Original Research

Groundwater Quality of Shallow Wells on Nigerian Poultry Farms

Peter Adeoye Aderemi[1]*, Hasfalina Che Man[1], Mohd Amin Mohd Soom[1], Thamer Ahmad Mohammed[2], Akinbile Christopher Oluwakunmi[3]

[1]Department of Biological and Agricultural Engineering, University Putra, Darul Ehsan, Selangor, Malaysia
[2]Department of Civil Engineering, University Putra, Darul Ehsan, Selangor, Malaysia
[3]Department of Agricultural and Environmental Engineering,
Federal University of Technology, Akure, Nigeria

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Abstract

In the present study, an assessment of water quality from 20 randomly selected shallow wells inside poultry farms in Minna, north-central Nigeria, was carried out in order to establish the effects of a poultry waste dump located close to the wells by determining some physico-chemical and microbiological parameters of the groundwater samples. Samples of water were collected from the shallow wells between November 2011 and January 2013, and analyzed for physical, chemical, and bacteriological parameters. Sampling was carried out during the dry and wet seasons to find out if the water quality changes with the season. Analysis of variance was used to analyze the results and the means obtained were compared with the New Duncan Multiple Range Test. The results of the bacteriological parameters showed that the water quality is very poor; highly contaminated with faecal matter. Only 15% of the water samples satisfy the WHO guideline of 0 cfu/100 ml in dry season but reduced to 5% in the wet season. For total coliform, 10% satisfy the WHO guideline value in the dry season but none of the wells sampled was totally coliform-free in the wet season. About 25% were free from faecal streptococci during the dry season, but only 5% was free from these bacteria in the wet season. Statistics ($p > 0.05$) shows significant difference between coliform values in the wet and dry seasons. Generally the wells are polluted with coliforms, which may have migrated from poultry waste dumps into the wells. The difference in physical parameter values was also statistically ($p>0.05$) significant between seasons, with 55% of the water samples satisfying WHO 5NTU turbidity value in the dry season but the reducing to 30% in the wet season. Lower values were recorded for TDS and EC in the wet season than in the dry season. For chemical tests, 50% of the water met up with WHO 50 mg/L nitrate guideline in the dry season and were reduced to 35% in the wet season. Statistics ($p>0.05$) show no significant difference in the phosphate values for wet and dry seasons. It is clear from these results that water from the shallow wells is more contaminated in the wet season than the dry season.

Keywords: contamination, pathogens, poultry waste, shallow aquifer, waterborne diseases

Introduction

Anthropogenic pollution of groundwater in recent times has become a common occurrence because of the increased quest to satisfy the food needs of an ever-increasing world population. This has led to massive agricultural production in the area of crop cultivation as well as animal production. Many arable lands are cultivated annually and the rate at which poultry farms, dairy farms, abattoirs, and other small and medium-scale agro-allied industries are coming up is

*e-mail: pheterhardey@yahoo.com

alarming [1]. This development, though commendable, brings with it the generation of a huge amount of solid and liquid wastes that the farmer has to contend with and manage properly in order to prevent surface water, groundwater, and the air environment from pollution [2]. These farms dispose of generated waste to an available limited area of land and this has led to the application to land of manure quantities far in excess of crop requirements because the agronomical requirements of the crops are not considered. The underutilized nutrients that are most often nitrates, phosphates and pathogens will then be left and allowed to pollute surface and groundwater environments [3].

Provision of safe drinking water is needed as a tool in poverty alleviation since potable water supply prevents the spread of waterborne diseases. Primary sources of water were streams and rivers, rainfall, tap water, and groundwater [4]. Adekunle et al. [5] reported that among these available sources, groundwater happens to be the most reliable source because of its relative abundance and its unpolluted nature as a result of restricted movement of pollutants in the soil profile. Potable water is the one that is free from pathogens and low in compounds that are toxic to human health. It should be clear, not saline, and free from color, odour and taste [6]. Groundwater will possess all these attributes if the top surface from where the aquifer recharge is taking place is protected from both natural and anthropogenic pollution. This will be achieved if the soil stratum is not too permeable, the water table is deep down, and the aquifer bedrock is not polluted by lateral contaminant transfer from other sites [7]. Pollution of an aquifer is indeed a function of many factors because as water percolates through the soil to recharge groundwater, harmful physical, chemical, and biological contaminants travel with it, rendering the water below unfit for consumption. Therefore, susceptibility or vulnerability of an aquifer is determined by such factors as contaminants, soil, and aquifer properties [8, 9]. This is because the anthropogenically influenced vadose zone has limited contaminant attenuation capacity, thereby rendering groundwater beneath to quality deterioration whenever recharge takes place [10].

Among the agricultural activities coming up as a result of world population increase, the poultry industry remains the fastest growing [11]. This may be attributed to increased demand for egg products and poultry meat because of the latter's low cholesterol content. However, like any other farm activities, the poultry industry is faced with the problem of large-scale generation of waste [11]. The waste from poultry farms is highly organic in nature, and has a strong ability to cause air, surface, and groundwater pollution if not properly managed and effectively disposed of. Components of poultry waste include bedding materials, feathers, manure, split feed, dead birds, and dietary supplements. It was reported by [12] that the composition of the waste varies from farm to farm depending on handling, stock density, ventilation, and storage operation. In Nigeria, like any developing nation, there is a rapid expansion of small- and medium-scale poultry farms with the attendant effect of huge waste generation. The magnitude of this generated poultry waste has given rise to improper disposal, which includes over-application to land and improper timing of application, thereby creating pollution problems in soil, water, and air environments [13]. Modern management methods for poultry waste like re-feeding to animals, green disposal, gasification, and biogas production have not gained prominence in Nigeria probably due to level of awareness, lack of strict government regulation in respect to poultry waste disposal, and the care-free attitude of the farm owners. It is still a common site in Nigeria to see huge deposits of poultry waste around a farm. Flushing the waste into water courses through open canals from farms also is a common site [14]. These method are not only unsightly, they also create groundwater pollution. The variables at the dump site that control contaminant mobility in the hydrosphere are soil and hydrogeological conditions, climate and land use. It was submitted by [7] that different soil and hydrogeological conditions will give rise to different vulnerabilities and give different degrees of protection to the underlying aquifer. It is also important to note the depth to the water table while assessing vulnerability.

Minna, a town in north-central Nigeria is not an exception to the revolution of poultry farms emergence and poor poultry waste management systems. The management pattern in Minna is characterized by a low level of specialization. Most of the huge amount of poultry waste produced in Minna was either applied excessively to agricultural land or flushed into water courses, thereby creating serious pollution of eutrophication and oxygen depletion for aquatic animals. Some percentage of the waste is burnt while the remainder is buried inside soil without any prior treatment. This process is known to be capable of causing groundwater pollution by nitrates, phosphates, heavy metal, and pathogenic organisms [15].

Groundwater is the major source of potable water in Minna, probably because other sources are not readily available coupled with the fact that groundwater could be abstracted and consumed without expensive treatment. Minna is continually growing in population due to its proximity to Federal Capital and this has resulted in an increase in the establishment of poultry farms and also increase in water consumption demand. This has led to persistent water shortage in the city and the suburbs. To meet this shortfall, shallow groundwater is constructed as a supplementary water source and is tapped at shallow depth through hand dug holes due to ease of construction and relatively low cost. Shekwolo and Brisbe [16] has shown that 50.8% of people living in Minna rely on shallow hand-dug wells, 23.3% on boreholes, 16.3% tap, 3.5% river, and 6% springs.

The main sources of water for the poultry farms in Minna are boreholes and shallow wells. It is important to know the quality of this water that the farmers and other people living nearby use for drinking and domestic activities because the majority of these open wells are located close to the poultry waste dump sites. Up to the present there has been little information about the quality of groundwater inside the farms. Improper well construction, poor maintenance of the well, and proximity to contamination sources have been reported by [17] as factors that enhance contamination of well water, putting family health at risk of waterborne diseases.

Different cases of waterborne diseases have been reported in Minna over the years. Nine years of waterborne disease records have been reported by [18], which concluded that the majority of people affected by these diseases are people living in the suburbs and close to areas where there are intensive farming activities like dairy, slaughter houses and poultry activities. The rampant cases of waterborne diseases may be a result of animal waste dumps located close to their sources of water. It was also reported from the research that the occurrence of diseases peaked in July-August, when recharge is highest and therefore the pollution of the wells can be linked to human activities happening on the surface.

While assessing the contamination effect of poultry waste, especially in the groundwater environment, the major contaminants of concern are nitrates, phosphates, microbiological parameters, and heavy metals [7]. Nitrates are derived from the organic nature of the contaminants and it is very soluble and mobile in the subsurface environment, thereby giving it a strong capacity to migrate into groundwater. Nitrates and ammonium are two forms of organic nitrogen in soil; nitrate ion is freely mobile in the soil solution and therefore potentially vulnerable to leaching below the rooting zone as water moves through the soil. Consumption of water containing nitrates at levels higher than 49 $mgNO^{3-}/l$ can lead to methaemoglobinemia, or blue baby syndrome in infants, and in the long term may be potentially carcinogenic for human beings [8]. Bacteriological parameters, especially faecal and total coliform, are pollutants because of their heavy presence in poultry slurry. They are persistent in the subsoil because of their small surface area and difficult to attenuate unless the soil is impermeable with low effective porosity. Faecal coliforms are important parameters to consider when assessing the suitability of a water source for drinking because the presence of coliform usually indicates contamination by mammals and bird waste and signifies the possible presence of pathogenic bacteria and viruses that are responsible for water-related diseases, [19]. Though phosphates are immobile in the subsurface, researchers have reported their potential to pollute groundwater if the aquifer is shallow and the overlying soil is permeable [17], a typical case that is common in Minna. Heavy metals are added as additives to poultry waste to improve a bird's performance. For instance, arsenic is introduced into animal feed in the form of arsenic-based drugs like nitarzone and rosarzone to increase weight gain and improve feed efficiency of the bird, while copper is added to give the bird a strong immunity against coccidiosis. However, as a result of their carcinogenic tendency, especially if consumed by humans, most countries, including Nigeria, have instructed farmers to stop using them as additives, in poultry feeds and advised the farmers to look for other efficient additives, but with low polluting power and low human health risk. Therefore, their presence in the Minna aquifer may not necessarily be linked to poultry waste dumps, but may come from other agrochemical use.

Sources of groundwater contamination in Minna and all north central Nigeria are not known. Researchers [19-21] have tried to correlate the outbreak to groundwater consumption but they focused more on borehole and surface water within town with a complete neglect of shallow wells in the town and inside the poultry farms. This research was therefore conducted to assess the physical, chemical, and microbiological parameters of groundwater from shallow wells in select poultry farms in Minna, Nigeria. The research is also aimed at assessing the variation in these parameters of water between seasons.

Study Location

The study area for this work is Minna, the capital of Niger State, a semi-arid town in north-central Nigeria (Fig. 1). The city lies at latitude 90º36' 50''N and longitude 60º33'25''. Minna has two local Governments: Chanchaga, which has its headquarters in Minna, and Bosso with headquarters in Maikunkele, a peri-urban slum in Minna. The population of Minna as of 2012 was 613,246 [22]. The Chinchaga River is the major river in Minna, which drains into the Kaduna River at about 45 km on the northwestern

Fig. 1. Map of Nigeria's Niger State, showing Minna.

side. The geology of Minna belongs to basement complex rock of Precambrian in age, though some of them are found in the early Paleozoic. The rock has been grouped into four lithological units by [16] as gneiss-quartzite complex, schist belts, granitoids, and metamorphosed basic rocks. Aquifers in Minna are either confined or semi-confined or unconfined. The unconfined aquifer has generally a shallow water table of about 20 meters depth in some places. Though perched conditions in some places, the Minna aquifer is recharged through rainfall. Minimum temperature in Minna is between 19ºC and 22ºC, while maximum ranges between 38ºC and 40ºC. Precipitation separates the town into two major seasons: wet (May to October) and dry (November to April). Average annual precipitation is 1,300 mm, with highest rainfall in August. Average daily sunshine is 9.2 hours and evapotranspiration ranges from about 25 mm in august and 90 mm in March. Annual groundwater recharge in Minna is about 17% of total annual precipitation [23].

Data Collection Technique

There are 43 large scale and 74 medium and small scale poultry farms in Minna (Ministry of Agriculture and rural development, Niger State). For this study, 20 registered poultry farms were randomly selected in the two local governments (Fig. 2). Physical conditions of the shallow wells inside the poultry farms such as diameter, depth, lining, headwall height, and distance of waste dump site to the shallow wells inside the farms were evaluated and water samples were collected from the wells for analysis.

Pre-sampling activities include pumping stagnant water out with a centrifugal pump for 90 seconds and allowing the well to recharge for about 15 minutes [5]. A sterilized sampling bottle capped with a metal bob was then used to take the water samples; it was inserted into the well to a water depth of about 0.3 m before the bob was removed. This was done to make sure the sample taken is representative of water from the shallow aquifers [6]. Physical parameters of the water samples were determined on-site; temperature and pH were determined using an Ohaus S2000 bench pH/temperature meter while the total dissolved solid (TDS), electrical conductivity (EC), and turbidity were determined with a Jenway M470 portable conductivity/TDS meter. Other samples for chemical and bacteriological analysis were stored under ice pack to maintain a temperature of 4ºC and transported to the laboratory. For chemical analysis, the reagent bottles used were rinsed with distilled water and then with the water samples. Phosphate and nitrates were determined with a Hach DR 4000 colorimeter using PhosVer 3 and PhosVer 5 as dilution chemical for phosphates and phosphorus pentoxide (P_2O_5) respectively, while NitraVer 3 and NitraVer 5 diluting chemicals were used to determine nitrite and nitrate respectively. Tne membrane filtration technique was used for bacteriological analysis. This was done by filtering 100 ml of the sample through 0.45 µ Millipore membrane filter and using a vacuum pump. After one hour recovery period, the membrane was inoculated on Membrane Lauryl Tryptose Broth (Difco, Detroit, Michigan, USA) and incubated at 37ºC for 24 hours for faecal coliform (FC), and at 45ºC for 24 hours for total coliform (TC). Colonies that were enumerated as faecal coliform were blue while colonies with green metallic sheen were counted and recorded as total coliform. Faecal streptococci (FS) were isolated and enumerated by growth on membrane enterococcus agar (Slanetz and Barltey Agar Oxoid Ltd). The filters were placed on the agar and pre-incubated at ambient temperature (25ºC) for four hours to resuscitate the bacteria. The plates were then incubated at 45ºC for 44 hours. All red, maroon and pink colonies were counted and recorded as faecal streptococci. Sterile condition was obtained in the laboratory environment using

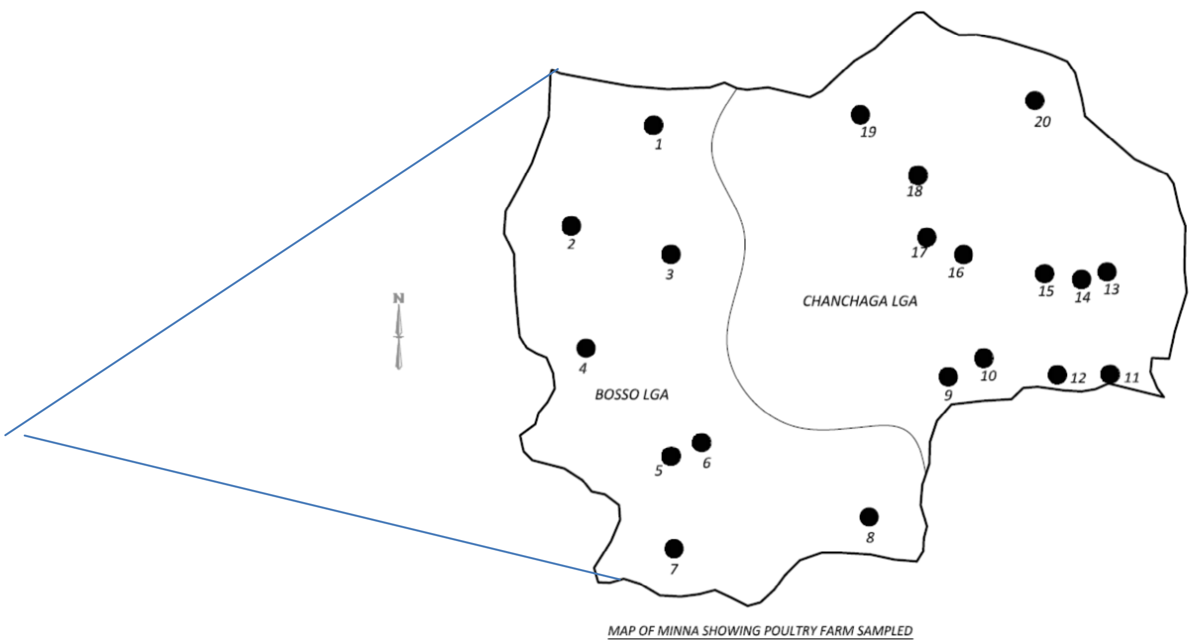

Fig. 2. Map of Nigeria showing Minna and map of Minna showing poultry farms visited.

Table 1. Properties of the well samples.

Name of well	Depth to bottom (m)	Depth to water (m)		Diameter (m)	Distance from dump (m)	Age (yrs)	Lining	Cover	Headwall height (m)	Approx. population served
		Dry season	Wet season							
Abu Turab	8.2	6.8	3.4	1.0	8.0	5	No	Steel	0.8	218
Al-Amin	5.2	4.4	2.1	0.94	3.3	5	No	wood	No	120
Bache	7.8	4.4	0.9	0.84	4.9	5	Stone	wood	No	100
El-kareem	6.1	4.7	1.5	0.92	4.9	6	Stone	Steel	0.74	315
FUT Minna	7.3	5.2	3.1	0.96	7.1	14	Concrete	No	0.78	220
I K	7.8	4.6	2.4	1.1	4.3	6	No	Steel	0.42	90
Jamilla ville	10.0	6.0	2.6	1.0	11.6	13	Concrete	Steel	0.81	85
Jamil	7.0	2.4	0.6	1.0	30	3	Concrete	Steel	0.94	40
Joe	5.4	3.6	2.8	1	4.6	7	No	No	No	270
Jumik	7.3	6.2	0.9	0.94	6.8	4	Concrete	Steel	1.2	58
Jumra	6.1	3.5	1.4	0.9	6.0	5	Concrete	steel	0.67	170
Limawa	5.2	3.1	0.6	1.0	5.6	2.5	No	Wood	0.51	100
Na Adama	7.0	4.0	1.9	1.0	5.6	6	No	No	0.26	270
Nabil	6.1	5.1	1.6	0.98	3.6	6	No	Wood	0.53	160
Nanas	5.6	3.1	2.0	1.0	3.2	10	No	wood	No	144
Natti	7.4	3.8	1.5	1.0	4.1	10	No	wood	0.56	80
Niger	6.5	2.9	0.9	0.9	3.3	10	Concrete	Steel	1.0	60
Sarkin akin	9.4	6.6	1.3	1.0	18.2	3	No	Wood	0.71	150
Mil	3.4	1.5	0.6	0.8	8	3	Precast	Steel	0.68	140
Abdullahi	7.8	3.5	1.0	1.0	9.0	7	No	Wood	0.81	240

flaming technique. The table top and the entire equipment surface were cleaned with 70% methanol [24] during bacterial isolation to reduce the risk of external contamination. The results were compared with guidelines of the World Health Organization, [29] the National Agency for Food and Drug Administration and Control, [30] and the Nigerian Standard for Drinking Water Quality [31]. Tests were carried out in triplicate to minimize experimental error. The mean, standard deviation, and test for significance were determined analysis of variance and new Duncan multiple range test.

Results and Discussions

The results of the physical conditions of the wells are presented in Table 1. It was evident from the table that well construction details are poor. The majority of the wells are unlined, uncovered, and with no headwall. This may give rise to lateral movement of the contaminants from different sources into the well. A minimum distance of 30 m has been recommended [24] in Kenya as lateral distance between a well and any polluting source. However, from the table, there were some wells that were located as close as 3.3 m from the poultry waste dump site. Only one well, Jamil, was located 30 m from the polluting source. From the questionnaire administered in the poultry farms, 45% of the well users use the water for drinking, domestic purposes, and to take care of birds, 30% use it for domestic purposes only but fetch their drinking water from boreholes located within the farms, and only 25% reserved the water for bird use only. Among the users, 63% of the respondents do not treat the water before use while 20% treat the water by the addition of aluminium sulphate (alum), which only aids coagulation after the water has been fetched. Only 17% chlorinate their wells every two months, but the dosage of chlorine being added could not be ascertained by the users.

Microbiological Parameters

Microbiological water quality standard values set by WHO, NAFDAC, and NSDWQ presented in Table 2 were used to compare the microbiological parameter values obtained for the wells inside the poultry farms as presented in Table 3. Water samples from the Sarkin-Yakin well yields water that meets WHO guideline for total coliform (0.00

Table 2. Standard bacteriological drinking water values.

Parameters / Standards	Faecal coliform (cfu/100 ml)	Total coliform (cfu/100 ml)	Faecal streptococci (cfu/100 ml)
WHO, (2010)	0	0	0
NAFDAC, (2010)	10	10	10
NSDWQ, (2010)	5	5	5

cfu/100 ml), but have some traces of contamination of 2.56 and 1.33 cfu/100 ml for total coliform and faecal streptococci, respectively. Water from Jamilla Ville well was also free of these pathogenic organisms except for total coliform during the dry season. The Jamil well yielded water of superior quality during the dry season, but with some level of contamination (3.96 cfu/100 ml for FC, 5.66 cfu/100 ml for TC, and 1.81 cfu/100 ml for FS) in the wet season. The relatively better quality of water from these three wells may be attributed to their surrounding and construction details. They are located far from the poultry waste dump site at 18.2, 11.6, and 30 m, respectively. The three wells are deeper, lined, and covered, thereby preventing entry of contaminated water through runoff. However, because there was higher recharge during the wet season, there may be lateral influx of contaminated water from the aquifer into the wells since the soil is permeable and the water level is higher during the wet season. Water samples from the remaining wells do not meet up with WHO guideline values though a few of them satisfy NAFDAC and NSDWQ, especially during the dry season when the wells were deeper. Contamination by coliforms indicates the presence of mammal and bird faeces in the water and also the possible presence of pathogens and viruses that cause water-related diseases like typhoid, cholera, dysentery, and diarrhea.

Physical Parameters

The physical parameter standard values set by WHO, NAFDAC, and NSDWQ are presented in Table 4, and physical parameter values obtained for the water samples

Table 3. Bacteriological properties of the water samples.

Farms	Faecal coliform (cfu/100 ml)		Total coliform (cfu/100 ml)		Faecal streptococci (cfu/100 ml)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Abdulahi	16.0^{a}±2.0	27.4^{b}±1.5	20.33^{a}±1.53	35.82^{b}±1.72	6.33^{a}±1.53	12.31^{b}±1.76
Abu Turab	0.67^{a}±0.5h	10.46^{b}±0.70	0.97^{a}±0.95	16.12^{b}±2.59	1.00^{a}±1.0	2.60^{a}±0.19
Al-Amin	191.67^{a}±3.9	336.2^{b}±9.12	465.7^{a}±49.2	673.8^{b}± 58.2	114.0^{a}±3.6	211.37^{b}±5.8
Bache	158.7^{a}±3.51	246.95^{b}±14.2	177.67^{a}±4.51	312.69^{b}± 1.72	190.67^{a}±9.87	220.9^{b}±3.8
El-Kareem	0.67^{a}±1.15	4.76^{b}±0.74	2.0^{a}±0.44	18.25^{b}±0.84	0.00^{a}± 0.00	2.81^{b}±0.56
Fut, Minna	18.33^{a}±2.51	65.04^{b}±13.29	34.0^{a}±3.61	121.9^{b}±19.7	9.67^{a}±2.08	24.45^{b}±3.08
IK	36.68^{a}±3.2	348.67^{b}±15.9	71.79^{a}±1.81^{a}	408.0^{b}±5.57	10.33^{a}±1.69	16.85^{a}±1.42
Jamil	0.00^{a}±0.0	3.96^{b}±2.43	0.00^{a}±0.0	5.66^{b}±0.79	0.00^{a}±0.0	1.81^{b}±6.44
Jamilla-Ville	0.00±0.00	0.00±0.00	0.00^{a}±0.00	0.33^{b}±0.58	0.00±0.00	0.00±0.00
Joe	73.33^{a}±0.66	151.44^{b}±31.8	96.67^{a}±5.51	242.76^{b}±9.9	23.67^{a}±2.5	36.20^{b}±3.6
Jumik	0.33^{a}±0.58	95.74^{b}±2.5	0.00^{a}±0.00	55.77^{b}±3.74	0.67^{a}±0.58	18.07^{b}±9.31
Jumra	103.0^{a}±15.5	332.58^{b}±7.8	132.33^{a}±3.1	442.6^{b}±2.8	53.33^{a}±3.0	82.75^{b}±4.8
Limawa	65.33^{a}±5.1	107.0^{b}±2.7	96.67^{a}±2.18	415.5^{b}±6.21	19.67^{a}±3.6	69.53^{b}±7.8
MIL	0.67^{a}±0.08	174.81^{b}±2.61	1.67^{a}±0.38	92.56^{b}± 0.49	1.33^{a}±0.31	43.15^{b}±3.84
Na-Adama	91.33^{a}±9.07	234.74^{b}±9.45	116.0^{a}±5.29	349.76^{b}±11.7	27.0^{a}±8.19	84.81^{b}±4.17
Nabil	113.0^{a}± 9.64	351.73^{b}±6.58	320.33^{a}± 16.1^{a}	744.78^{b}± 22.6	80.67^{a}±9.45	97. 46^{b}±3.8^{a}
Nanas	85.67^{a}±4.93	168.36^{b}±9.81	43.33^{a}±1.02	87.32^{b}±7.87	19.0^{a}±7.0	44.53^{b}±7.62
Natti	64.33^{a}±4.51	155.48^{b}±31.7	125.0^{a}±7.94	437.95^{b}±27.4	82.67^{a}±3.6	107.53^{b}±5.6
Ng. State	1.33^{a}±1.15	4.87^{a}±2.32	0.33^{a}±0.08	8.84^{b}±0.43	0.00^{a}±0.0	2.57^{b}±2.27
Sarki Yakin	0.00±0.00	0.00±0.00	0.67^{a}±1.15	2.56^{b}±3.78	0.00^{a}±0.00	1.33^{b}±0.15

*Values are means of triplicate reading ±standard deviation.
Values on the same column for same parameter with different superscript are significantly different ($P \leq 0.05$), while those with the same superscript are not significantly different ($P \geq 0.05$) as assessed by Duncan's Multiple Range Test.

Table 4. Standards physical drinking water values.

Standards \ Parameters	pH	Turbidity (NTU)	Electrical conductivity (us/cm)	Total dissolved solids (mg/L)
WHO, (2010)	6.5-8.5	5	*	1000
NAFDAC, (2010)	6.5-8.5	10	1500	1200
NSDWQ, (2010)	6.5-8.5	5	1200	1200

*No guideline value set

Table 5. Physical properties of the water samples.

Farms	pH		Turbidity (NTU)		Electrical conductivity (μs/cm)		Total dissolved solids (mg/L)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Abdulahi	8.17^{a}±0.2	7.54^{a}±0.4	0.67^{a}±0.06	1.50^{b}±0.1	15.23^{a}±1.5	11.71^{a}±0.49	61.67^{a}±0.55	52.1^{a}±1.31
Abu Turab	6.93^{a}±0.8	6.77^{a}±0.3	0.73^{a}±0.16	1.39^{b}±0.19	13.37^{a}±0.6	10.64^{a}±0.84	60.37^{a}±5.0	60.63^{a}±0.7
Al- Amin	6.63^{a}±0.15	6.34^{a}±0.2	3.90^{a}±0.5	28.8^{b}±4.70	565.2^{a}±31.3	416.33^{b}±9.9	2129.9^{a}±28.7	1720.3^{b}±32.5
Bache	8.2^{a}±0.6	8.76^{a}±0.12	14.5^{a}±7.2	48.15^{b}±0.5	856.41^{a}±29.6	533.67^{b}±17.1	1549.2^{a}±13.2	1219.3^{b}±16.2
El-Kareem	6.63^{a}±0.23	7.10^{a}±0.3	2.83^{a}±0.7	19.64^{b}±1.5	196.53^{a}±6.3	5.45.60^{b}±2.9	245.24^{a}±4.23	26.53^{b}±2.45
Fut, Minna	6.97^{a}±0.21	7.07^{a}±0.15	13.03^{a}±4.9	56.61^{b}±2.2	748.11^{a}±13.6	313.07^{b}±6.73	1197.8^{a}±27.3	987.0^{a}±3.61
IK	7.43^{a}±0.42	7.18^{a}±0.34	17.7^{a}±5.6	68.50^{b}±1.0	748.98^{a}±3.4	65.9^{b}± 2.49	145. 99^{a}±9.6	64.7^{b}±29.4
Jamil	7.4^{a}±0.95	6.77^{a}±0.15	0.98^{a}±0.31	3.94^{b}±0.32	21.88^{a}±0.64	14.47^{b}±0.50	55.78^{a}±3.27	27.3^{b}±0.95
Jamilla-Ville	6.83^{a}±0.7	7.07^{a}±0.36	0.65^{b}±0.18	1.12^{a}±0.1	15.42^{a}±2.5	10.2^{a}±1.6	22.12^{a} ±1.8	21.67^{a}±0.71
Joe	6.8^{a}±0.1	7.34^{a}±0.32	24.6^{a}±1.9	52.53^{b}± 5.4	826.9^{a}±16.5	577.93^{b}±4.6	2046.2^{a}±12.3	1645.5^{b}±8.6
Jumik	7.27^{a}±0.3	7.52^{a}±0.17	0.79^{a}±0.08	61.44^{b}±6.5	304.74^{a}±5.9	118.33^{b}±8.1	1615.0^{a}±5.5	232.6^{b}±8.41
Jumra	6.03^{a}±0.1	6.77^{a}±0.3	29.9^{a}±5.6	57.27^{b}±9.8	371.5^{a}±13.1	293.3^{b}±37.4	1393.8^{a}±25.2	1027.4^{b}±6.5
Limawa	5.63^{a}±0.25	6.55^{b}±0.3	14.2^{a}±2.6	24.43^{b}±4.2	471.0^{a}±27.9	35.37^{a}±3.6	553.0^{a}±12.8	104.63^{b}±3.4
MIL	6.83^{a}±0.4	6.78^{a}±0.14	1.32^{a}±0.74	24.47^{b}±0.5	309.9^{a}±8.03	25.53^{b}±5.0	1099.2^{a}±11.6	428.47^{b}±5.08
Na-Adama	7.23^{a}±0.15	7.27^{a}±0.25	22.7^{a}±2.5	67.64^{a}±9.4	751.51^{a}±32.7	431.6^{b}±12.5	1903.8^{a}±50.6	1669.7^{b}±6.79
Nabil	7.23^{a}±0.4	7.48^{a}±0.25	4.49^{a}±1.1	11.9^{b}±1.6	506.82^{a}±8.5	326.7^{b}±10.0	1148.4^{a}±21.7	936.40^{b}±18.7
Nanas	8.8^{a}±0.26	7.59^{a}±0.32	17.17^{a}±0.3	43.44^{b}±6.6	640.87^{a}±9.8	404.67^{b}±5.94	1636.9^{a}±8.11	1142.0^{b}±7.7
Natti	5.6^{a}±0.27	5.51^{a}±0.16	25.63^{a}±2.7	45.37^{b}±1.8	776.2^{a}±15.9	15.17^{b}±0.93	929.12^{a}±3.69	73.98^{b}±8.46
Ng. State	7.2^{a}±0.36	6.58^{a}±0.12	0.69^{a}±0.2	3.82^{b}±0.72	204.29^{a}±9.35	134.07^{b}±6.9	752.0^{a}±12.8	615.8^{b}±4.7
Sarki Yakin	6.81^{a}±0.46	6.78^{a}±0.14	0.27^{a}±0.05	4.34^{b}±0.10	29.49^{a}±2.69	14.6^{b}±1.61	54.04^{a}±3.31	21.27^{b}±1.04

*Values are means of triplicate reading ±standard deviation.
Values on the same column for same parameter with different superscript are significantly different ($P \leq 0.05$), while those with the same superscript are not significantly different ($P \geq 0.05$) as assessed by Duncan's Multiple Range Test.

from tested shallow wells are presented in Table 5. From Tables 4 and 5, the physical parameters of the water samples meet pH standards for WHO, NAFDAC, and NSDWQ during both dry and wet seasons. However, though 55% of the wells satisfy WHO turbidity value during the dry season, only 30% satisfy the standard during the wet season. The same result was obtained by [1] and [25], who concluded that rainfall raised the turbidity levels in well during the wet season by transporting colloidal particles into the wells. High turbidity in water inhibits treatment; therefore, the addition of chlorine to the well as being done in some farms may be of no effect. A factor that may be responsible for high coliform presence in both the wells treated and the untreated wells as high turbidity in the water could shield the bacteria from the effect of added chlorine [20, 24]. All the water samples also satisfy guidelins for electrical conductivity, though there are marked differences between wet and dry season values which is confirmed by the statistical significance difference at 95% ($p>0.05$) confidence value shown in Table 4. The lower EC value recorded in wet season may be a result of dilution by higher recharge. 50% of the well water sample failed to meet the standard for total

Table 6. Standard chemical drinking water values.

Standards \ Parameters	PO_4^{3-} (mg/L)	NO_3^- (Mg/L)	NO_3-N (Mg/L)	NH_4-N (Mg/L)	NO_2^- (Mg/L)
WHO, (2010)	2.2	50	10	1.5	3.0
NAFDAC, (2010)	5.0	45	10	*	*
NSDWQ, (2010)	2.5	45	10	*	*

*No guideline value set

Table 7. Chemical properties of the water samples.

Farms	PO_4^{3-} (mg/L)		NO_3^- (Mg/L)		NO_3-N (Mg/L)		NH_4-N (Mg/L)		NO_2^- (Mg/L)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Abdulahi	$0.49^{a}\pm0.1$	$0.48^{a}\pm24$	$20.4^{ab}\pm1.7$	$18.7^{ab}\pm 0.6$	$4.6^{ac}\pm1.6$	$4.23^{ac}\pm0.4$	$0.3^{ad}\pm0.09$	$0.34^{ad}\pm0.1$	$0.05^{bc}\pm0.0$	$0.06^{bc}\pm0.08$
Abu Turab	$0.05^{a}\pm0.0$	$0.65^{a}\pm0.2$	$5.59^{ab}\pm0.6$	$5.62^{ab}\pm1.0$	$1.26^{ac}\pm0.6$	$1.27^{ac}\pm1.3$	$0.01^{ad}\pm0.0$	$0.02^{ad}\pm0.0$	$0.03^{bc}\pm 0.1$	$0.05^{bc}\pm0.02$
Al-Amin	$0.58^{a}\pm0.2$	$1.27^{b}\pm0.4$	$98.3^{a}\pm1.4$	$112.7^{b}\pm3.5$	$22.9^{ab}\pm2.4$	$25.4^{ab}\pm3.1$	$1.75^{bc}\pm0.2$	$1.3^{bc}\pm0.13$	$0.14^{a}\pm0.9$	$2.80^{b}\pm0.48$
Bache	$0.6^{a}\pm0.0$	$2.48^{b}\pm0.2$	$99.9^{a}\pm2.7$	$142.9^{b}\pm4.8$	$22.55^{a}\pm2.1$	$32.6^{b}\pm6.1$	$0.94^{a}\pm0.1$	$1.56^{b}\pm0.3$	$1.50^{a}\pm0.64$	$5.93^{b}\pm0.18$
El-Kareem	$0.07^{a}\pm0.3$	$1.33^{b}\pm0.8$	$129.3^{a}\pm2.8$	$182.6^{b}\pm7.3$	$29.19^{a}\pm4.5$	$41.22^{b}\pm2.4$	$6.5^{c}\pm 0.47$	$8.68^{c}\pm0.39$	$1.14^{d}\pm0.2$	$1.37^{d}\pm2.62$
Fut, Minna	$1.5^{a}\pm0.9$	$0.63^{b}\pm0.3$	$39.7^{a}\pm3.5$	$62.8^{b}\pm1.8$	$8.96^{a}\pm1.2$	$14.18^{b}\pm0.7$	$4.52^{a}\pm1.3$	$9.2^{b}\pm2.38$	$1.63^{a}\pm 0.7$	$2.49^{b}\pm0.07$
IK	$6.57^{a}\pm0.3$	$11.8^{b}\pm0.5$	$126.7^{a}\pm1.5$	$153.7^{b}\pm6.1$	$28.6^{ab}\pm3.1$	$34.7^{ab}\pm1.2$	$6.54^{ac}\pm0.8$	$7.4^{ac}\pm0.17$	$0.17^{ad}\pm0.03$	$0.24^{ad}\pm0.02$
Jamil	$0.02^{a}\pm0.2$	$0.68^{b}\pm0.4$	$1.89^{a}\pm0.6$	$14.6^{b}\pm0.8$	$0.43^{a}\pm0.0$	$3.30^{b}\pm0.6$	$0.38^{a}\pm0.1$	$1.25^{b}\pm0.34$	$0.93^{a}\pm0.07$	$1.77^{b}\pm0.19$
Jamilla-Ville	$0.02^{a}\pm0.1$	$3.0^{b}\pm1.7$	$8.31^{a}\pm4.7^{a}$	$26.8^{b}\pm3.4$	$1.88^{a}\pm0.03$	$5.89^{b}\pm0.6$	$0.78^{a}\pm0.1$	$2.42^{b}\pm0.4$	$1.23^{a}\pm0.01$	$3.28^{b}\pm0.44$
Joe	$3.33^{a}\pm0.7$	$29.9^{b}\pm1.7$	$2.72^{a}\pm0.4$	$232.5^{b}\pm6.1$	$0.61^{a}\pm0.21$	$52.48^{b}\pm1.4$	$0.34^{a}\pm0.05$	$23.4^{b}\pm0.95$	$1.78^{a}\pm0.17$	$4.70^{b}\pm0.3$
Jumik	$1.87^{a}\pm0.9$	$6.88^{b}\pm0.7$	$9.9^{a}\pm2.7$	$52.8^{b}\pm2.3$	$2.23^{a}\pm0.34$	$11.92^{b}\pm0.8$	$0.62^{a}\pm0.2$	$1.29^{b}\pm0.09$	$1.40^{a}\pm0.08$	$4.79^{b}\pm0.28$
Jumra	$1.46^{a}\pm0.5$	$4.67^{b}\pm 0.6$	$15.3^{a}\pm2.9$	$23.9^{b}\pm4.1$	$3.5^{bc}\pm0.16$	$5.4^{bc}\pm1.3$	$5.58^{bd}\pm0.3$	$5.9^{bd}\pm0.29$	$1.35^{de}\pm0.1$	$3.52^{de}\pm0.39$
Limawa	$2.68^{a}\pm0.9$	$5.13^{a}\pm2.3$	$80. 3^{b}\pm3.6$	$144.5^{c}\pm1.8$	$18.61^{a}\pm4.3$	$32.62^{b}\pm3.6$	$4.26^{c}\pm0.3$	$2.82^{c}\pm3.34$	$1.55^{a}\pm1.81$	$4.96^{b}\pm0.89$
MIL	$0.29^{a}\pm0.3$	$0.41^{a}\pm0.4$	$20. 8^{b}\pm0.6$	$86.3^{c}\pm4.9$	$4.69^{a}\pm2.54$	$19.48^{d}\pm2.5$	$1.45^{a}\pm0.5$	$0.76^{b}\pm0.19$	$0.65^{d}\pm0.03$	$0.62^{d}\pm0.09$
Na-Adama	$12.6^{a}\pm3.3$	$24.7^{b}\pm1.4$	$153.1^{c}\pm3.5$	$235.0^{d}\pm9.7$	$34.56^{e}\pm1.9$	$53.05^{f}\pm1.4$	$0.59^{g}\pm0.3$	$1.74^{h}\pm1.0$	$0.59^{i}\pm0.60$	$1.40^{k}\pm0.84$
Nabil	$2.66^{a}\pm0.6$	$20.6^{b}\pm3.8$	$66.3^{ab}\pm3.5$	$147.8^{bc}\pm2$	$14.9^{a}\pm1.7$	$33.36^{b}\pm3.2$	$0.69^{c}\pm0.5$	$3.13^{d}\pm0.65$	$2.21^{e}\pm0.39$	$8.42^{f}\pm0.6$
Nanas	$4.25^{a}\pm0.6$	$6.37^{a}\pm2.4$	$111.2^{b}\pm4.6$	$181.5^{c}\pm1.4$	$25.1^{a}\pm2.45$	$40.97^{b}\pm3.4$	$0.69^{a}\pm0.07$	$3.49^{b}\pm0.24$	$0.6^{a}\pm0.15$	$1.34^{b}\pm0.86$
Natti	$4.88^{a}\pm1.9$	$3.14^{a}\pm0.4$	$124.4^{a}\pm6.1$	$170.6^{b}\pm3.8$	$28.1^{a}\pm1.76$	$38.51^{b}\pm1.7$	$3.45^{a}\pm0.43$	$0.68^{b}\pm0.47$	$1.07^{a}\pm0.94$	$2.79^{b}\pm0.72$
Ng. State	$6.72^{a}\pm1.8$	$6.05^{a}\pm0.75$	$18.2^{b}\pm2.8$	$27.1^{b}\pm1.6$	$4.11^{c}\pm0.37$	$6.12^{c}\pm0.5$	$0.58^{a}\pm0.1$	$1.31^{b}\pm0.06$	$0.17^{a}\pm1.26$	$2.54^{b}\pm1.01$
Sarki Yakin	$0.30^{a}\pm0.4$	$1.35^{b}\pm0.4$	$1.27^{c}\pm0.4$	$1.72^{c}\pm1.1$	$0.29^{d}\pm0.0$	$0.39^{d}\pm0.02$	$0.46^{a}\pm0.5$	$0.01^{b}\pm0.01$	$0.01^{a}\pm0.01$	$0.07^{a}\pm0.02$

*Values are means of triplicate reading ±standard deviation.
Values on the same column for same parameter with different superscript are significantly different ($P\leq0.05$), while those with the same superscript are not significantly different ($P\geq0.05$) as assessed by Duncan's Multiple Range Test.

dissolved solid during the dry season, but probably as a result of the dilution effect on this pollutant when the water level in the well is higher, the values increased to 80%. This may confirm the surface water-groundwater interaction suspected by [26], who concluded that the influx of surface water into the well during and immediately after rainfall may be responsible for this scenario, considering the fact that some of the wells are not lined, covered, and the head wall, if exist, are not high enough to prevent surface flow into the wells. High total dissolved solids (TDS) in the water may make it unpalatable. It may also lead the water user to opt for better water sources, if any. However, in Minna, during the dry season when the TDS is high, streams and springs dry up, leaving the user no alternative but to make do with the shallow well water.

Chemical Parameters

The maximum value for chemical water quality recommended by WHO, NAFDAC, and NSDWQ were as presented in Table 6. The result for chemical analysis of the water sample is presented in Table 7.

Parameters of health concern with respect to poultry waste dump are organic nitrogen, phosphates, and heavy metals. Researchers have sampled shallow wells in north-central Nigeria and have reported no case of heavy metals in shallow aquifers [20, 19]. Phosphate presence in water has more effect on surface water than groundwater because of eutrophication and algae bloom. However, [17] reported that phosphates in groundwater aid microbial growth. Oenema et al. [3] also reported that even phosphates as low as 15 μg/L in groundwater increased microbial growth in water significantly. From Table 7, 70% of the water samples satisfy WHO guideline value for phosphorus, but the value is reduced to 45% in wet season. There was also no significant difference ($p>0.05$) between wet and dry season phosphate values. This result agreed with [5, 4, 9] in Igboora, Lagos, and Okemesi, respectively – all in southwestern Nigeria. Though from poultry waste characterization, 1 g of poultry waste is reported to contain 65% of phosphorus, its low detention in shallow aquifer may be attributed to phosphorus' low mobility in the subsurface and the high sorption affinity phosphorus has toward soil particles, especially if the soil grain size is big [12]. The health effect implication of nitrates of any form in water has been associated with blue baby diseases in infants and colon cancer risk in adults [21]. Results in Table 7 showed that 50% of the water samples have nitrogen value less than WHO guideline in the dry season, but the value was reduced to 35% in the wet season. Statistical analysis ($p>0.05$) showed a significant difference between dry and wet season phosphate values. This agreed with the findings of [27, 28, 21] that attributed the seasonal changes in nitrogen values to high solubility of nitrates in water and its relatively higher mobility in the subsurface, especially if the vadose zone of the aquifer is of low attenuation capacity.

Seasonal Variations in the Parameter Values

There was a noticeable increase in the number of coliform counts in the wet season when compared with the dry season. Fig. 3 showed variation in total coliform values in dry and wet seasons for all the wells sampled. The observed variation may be attributed to the fact that contaminants were freely transported by moving water to wells, and there happen to be higher recharge during the wet season, which makes the static water level in the well rise (Table 1). Therefore, a high coliform count could be caused by lateral movement of pollutants, [9] including pollution sources (poultry waste dump) located close to the wells. The wells are shallow, giving low attenuation tendency to the overlying soil of the aquifer and thereby making the groundwater vulnerable to anthropogenic pollution.

From Fig. 3, seven wells (Abdulahi, Abu-Turab, Jamil, Jamilla Ville, Ng. State, and El-Kareem) have low bacteriological contaminant values, which may be due to better siting and construction details from Table 3. All the seven wells except El-kareem are very deep with high headwall, they are lined and covered and also located relatively far from the poultry waste dump sites. Therefore, it is possible to have water of zero microbiological value in Minna's shallow aquifer if the wells are properly sited, probably at a safe distance of 30 m, [24] and are constructed in such a way that the surroundings of the wells are hygienic.

Conclusions

Our study has shown that shallow wells within Minna poultry farms yield water of poor quality. Less than 50% of the water samples from the wells met the lowest drinking water guidelines of WHO, as more than 90% of the wells assessed failed to meet zero coliform count standards of the WHO, NAFDAC, and NSDWQ values. Water samples were of inferior quality in the wet season but six out of the twenty wells have better water quality, especially during the dry season. Phosphate values did not show much noticeable change within seasons, and their values met maximum contaminants level (MCL) values for WHO in about 55% of the wells. Electrical conductivity (EC) and TDS values

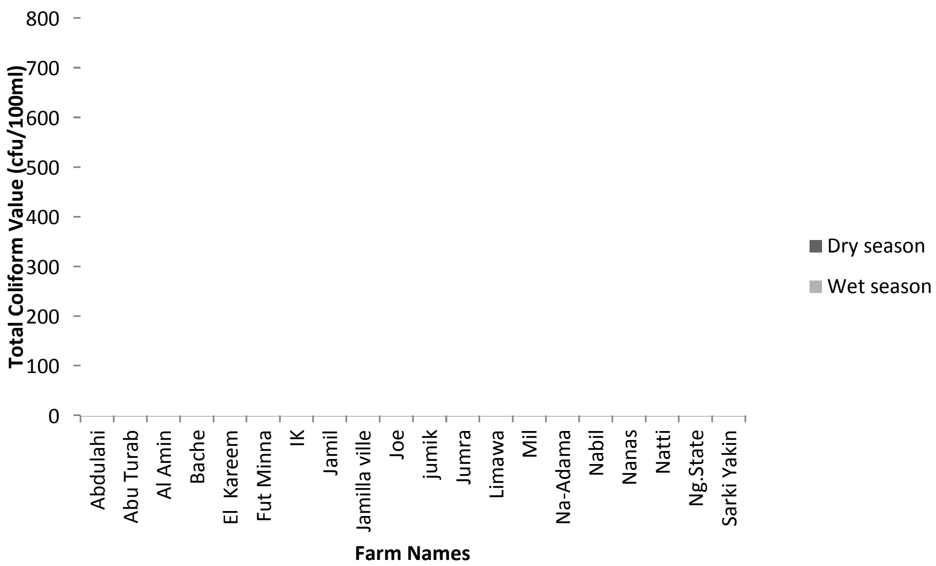

Fig. 3. Seasonal variation in total coliform values.

were significantly higher in dry season than in wet season. The results also have shown that covering the wells and lining them did not prevent contamination, and the water samples in the wells have potential fatal consequence if consumed by humans without treatment. It was observed that the location of the wells with respect to the poultry waste dump site plays a big role in contamination.

A local affordable treatment method to purify the water from these wells would be required to prevent people using this water from the danger associated with waterborne diseases. The method of water extraction from the shallow wells through bucket and rope is also unhygienic and may contribute to pollution. Replacing them with small pumping machines can guarantee better quality water from the wells. It was observed from the study that disinfecting the wells with chlorine was not only unaffordable and unsustainable, but offers low and temporary treatment ability. Therefore, there is urgent need to develop cost-effective technologies to treat groundwater from Minna poultry farms and the entire city. Government should not neglect the people living inside these farms in terms of provision of potable water because the farmers and their workers contribute their own quota to national gross domestic product (GDP).

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References

1. KULABAKO N.R., NALUBEGA M., THUNVIK R. Study of the impact of land use and hydrogeological settings on the shallow groundwater quality in a peri – urban area of Kampala, Uganda. Sci. Total Environ., **381**, 180, **2007**.
2. FABIANA C. PARISE M. Waste management and problem of groundwater pollution in Karst environment in the context of a post-conflict scenario: the case of Mostar (Bosnia Herzegovina). Habitat Int., **33**, 63, **2009**.
3. OOENEMA O., LIEVE L.V., SCHOUMAN O. Effect of lowering nitrogen and phosphorus surpluses in agriculture on the quality of groundwater and surface water in the Netherlands. J. Hydrol., **304**, 289, **2005**.
4. ADEJUWON J.O., MBUK C.J. Biological and physiological properties of shallow wells in Ikorodu town, Lagos, Nigeria. J. Geol. and Mining Res. **3**, (6), 161, **2011**.
5. ADEKUNLE I.M., ADETUNJI M.T., GBADEBO A.M., BANJOKO O.B. Assessment of groundwater quality in a typical rural settlement in Southwest Nigeria. Int. J.Env. Res. and Public Health, **4**, (4), 307, **2007**.
6. PRITCHARD M., NKANDAWIRE T., O'NEILL J.G. Assessment of groundwater quality in shallow wells within the southern districts of Malawi. Phys. Chem. Earth, **33**, 812, **2008**.
7. LERNER D.N., HARRIS. The relationship between land use and groundwater resources and quality. Land Use Policy, **26s**, S265, **2009**.
8. NKANDAWIRE T. Quality of groundwater from shallow wells of selected villages in Blantyre district, Malawi. Phys. Chem. Earth, **33**, 807, **2008**.
9. AYODELE S.O. Groundwater quality appraisal of some hand dug – well and boreholes around Okemesi and Ikoro area, Southwestern Nigeria. Global Journal of Science Frontier Research. **12**, (2), 17, **2012**.
10. LOCAS A., BARTHE C., MARGOLIN B.A., PAYMENT P. Groundwater microbiological quality in Canadian water municipal wells. Can. J. Microbiol., **54**, 472, **2008**.
11. TIQUIA M.S., TAM F.Y. Characterization and composting of poultry litter in forced aeration piles. Process Biochem., **37**, 869, **2002**.
12. BOLAN N.S., SZGOZY A.A., CHUASAVATHI T., SESHADRI M.J., ROTHROCK J.R., PANNEERSELVAM P. Uses and management of poultry litter. World. Poultry Sci. J., **66**, 673, **2010**.
13. ADEOYE G.O., SHRIDAR M.K.C., MOHAMMED O.E. Poultry waste management for crop production: Nigerian experience. Waste Manage. Res. **22**, 165, **2004**.
14. OJOLO S.J., OKE S.A., ANIMASAHUN K., ADESUYI B.K. Utilization of poultry, cow and kitchen wastes for biogas production: A comparative analysis. Ir. J. Env. Health Sci. Eng. **4**, (4), 223, **2007**.
15. MOREKI J.C., CHIRIPASI S.C. Poultry waste in Botswana: A review. J. Anim. Feed Res., **1**, (6), 285, **2011**.
16. SHEKWOLO P.D., BRISBE M.O. Bacteriological properties of groundwater in parts of Niger State, Nigeria. J. Env. Hydrology, **7**, 1, **1999**.
17. QUAN J., WANG L., ZHAN H., CHEN Z. Urban land use effects on groundwater phosphate distribution in a shallow aquifer, Nanfei river basin, China. Hydrogeol. J., DOI: 10. 1007/S10040-001-0770-X. **2011**.
18. CHUKWU P., EJIEJI C.Y., ALONGE F.S. Appraisal of prevalence of water-borne and water-based diseases in selected cities of north central Nigeria. Nig. J. Tech. Dev., **8**, (2), 209, **2004**.
19. ISIKUWE M.O., LORVER D., ONOJA S.B. Effect of depth on microbial pollution of shallow wells in Makurdi metropolis, Benue state, Nigeria. British J. Env. and Climate Change, **1**, (3), 66, **2011**.
20. AKAAHAN T.J., HYACINTH O.A., RUFUS S. Physico – chemical and bacteriological quality of water from shallow wells in two communities in Benue State, Nigeria. Pak. J. Anal. Env. Chem., **11**, (1), 73, **2010**.
21. TAIWO A.M., ADEOGUN A.O., OLATUNDE K.A., ADEGBITE K.I. Analysis of groundwater quality of hand – dug wells in peri – urban area of Obantoko, Abeokuta, Nigeria for selected physico-chemical parameters. Pacific J. Sci. and Tech., **12**, (1), 527 , **2011**.
22. NPC. Nigeria Population Commission annual reports. Ministry of Internal Affairs, Nigeria. **2012**.
23. EDOGA R. N., SUZZY A.B.U. Effect of Temperature changes on Evapotranspiration in Minna, Niger State. J. Eng. Appl. Sci. **3**, (6), 482, **2008**.
24. ABILA R., MUTHANGYA M., MUTUKU E., MUTATI K., MUNGUTI M., MUSYOKA M.C. Physico-chemical and bacteriological quality assessment of shallow wells in Kitui town, Kenya. J. Env. Sci. and Water Res. **1**, (2), 27, **2012**.
25. PRITCHARD M., NKANDAWIRE T., O'NEILL J.G. Biological, chemical and physical drinking water quality from shallow wells in Malawi: Case study of Blantyre, Chiradzulu and Mulanje. Phys. Chem. Earth, **32**, 1167, **2007**.

26. SWISTOCK R.B., SHARPE E.W. The influence of well construction on bacterial contamination of private wells in Pennsylvanian. J. Environ. Health, **68**, (2), 17, **2005**.
27. CARBO L.I., FLORES M.C., HERRERO M.A. Well site conditions associated with nitrate contamination in a multi-layer semi confined aquifer of Buenos Aires, Argentina. J. Env. Geol. **57**, 1489, **2009**.
28. DONGOL B.S., MERZ J., SCHAFFNER M., NAKARMI G., SHAH B.P., SHRESTHA K.S., DHAKAL P.M. Shallow groundwater in a middle mountain catchment of Nepal: quantity and quality issues. J. Env. Geol. **49**, 219, **2005**.
29. WORLD HEALTH ORGANIZATION, WHO Guidelines for drinking water quality. First addendum to Third Edition, **1**, **2010**.
30. NAFDAC National Food and Drug Administration and Control Technical Bulletin. Nigerian Ministry of Health, Abuja: pp. 17-38, **2010**
31. NSDWQ. Nigerian Standards for Drinking Water Quality. Water Guidelines, Ministry of Environments, Abuja. pp. 18-76, **2010**.