases such as colon and rectum cancers, methemoglobinemia in infants and non-Hodgkin's lymphoma. The $NO_3^-$ concentrations in wells' water of the two cities are relatively high and deserve attention. Hence, more modern sanitary facilities should be put in place in the two cities in addition to intensive education on sanitation and hygiene practices.

## Acknowledgements

The authors are grateful to some students that participated in administering the questionnaires during the sanitary surveys as well as in the hydrochemical sampling operations of this research.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Conflicts of Interest

The authors declared that there is no conflict of interest.

## References


Abascal, E., Gómez-Coma, L., Ortiz, I., & Ortiz, A. (2022). Global Diagnosis of Nitrate Pollution in Groundwater and Review of Removal Technologies. *Science of the Total Environment, 810,* Article ID: 152233. https://doi.org/10.1016/j.scitotenv.2021.152233 https://www.sciencedirect.com/science/article/pii/S0048969721073095

Adebayo, W. O., & Arohunsoro, S. J. (2014). Environmental Effects of Urbanization of River Ajilosun Drainage Basin in Ado-Ekiti, Ekiti State, Nigeria. *Journal of Natural Sciences Research, 4,* 113-124.

Adelana, S. M. A., & Olasehinde, P. I. (2003). High Nitrate in Water Supply in Nigeria: Implications for Human Health. *Water Resources, 14,* 1-11.

Adeniyi, J. O., & Odogiyon A. H. (2018). Spatial Analysis of Sanitation Facilities in Ado-Ekiti, Ekiti State, Nigeria. *International Journal of Research and Innovation in Social Science (IJRISS), 2,* 73-79.

Adeyemi, G. O., Adesile, A. O., & Obayomi, O. M. (2003). Chemical Characteristics of Some Well Waters in Ikire, Southwestern Nigeria. *Water Resources Journal of the Nigerian Association of Hydrogeologists (NAH), 14,* 12-18.

Ale, P. T., Dada, J. A., & Adewumi, A. J. (2014). Industrial Minerals Potentials of Ijero Pegmatite in Ekiti State, Southwestern Nigeria. *World Applied Sciences Journal, 29,* 415-420.

Alirol, E., Getaz, L., Stoll, B., Chappuis, F., & Loutan, L. (2011). Urbanisation and Infectious Diseases in a Globalised World. *The Lancet Infectious Diseases, 11,* 131-141. https://doi.org/10.1016/S1473-3099(10)70223-1

Allen, A., Dávila, J., & Hofmann, P. (2006). *Governance of Water and Sanitation Services for the Periurban Poor: A Framework for Understanding and Action in Metropolitan Regions*. The Development Planning Unit University College.

Aluko, O. E. (2010). The Impact of Urbanization on Housing Development: The Lagos Experience, Nigeria. *Ethiopian Journal of Environmental Studies and Management, 3,* 64-74. https://doi.org/10.4314/ejesm.v3i3.63967

APHA (2012). *Standard Methods for Examination of Water and Waste-Water* (22nd ed.). American Public Health Association.

Athamena, A., & Menani, M. R. (2018). Nitrogen Flux and Hydrochemical Characteristics of the Calcareous Aquifer of the Zana Plain, Northeast of Algeria. *Arabian Journal of Geosciences, 11,* 356. https://doi.org/10.1007/s12517-018-3681-5

Bos, R., Alves, D., Latorre, C., Macleod, N., Payen, G., Roaf, G., & Rouse, M. (2016). *Manual on the Human Rights to Safe Drinking Water and Sanitation for Practitioners* (120 p.). IWA Publishing.

Colorado Department of Public Health and Environment—Water Quality Control Division Engineering Section (2010). *Drinking Water Sanitary Surveys Background & Preparation Checklist*.

Cotruvo, J. (2017). 2017 WHO Guidelines for Drinking Water Quality: First Addendum to the Fourth Edition. *Journal—American Water Works Association, 109,* 44-51. https://doi.org/10.5942/jawwa.2017.109.0087

De Roos, A. J., Ward, M. H., Lynch, C. F., & Cantor, K. P. (2003). Nitrate in Public Water Supplies and Risk of Colon and Rectum Cancers. *Epidemiology, 14,* 640-649. https://doi.org/10.1097/01.ede.0000091605.01334.d3

Dhania, G., & Rani, K. (2014). Impact of Urbanization on Ground Water Pollution—An Emerging Problem. *Journal of International Academic Research for Multidisciplinary, 2,* 123-133.

Dragon, K. (2008). The Influence of Anthropogenic Contamination on the Groundwater Chemistry of a Semi-Confined Aquifer (The Wielkopolska Buried Valley Aquifer, Poland). *Water Resources Management, 22,* 343-355. https://doi.org/10.1007/s11269-007-9165-0

Edet, A. E. (2000). Water Pollution by Nitrate near Some Waste Disposal Sites in Calabar (Nigeria). In *Proceedings of International Conference on Groundwater Research* (pp. 239-240). CRC Press. https://doi.org/10.1201/9781003078593-119

Ghodbane, M., Boudoukha, A., & Benaabidate, L. (2015). Hydrochemical and Statistical Characterization of Groundwater in the Chemora Area, Northeastern Algeria. *Desalination and Water Treatment, 57,* 14858-14868. https://doi.org/10.1080/19443994.2015.1067924

Giridharan, L., Venugopal, T., & Jayaprakas, M. (2008). Evaluation of the Seasonal Variation on the Geochemical Parameters and Quality Assessment of the Groundwater in the Proximity of River Cooum, Chennai, India. *Environmental Monitoring Assessment, 143,* 161-178. https://doi.org/10.1007/s10661-007-9965-y

Guezgouz, N., Boutoutaou, D., Zeggane, H., & Chefrour, A. (2017). Multivariate Statistical Analysis of the Groundwater Flow in Shallow Aquifers: A Case of the Basins of Northern Algeria. *Arabian Journal of Geosciences, 10,* Article No. 336. https://doi.org/10.1007/s12517-017-3079-9

Güler, C., Thyne, G. D., McCray, J., & Turner, A. (2002). Evaluation of Graphical and Multivariate Statistical Methods for Classification of Water Chemistry Data. *Hydrogeology Journal, 10,* 455-474. https://doi.org/10.1007/s10040-002-0196-6

International Association of Hydrogeologists (2020). *Groundwater—More about the Hidden Resource.* https://iah.org/education/general-public/groundwater-hidden-resource

Johnson, R. C., Boni, G., Barogui, Y., Sopoh, G. E., Houndonougbo, M., Anagonou, E., Agossadou, D., Diez, G., & Boko, M. (2015). Assessment of Water, Sanitation, and Hygiene Practices and Associated Factors in a Buruli Ulcer Endemic District in Benin (West Africa). *BMC Public Health, 15,* Article No. 801. https://doi.org/10.1186/s12889-015-2154-y

Knobeloch, L., Salna, B., Hogan, A., Postle, J., & Anderson, H. (2000). Blue Babies and Nitrate-Contaminated Well Water. *Environmental Health Perspectives, 108,* 675-678. https://doi.org/10.1289/ehp.00108675

Kuddus, M. A., Tynan, E., & Mcbryde, E. (2020). Urbanization: A Problem for the Rich and the Poor? *Public Health Reviews, 41,* Article No. 1. https://doi.org/10.1186/s40985-019-0116-0

Lü, X., Han, Z., Li, H., Zheng, Y., & Liu, J. (2022). Influence of Urbanization on Groundwater Chemistry at Lanzhou Valley Basin in China. *Minerals, 12,* 385. https://doi.org/10.3390/min12030385

McLay, C. D. A., Dragten, R., Sparling, G., & Selvarajah, N. (2001). Predicting Groundwater Nitrate Concentrations in a Region of Mixed Agricultural Land Use: A Comparison of Three Approaches. *Environmental Pollution, 115,* 191-204. https://doi.org/10.1016/S0269-7491(01)00111-7

McMichael, A. J. (2000). The Urban Environment and Health in a World of Increasing Globalization: Issues for Developing Countries. *Bulletin of the World Health Organization, 78,* 1117-1126.

Moore, M., Gould, P., & Keary, B. S. (2003). Global Urbanization and Impact on Health. *The International Journal of Hygiene and Environmental Health, 206,* 269-278. https://doi.org/10.1078/1438-4639-00223

National Population Commission (2006). *1963, 1991, and 2006 Census of Each Local Government Area of Ekiti State*. National Population Commission, Ekiti State Chapter.

NSDWQ (2007). *Nigerian Standard for Drinking Water* (pp. 13-14). Nigerian Industrial Standard, NIS: 554.

Obeidat, M. M., Awawdeh, M., Al-Rub, F. A., & Al-Ajlouni, A. (2012). An Innovative Nitrate Pollution Index and Multivariate Statistical Investigations of Groundwater Chemical Quality of Umm Rijam Aquifer (B4), North Yarmouk River Basin, Jordan. In K. Voudouris, & D. Voutsa (Eds.), *Water Quality Monitoring and Assessment* (pp. 169-188). IntechOpen.

Odeloui, D., Celle-Jeanton, H., Huneau, F., Boukari, M., Alassane, A., Garel, E., Lavastre, V., & Bertrand, G. (2016). *Groundwater Contamination in Relation with the Increasing Urbanization Rate in Africa. Case of Cotonou and Porto Novo (Benin)*. EGU General Assembly Conference Abstracts. eid EPSC2016-9070.p EPSC2016-9070. https://ui.adsabs.harvard.edu/abs/2016EGUGA..18.9070O/abstract

Oyeleye, O. I. (2013). Challenges of Urbanization and Urban Growth in Nigeria. *American Journal of Sustainable Cities and Society, 2,* 79-96.

Priya, K., & Arulraj, G. P. (2011). A Correlation-Regression Model for the Physicochemical Parameters of the Groundwater in Coimbatore City, India. *Environmental Technology, 32,* 731-738. https://doi.org/10.1080/09593330.2010.510852

Proksch, E. (2018). pH in Nature, Humans and Skin. *The Journal of Dermatology, 45,* 1044-1052. https://doi.org/10.1111/1346-8138.14489

Prüss, A., Kay, D., Fewtrell, L., & Bartram, J. (2002). Estimating the Burden of Disease from Water, Sanitation and Hygiene at a Global Level. *Environmental Health Perspectives, 110,* 537-542. https://doi.org/10.1289/ehp.02110537

Raghunath, I. I. M. (1987). *Groundwater* (2nd ed., pp. 344-369). Wiley Eastern Ltd.

Rajmohan, N., & Elango, L. (2005). Nutrient Chemistry of Groundwater in an Intensively Irrigated Region of Southern India. *Environmental Geology, 47,* 820-830. https://doi.org/10.1007/s00254-004-1212-z

Samra, S. C. J., & Fawzi, S. C. M. (2011). The Right to Water in Rural Punjab: Assessing Equitable Access to Water through the Punjab Rural Water Supply and Sanitation Project. *Health and Human Rights, 13,* 36-49.

Sehlaoui, H., Hassikou, R., Dakak, H. Zouahri, A., El Hasini, S., Iaaich, H., Ghanimi, A., & Douaik, A. (2022). Nitrate Contamination and Associated Health Risks of the Benslimane Groundwater, Morocco. *Environmental Geochemistry and Health*. https://doi.org/10.1007/s10653-021-01186-5

Setyaningsih, S. (2012). Using Cluster Analysis Study to Examine the Successful Performance Entrepreneur in Indonesia. *Procedia Economics and Finance, 4,* 286-298. https://doi.org/10.1016/S2212-5671(12)00343-7

Spalding, R. F., & Exner, M. E. (1993). Occurrence of Nitrate in Groundwater—A Review. *Journal of Environmental Quality, 22,* 392-402. https://doi.org/10.2134/jeq1993.00472425002200030002x

Talabi, A. O. (2022). Sanitary Survey of Wells in Ekiti State, Southwestern Nigeria: Implications on Groundwater Quality. *International Journal of Environment, Ecology, Family and Urban Studies (IJEEFUS), 12,* 41-50.

Umar, R., Muqtada, M., Khan, A., & Absar, A. (2006). Groundwater Hydrochemistry of a Sugarcane Cultivation Belt in Parts of Muzaffarnagar District, Uttar Pradesh, India. *Environmental Geology, 49,* 999-1008. https://doi.org/10.1007/s00254-005-0138-4

United Nations Committee on Economic, Social and Cultural Rights (2002). *General Com-*

*ment No. 15 on the Right to Water*. UNCESCR.

USEPA (2019). *How to Conduct a Sanitary Survey of Drinking Water Systems*. Office of Water (4606M), EPA 816-R-17-001.

Ward, M. H., Jones, R. R., Brender, J. D., de Kok, T. M., Weyer, P. J., Nolan, B. T., Villanueva, C. M., & van Breda, S. G. (2018). Drinking Water Nitrate and Human Health: An Updated Review. *International Journal of Environmental Research and Public Health, 15,* 1557. https://doi.org/10.3390/ijerph15071557

WHO (2004). *Guidelines for Drinking Water Quality: Training Pack.* WHO.

WHO World Health Organization (1997). *Guidelines for Drinking Water Quality* (Vol. 2). World Health Organization.

WHO World Health Organization (WI 10) (2000). *Health Systems: Improving Performance*. World I Lea/Th Report, WHO.

WHO World Health Organization (WI 10) (2010). *Water Supply, Sanitation, and Hygiene Development.* http://www.pubmed.ncbi.nlm.nih.gov/