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IMPACT OF URBAN LAND USE ON RAINWATER QUALITY: CASE STUDY IN ILORIN METROPOLIS, NIGERIA

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Abstract

In Ilorin being one of the fastest growing urban centres in Nigeria, the physical transformation in land use and population density have effects on the rainwater quality. Therefore, we aimed to analyse the relationship between physical and chemical properties of rainwater and urban land uses. A total of 15 rainwater samples were collected after two major rainfall events with an average duration of 20 minutes during the rainy season and analysed for 15 physical and chemical parameters namely: colour, conductivity, pH, total dissolved solids, turbidity, aluminium (Al^{3+}), copper (Cu^{2+}), iron (Fe^{2+}), nitrate (NO^{3-}), lead (Pb^{2+}), nickel (Ni), sodium (Na^{+}), phosphorus (K^{+}), zinc (Zn^{2+}) and sulphate ($SO_4{}^{2-}$). Their mean, standard deviation, coefficient of variation, Pearson correlation coefficient were used to interpret the results. The land use types in the area were agricultural, commercial, industrial, institutional and residential. The result revealed that the urban land uses and rainwater quality has a significant relationship in Ilorin Metropolis. Agricultural, industrial and institutional land uses had the least significant effect on the quality of rainwater with the significant value ($P<0.05$) of 0.044, 0.035 and 0.014 respectively. In contrary, under residential land use the rainwater had poor quality (significant value: 0.724), while under commercial land use the rainwater had fairly good quality (0.585; $P>0.05$). The study concluded that the urban land uses has an impact on the rainwater quality. The study recommends that rainwater should be purified before drinking, and sustainable urbanization policies should be developed to prevent atmospheric pollution in Ilorin Metropolis.

Keywords: physical and chemical properties, rainwater, rainwater quality, urban land use

INTRODUCTION

Rainfall is a major component of the water cycle and it is responsible for the replenishment of the freshwater supply on the Earth. The amount of rainfall varies with time and space (Atedhor et al., 2019), therefore the rainfall situation of a place can be described by its intensity, duration and frequency. One of the problems posed by climate change is quantification, identification and ascertainment of rainfall and its implications on anthropogenic activities in order to assist in the development of measures of adaptation through relevant strategies for water resources management (De Luis et al., 2000). Rainfall is referred as the most important meteorological parameter that has the greatest impact on human activity. The principal characteristics of rainfall are its amount and frequency. Rainfall amount is expressed as the rate of rainfall in millimetres per hour, while its frequency is expressed as the number of times it occurred in a given area, and it is expressed in days per year (Okonkwo and Mbajiorgu, 2010).

Rainwater can dissolve impurities from the air and cause contamination (e.g. heavy metals). Heavy metals are majorly found in geological structures and minerals of the earth. In most cases, their concentrations in rainwater are within acceptable limits; yet, elevated levels of zinc and lead have sometimes been reported (Atedhor et al., 2019).

On the other hand, rainwater is often used as drinking water, especially in dry areas. The chemistry of drinking water commonly has been cited as an important factor in many diseases. These diseases are apparently related to contaminated drinking water by heavy metals. This could result from leaching from metallic roofs and storage tanks, or from atmospheric pollution (Milovanovic, 2007). As reported by several researchers, rainwater can contain significant amount of pollutants such as heavy metals, nutrients and pathogens, as a result of various anthropogenic activities resulting from the actual land use type (Gromaire-Mertz et al., 1999; Lye, 2002; Zhu et al., 2004; Evans et al., 2006; Yufen et al., 2008). Thus, in determining the end use and the potential success of potable use of rainwater in the study area, the possible problems associated with its quality need to be assessed.

The interference of some elements with rainwater leads to changes in the properties of the collected rainwater (or drinking water). Normally, the drinking contains magnesium, nitrate, calcium, manganese, sulphate, iron and gases such as carbon dioxide, oxygen and nitrogen. Some of these elements are beneficial at certain levels (e.g., fluoride and chloride), while others, such as the heavy metals (e.g., lead, nickel, and arsenic) are toxic. These pollutants are in form of polycyclic aromatic hydrocarbons, sulphates, nitrates and dioxins, at diverse quantities (Amodio et al., 2014). Gaseous or solid pollutants move up in the atmosphere, they dislocate and affect the quality of air; these condense in the clouds and then in the form of rainfall they return to the surface (Dami et al., 2012).

With the increase in urban population, the land-use related challenges have also increase. Most cities in Sub-Saharan Africa are being affected by increasing waste disposal and pollution problems, as a result of urban rapidly increasing population, widespread poverty, inadequate and weak local governance and limited financial resources (Simmons et al., 2001). Ilorin City, in Nigeria, displays similar problems, especially because the city has expanded in size, and new types of various land uses (e.g. industrial, agricultural, institutional etc) appeared. Its most worrisome effect is indiscriminate solid waste dumping: the waste is carried by surface overflow and contaminates water resources. Besides, the rapid growth of real estate development, winning/mining of sand and wood collection within catchment areas of water bodies are also problematic in the city.

Ilorin Metropolis is one of the fastest rising urban centres in Nigeria, and there has been a huge increase in the population since it became the state capital in 1976. Therefore, in 2022 the population of the Metropolis was 1 million (UN, 2022). The population growth rate of 2.67% is much higher than in other cities (national growth: 2.5%). The increase in population is a result of high natural growth rate and migration from rural to urban areas. These have caused in the emergence of new land use types within the state, that results in uncontrolled management and planning (Agaja et al., 2020).

Rapid population growth drives other urban systems, such as pollution accumulation, urbanization and increased knowledge leading to increase in poor housing and sanitary conditions, and generation of waste. The physical transformation in land use and high population density are characteristic of Ilorin, and as an emerging urban centre it effects the water quality of the city. This is monitored by the Institute of Water Resources (IWR, 1997) as cited by Fashae et al., (2017), whose findings revealed that different land use types are characterized by enormous potential of introducing pollutants into aquatic and atmospheric ecosystems, largely due to the diversity of human activities.

Urban land is characterised by areas of intensive use, where much of the land covered by artificial structures (Ibrahim et al., 2014). Urban areas include cities, towns, villages; strip developments along highways, transportation routes, power and communications facilities, and areas occupied by mills, shopping centres, industrial and commercial complexes and institutions that may, in some instances, be isolated from urban areas (Anderson et al.,1976).

Rainwater quality refers to the, chemical, physical and biological characteristics of rainwater and its general composition. The quality of rainwater is a degree of the condition of rainwater relative to the requirements of one or more biotic species, and to any need of humans. It is frequently used by reference to a set of standards against which compliance can be assessed (Nwajei, 2007). Rainwater must possess the characteristics of being aesthetically wholesome, chemically tolerable and bacteriological safe before it meets up with the requirements of the World Health Organization as a potable water (Atedhor et al., 2019).

Rainwater quality is determined by the composition of rainwater as affected by natural processes and human activities. Rainwater quality depends on the constituents dissolved or contained within the rainwater. It is not possible to find completely pure rainwater in nature, since droplets of water already begin to dissolve a whole range of constituents in the atmosphere, such as airborne dust particles, gases and salt from sea spray (RAIN, 2008). In response to increasing unavailability of potable drinking water, the need to utilize rainwater as an alternative to surface water sources has increased. Despite having some promising merits over other sources, rainwater use has often been rejected as a source of potable water supply on the grounds of its water quality concerns (Meera and Ahammed, 2006).

Impacts of urban land use on rainwater quality are multifaceted, diverse and wide ranging. On its transit through the landscape, water is left bare to the properties of the terrestrial surface which is a vital determining factor for both water quantity (sufficient freshwater supply for human and natural systems support) and quality (appropriate supply for an intended use). While land is used by humans in diverse ways to improve their life quality, most usages have caused undesirable effects on the environment. According to Nuissl and Siedentop (2021), many of the environmental difficulties which countries are undergoing are resulting from the growing rapidity of change in land use; and one of the critical facts about land use changes is that the effects may be long-lasting and sometimes unalterable. This submission is in line with Nuissl and Siedentop (2021) arguing that some changes are as a result of processes that are natural, but that we now know that anthropogenic activities are accountable for many of the environmental challenges we are currently facing.

Built-up land use produces impermeable surfaces as a result of amplified development in the form of commercial and residential buildings (rooftops), driveways, highways and car parks etc.; these give increase to larger overflow, increasing the peril of canal dilapidation and other environmental consequences. Ibrahim et al. (2014) argued that overflow from impervious surfaces such as car parks, heavily trafficked motorways etc. has consequences for the water cycle, both in terms of quality and quantity. An extensive range of metallic, organic and inorganic pollutants may be detached from the road and land surfaces and occur at high concentrations in the runoff water, which is then carried into atmospheric water and water bodies.

Considering the size and environmental problems of Ilorin Metropolis in Nigeria, this study aims (1) to assess the physical and chemical properties of rainwater in the prominent urban land use types; (2) to compare the results to the World Health Organization's water quality standards; and (3) to analyse the relationship between various urban land uses and the physical and chemical properties of rainwater in the study area.

MATERIALS AND METHODS

Study Area

Ilorin is the state capital of Kwara State, which is located in North Central Nigeria (Figure 1). The settlement was founded in 1967. It is positioned north of the Equator, between the longitudes 4^{o} 20’ and 4^{o} 35’E; and latitudes 8^{o} 30’ and 8^{o} 50’N (Agaja et al., 2020). The city of Ilorin occupies an area of about 468 km2, and it is located in a transition zone between the guinea savannah and forest regions. The city is about 500 km from Abuja, the federal capital of Nigeria, in the North and 300 km away from Lagos in the South. Ilorin has three Local Government Areas, e.g. Ilorin South, Ilorin West and Ilorin East (Figure 1).

The climate in Ilorin Metropolis belongs to the tropical continental with high temperature throughout the year (Ifabiyi, 2000). Average temperature ranges between 30-35ºC. The climate of the study area is characterized by tropical dry and wet seasons for about six months. The dry season begins in November and ends early March, while the wet season starts at about the end of March and lasts till the end of October. The total average of annual rainfall in Ilorin is 1200 mm (Agaja et al., 2020).

In Ilorin Metropolis the drainage system has dendritic pattern. The most important river in the city is River Asa, which flows in a South-North direction across the city. There are a few seasonal springs in or close to the floodplain (Alao, 1982).

The general elevation of Ilorin Metropolis varies from 273 to 364 m. The Sobi Hill is an isolated inselberg with its summit at about 394 m, and it is located towards the North of the Western Part of the city. Ilorin Metropolis has a well-dissected landscape, with plateau-like surfaces shielded by laterite crust. The plateau-like surfaces are best detected at the Adewole Housing Estate facing the Sobi Hill, and at the Kwara State Polytechnic facing to South. The lowest point (240-255 m) in the area is in the Asa Valley (Alao, 1983).

There are two extensive vegetation types in Ilorin Metropolis: forest and savannah. The savannah, especially Guinea and Sudan, are the major grains, tubers, grasses, and vegetable growing regions. Vegetation contains scattered grasses and tall trees such as Parkia biglobosa, Actosonia digitata, Butryspernum parkii, acacias, etc. (Ifabiyi, 2000). Ilorin Metropolis is covered mainly by ferruginous tropical soils and crystalline acid soils. These soil types possess good potential for a large variety of crop production, thus modern farming methods are applied. The alluvial plains of river belts provide suitable conditions for arable farming for most part of the year (Iroye, 2017).

Methods

The rainwater samples were collected directly from the open sky during three major rainfall event with an average duration 20 minutes (Table 1). The sampling sites were randomly selected by purposive random sampling. Sterilized rainwater collectors were installed in open surfaces representing each urban land use types. The choices of the land uses are due to their prominence in the study area as well as the anthropogenic activities concentrated in such areas. The rainwater samplers were mounted 1.5 m above the ground to avoid rain splash. A total of 15 composite rainwater samples were collected (from 5 land use types and at 3 major rainfall events) The rainwater samples were labelled, cooled and transported immediately after collection to the University of Ilorin Biochemistry Laboratory for laboratory analysis.

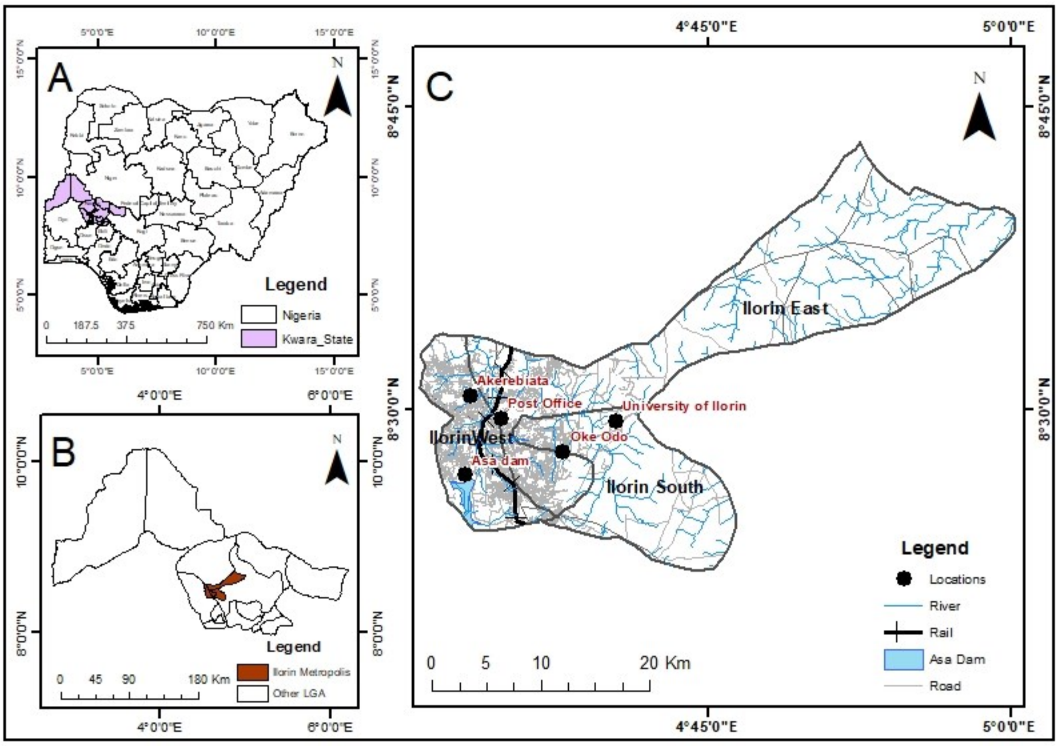

Fig. 1 Ilorin Metropolis is located in Nigeria (A) Kwara State (B). Drainage system and rainwater sampling locations within the Ilorin Metropolis (C)

Table 1 Laboratory analysis of physical and chemical water quality

S/N	PARAMETERS	LABORATORY METHODS	UNIT
1	Colour	Colorimetric	TCU
2	Electrical conductivity	Multimeter	μS/cm
3	pH	Electrometric	-
4	Total Dissolved Solids	Gravimetric	mg/l
5	Turbidity	Turbidity	NTU
6	Aluminium	AAS	mg/l
7	Copper	AAS	mg/l
8	Iron	AAS	mg/l
9	Lead	AAS	mg/l
10	Nickel	AAS	mg/l
11	Nitrate	AAS	mg/l
12	Phosphorus	AAS	mg/l
13	Sodium	AAS	mg/l
14	Sulphate	AAS	mg/l
15	Zinc	AAS	mg/l

A Global Positioning System (GPS) receiver was used to capture the geographical coordinates of the 5 sampling locations. The selected locations were in the following prominent urban land use types:

1. Agricultural – Akerebiata
2. Commercial – Post Office
3. Industrial – Asa Dam
4. Institutional – University of Ilorin
5. Residential – Oke-Odo

The analysed physical and chemical parameters in the rainwater samples, their units and the methods of their respective analysis are shown in Table 1. The physical and chemical data collected provided by the laboratory analysis were checked for quality, and computed using Microsoft Excel software and statistical package for social science (SPSS). Inferential and Descriptive statistical tools of mean, standard deviation, standard error of mean, coefficient of variation, percentage change, range, annual growth rate and Pearson correlation coefficient were used in the analysis and interpretation of the results.

RESULTS

Physicochemical Properties of Rainwater in Ilorin Metropolis

The actual physical and chemical properties of rainwater based on three times repeated measurements in Ilorin Metropolis are presented in Table 2. The average mean of pH, nickel and zinc were highest in institution land use with 9.2 mg/l, 0.061 mg/l and 0.165 mg/l respectively in the rainwater samples, while the lowest mean average in the institutional land use were conductivity, total dissolved solids and turbidity with values of 90 mg/l, 11 mg/l and 0.012 mg/l respectively. Thus all parameters fall within the World Health Organization Water Quality Standard, except for The Total Dissolved Solids (TDS) which was the highest (102 mg/l) at the commercial land use, but all values were within the World Health Organization Water Quality Standard. Although the amount of TDS was less than the World Health Organization Water Quality Standard, the impurities and particles in the rainwater could support the increase of physical and chemical parameters, if stored for a long period of time, which could lead to a majority of ill-health (Salem et al., 2000).

The high electric conductivity is because the rainwater has amassed various particles of dust, soil, carbon (IV) oxide, greenhouse gases and airborne aerosols that dissolve before deposition as a result of frequent and prolonged anthropogenic activities in the commercial land use (Dami et al., 2012). In all the land use, aluminium and colour were all the same and fall within the WHO standard.

The turbidity, aluminium, copper, lead, nickel and zinc values of the rainwater at all land uses had quite low values, often bellow the detection limit, therefore these parameters met the World Health Organization Water Quality Standard with no exception of any land use (Table 2 and Figure 2).Copper (0.21 mg/l), pH (7.2), iron (0.02 mg/l), phosphorus (0.38 mg/l), sulphate (36.4 mg/l) and zinc (0.056 mg/l) had lowest mean values in agricultural land use, and they are within the WHO standard of drinking water.

The sulphate content of the rainwater was highest on institutional land use with a mean value of 47.2 mg/l, while agricultural land use had the least mean value of 36.4 mg/l. Regarding the nitrate content of the rainwater, the values were below the World Health Organization Water Quality Standard (Table 2).

In Table 2, the mean iron content values were between 0.31 and 0.36 mg/l for institutional and industrial land uses, and they both exceeded the World Health Organization Water Quality Standard of 0.3 mg/l for iron ions. This implies that the rainwater in both institutional and industrial land uses could be detrimental to the environment and health of the consumers, as a result of the vehicles and heavy-duty trucks plying the roads and the industrial activities being carried out. This is in line with Igbinosa and Aighewi (2017), reporting that iron exceeded the maximum acceptable concentration by the World Health Organization in all the rainwater samples that were collected for their research

Relationship between urban land use types and rainwater quality in Ilorin Metropolis

The results on the relationship between urban land use types and rainwater quality in Ilorin Metropolis showed that between these parameters there was a significant relationship at P-value <0.05. Agricultural, industrial and institutional land uses had the least significant effect on the quality of rainwater with the significant value of 0.044, 0.035 and 0.014 respectively, which was less than 0.05 degree of freedom as shown in Table 3. This implies that at institutional land use the rainwater quality was better than at other urban land use types, followed by industrial and agricultural land uses. On the other hand, residential land use had very poor rainwater quality with significant value of 0.724 when compared to the other urban land use types, while commercial land use had fairly good quality with 0.585, which were both above the degree of freedom of 0.05.

This implies that institutional land use in Ilorin Metropolis contributes the least contaminants to the rainwater. This is as a result of very few anthropogenic activities being carried out within this land use type, as this contains mainly office buildings. The industrial land use in Ilorin Metropolis does not contribute so much to atmospheric pollution as it was expected, because Ilorin is not a highly industrialized urban centre, as the release of industrial contaminants into the atmosphere is not prominent. The agricultural land use in Ilorin Metropolis also does not have much effects on the rainwater quality, because many of the agricultural practices carried out within Ilorin Metropolis are not mechanized, and have very low interaction with the environment.

The commercial land use has significant effect on rainwater quality in Ilorin Metropolis, because many commercial activities are carried out within the Metropolis. The major commercial activities are located in the central business districts which include the shopping centres and markets, located along major highways and access routes to Ilorin Metropolis.

A bulk of junkyards, resorts, warehouses, banks, parking lots and driveways are located within the commercial land use type. These buildings and structures rely predominantly on the use of generators, as well as the intense use of automobiles which releases greenhouse gases and various dust particles into the atmosphere. This explains why the commercial land use contributes more to the contamination of rainwater.

Being the most prominent land use type, the residential land use has the most significant effect on rainwater in Ilorin Metropolis. The Metropolis is an emerging urban centre, that is experiencing increase in urban population growth. This has resulted in the development of high-density housing structures, which has resulted in the destruction of natural ecosystems within the area. The rapid urbanization has increased pollution, poor sanitary conditions, waste generation and deforestation. Most residential areas in Ilorin Metropolis have poor waste management, lack of access to portable drinking water, do not have adequate sewage disposal, and possess unsustainable urban structures. These, and many more have resulted in the release of contaminants into the atmosphere, which has increased the pollution of rainwater. This explains why the residential land use in Ilorin Metropolis has the poorest rainwater quality. This agrees with the result of Atedhor et al. (2019), revealing that there was a distinct variation in the physical and

Table 2 Urban land use types and measured rainwater parameters in Ilorin Metropolis

Parameters	Agricultural	Commercial	Industrial	Institutional	Residential	Mean	Standard Deviation	Max	Min	WHO standard
Colour (TCU)	Colourless	Colourless	Colourless	Colourless	Colourless	-	-	-	-	-
Conductivity (µS/cm)	160	450	130	90	360	238	157.702	450	90	750
pH	7.2	8.5	7.7	9.2	7.4	8	0.833	9.2	7.2	7.0-8.5
TDS (mg/l)	14	102	16	11	23	33.2	38.713	102	11	600
Turbidity (NTU)	0.026	0.032	0.018	0.012	0.03	0.0236	0.008	0.032	0.012	0.5
Aluminium (mg/l)	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0.001	0.2
Copper (mg/l)	0.021	0.053	0.026	0.048	0.056	0.0408	0.016	0.056	0.021	1
Iron (mg/l)	0.2	0.25	0.36	0.31	0.27	0.278	0.060	0.36	0.2	3
Lead (mg/l)	0	0	0	0	0	0	0	0	0	0.05
Nickel (mg/l)	0.02	0.012	0.01	0.061	0.022	0.025	0.020	0.061	0.01	0.1
Nitrate (mg/l)	31.6	30.9	37	31.7	28.4	31.92	3.137	37	28.4	50
Phosphorus (mg/l)	0.38	0.41	0.46	0.44	0.42	0.422	0.030	0.46	0.38	20
Sodium (mg/l)	0.58	0.49	0.32	0.33	0.37	0.418	0.113	0.58	0.32	50
Sulphate (mg/l)	36.4	41.8	49.2	42.2	44.5	42.82	4.641	49.2	36.4	250
Zinc (mg/l)	0.056	0.141	0.065	0.165	0.068	0.099	0.0502	0.165	0.056	3

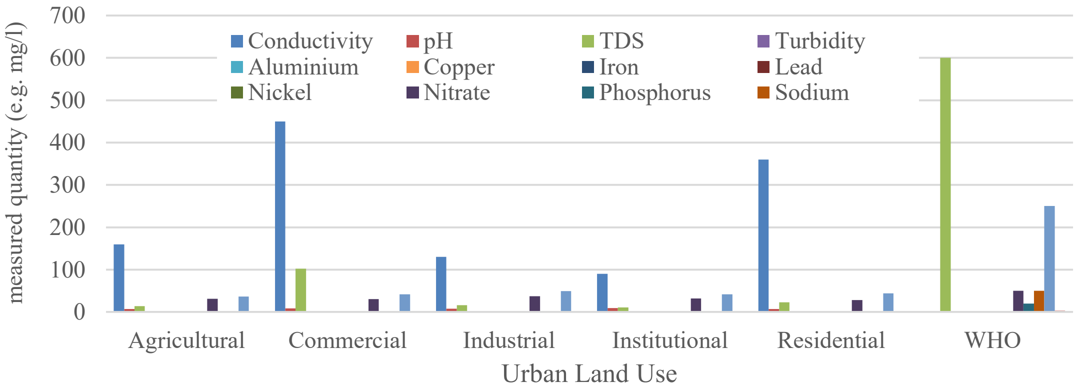

Fig. 2 Rainwater quality parameters on different urban land uses in the study area

chemical properties of rainwater among different urban land use types and locations within their study area. They also established that the variations in the rainwater quality is not only the result of the atmospheric cleansing role of rainfall, but other factors, such as wind profile and atmospheric stagnation also determines the concentration of atmospheric pollutants.

DISCUSSIONS

It is important to note, that the lesser the quantity of the physical and chemical parameters present in the rainwater, the better the quality of the rainwater. The study discovered that institutional land use has the least contaminated rainwater, followed by industrial land use, then agricultural land use, commercial land use and lastly residential land use (institutional land use has significant value of 0.014, industrial has significant value of 0.035 and agricultural land use has significant value of 0.044, which are all less than 0.05 degree of freedom). On the other hand, commercial land use has significant value of 0.585, while residential land use has significant value of 0.724, which are both greater than 0.05 degree of freedom (Igbinosa and Aighewi, 2017; Atedhor et al., 2019).

The residential area covers 52%, commercial covers 19%, institutional covers 12% while other mixed urban or built-up land covers the remaining 17% of the study area. The period between 2006 and 2020 witnessed a steady physical expansion of Ilorin. The area of Megacity increased by 17.48%, while the dense vegetation reduced by 5.73%, vegetation of farm-land reduced by 9.46%, the land use area of rock outcrop also reduced by 2.34%, and the water body have not increased neither reduced. This implies that annual growth rate of settlement in Ilorin is 126%, while the dense vegetation reduced by 41%, vegetation of farmland reduced by 68%, the land use area of rock outcrop also reduced by 17% and the water body neither increased or reduced. The growth in the settlement area, resulted in the increase of anthropogenic activities in Ilorin Metropolis, which made atmospheric pollution more prominent. This released more contaminants into the atmosphere thereby resulting in poor rainwater quality.

Table 3 Urban land use types and rainwater quality relationship in Ilorin Metropolis

		Agricultural	Commercial	Industrial	Institutional	Residential
Agricultural	Pearson Correlation	1	.971**	.987**	.968**	.989**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	14	14	14	14	14
Commercial	Pearson Correlation	.971**	1	.935**	.897**	.986**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	14	14	14	14	14
Industrial	Pearson Correlation	.987**	.935**	1	.995**	.954**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	14	14	14	14	14
Institutional	Pearson Correlation	.968**	.897**	.995**	1	.921**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	14	14	14	14	14
Residential	Pearson Correlation	.989**	.986**	.954**	.921**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	14	14	14	14	14

**. Correlation is significant at the 0.05 level

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, most tested physicochemical parameters met the World Health Organization's Water Quality Standards, with the exception of iron in the industrial and institutional land uses, where the concentrations exceeded the 3.0 mg/l limit value. The study discovered that institutional land use has the least contaminated rainwater, followed by industrial land use, then agricultural land use, commercial land use and lastly residential land use. There is a significant relationship between the prominent urban land use types of commercial, agricultural, industrial, residential, institutional land uses and rainwater quality in Ilorin Metropolis. The study recommends the full enforcement of atmospheric pollution control legislations within Ilorin Metropolis which will ensure that organizations, people, and groups that carryout activities that are causes of air pollution are reduced. Furthermore, the collection and further usage of the rainwater in the commercial areas should be recommended, as here the water has much better quality, whereas in other parts of the city, especially in the residential and business areas care should be taken when using the water for human purposes.

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