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ASSESSING RAINWATER QUALITY ACROSS URBAN LAND USES IN ILORIN METROPOLIS

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ABSTRACT

Rainwater can contain significant amounts of pollutants such as heavy metals, nutrients, and pathogens as a result of various anthropogenic activities resulting from land use types and population increase. This study assessed the rainwater quality of prominent urban land use types in Ilorin Metropolis, with the stated objectives: to determine the physicochemical properties of rainwater in the prominent urban land use types, to compare the physicochemical properties of rainwater in the prominent urban land use types with the World Health Organization water quality standards, to examine the variation in the physicochemical properties of rainwater in the prominent urban land use types, to identify the prominent urban land use types and to assess the urban land use changes between the year 2006 and 2020. A total of 5 rainwater samples was collected at selected locations within the prominent urban land use types and analysed for 15 major physicochemical parameters namely: colour, conductivity, pH, total dissolved solids, turbidity, aluminium (Al^{3+}), copper (Cu^{2+}), iron (Fe^{2+}), lead (Pb^{2+}), nickel (Ni), nitrate (NO_3^-), phosphorus (K^+), sodium (Na^+), sulphate (SO_4^{2-}) and zinc (Zn^{2+}) using the colorimetric method, multimeter method, electrometric method, gravimetric method and atomic absorption spectroscopy. The results reveal that there is a significant relationship between the prominent urban land use types of agricultural, commercial, industrial, institutional, and residential land uses and rainwater quality in Ilorin Metropolis. Agricultural, industrial, and institutional land uses have the least significant effect on the quality of rainwater with the significant value of 0.044, 0.035, and 0.014, respectively, which is less than 0.05 degree of freedom. However, residential land use has very poor rainwater quality with a significant value of 0.724, while commercial land use has fairly good quality with 0.585, which are both above the degree of freedom of 0.05. All the physicochemical parameters tested for met the World Health Organization Water Quality Standards, with the exception of iron in the industrial and institutional land uses, which both exceeded the 3.0 mg/l value. Between the year 2006 and 2020, Ilorin's settlement annual growth rate increased by 126%, on the other hand, the dense vegetation reduced by 41%, vegetation and farm land reduced by 68%, rock outcrop reduced by 17%, and the water body neither increased nor reduced. This study therefore recommends that rainwater should be purified appropriately before drinking, and effective, sustainable urbanization policies should be developed to prevent atmospheric pollution in Ilorin Metropolis.

Keywords: *Urban, Land Use, Rainwater Quality, Physicochemical Properties, Remote Sensing*

INTRODUCTION

Rapid urbanization in developing countries has significantly altered land use patterns, with consequential impacts on environmental quality and atmospheric chemistry (Seto et al., 2012). In tropical cities, accelerated population growth and infrastructural expansion have intensified anthropogenic emissions, thereby modifying atmospheric composition (Seto et al., 2012). Rainwater, once considered relatively clean, is now recognized as an effective medium for atmospheric pollutant deposition, including heavy metals, nutrients, and particulate matter through wet precipitation processes (Amodio et al., 2014; Dami et al., 2012). Consequently, rainwater quality has become a reliable indicator of urban air pollution and ecological health in rapidly urbanizing environments (Amodio et al., 2014).

Advances in remote sensing and Geographic Information Systems (GIS) have enhanced the monitoring of land use and land cover (LULC) dynamics and their environmental implications across spatial and temporal scales (Wulder et al., 2018; Gorelick et al., 2017). The integration of geospatial techniques with environmental assessment enables robust analysis of urban expansion and quantification of relationships between LULC changes and environmental indicators such as rainwater quality (Wulder et al., 2018).

Ilorin Metropolis, north-central Nigeria, exemplifies rapid urban growth characterized by the conversion of vegetation and agricultural land into built-up areas, leading to increased pollutant emissions. However, limited studies have integrated geospatial and physicochemical approaches to examine the relationship between land use patterns and rainwater quality. This study addresses this gap by assessing the influence of urban land use on rainwater quality alongside LULC change analysis using satellite imagery and GIS, thereby enhancing understanding of urbanization, atmospheric processes, and sustainability in tropical cities.

STUDY AREA

The study was conducted in Ilorin Metropolis, the capital city of Kwara State, Nigeria. Ilorin is located in the transitional zone between the forest and savannah regions of Nigeria and lies approximately between latitude 8°24′N and 8°36′N and longitude 4°10′E and 4°36′E. The metropolis serves as a major administrative, commercial, and educational hub in north-central Nigeria and has experienced rapid urban expansion over the past three decades (Ibrahim et al., 2014; Oyebanji, 2000).

Ilorin Metropolis comprises three major Local Government Areas (LGAs): Ilorin West, Ilorin East, and Ilorin South. The city has witnessed significant population growth, increasing from about 532,088 in 1991 to over 847,582 in 2006, with projections exceeding 1.2 million in recent years (Ibrahim et al., 2014). The city has witnessed significant population growth, increasing from about 532,088 in 1991 to over 847,582 in 2006, with projections exceeding 1.2 million in recent years (Ibrahim et al., 2014). More recent estimates indicate that the metropolitan population of Ilorin reached approximately 1,030,000 in 2023, rising to 1,064,000 in 2024 and 1,100,000 in 2025, reflecting a sustained annual growth rate of approximately 3.4% (Macrotrends, 2025), underscoring the continued and accelerating pace of urban expansion in the metropolis.

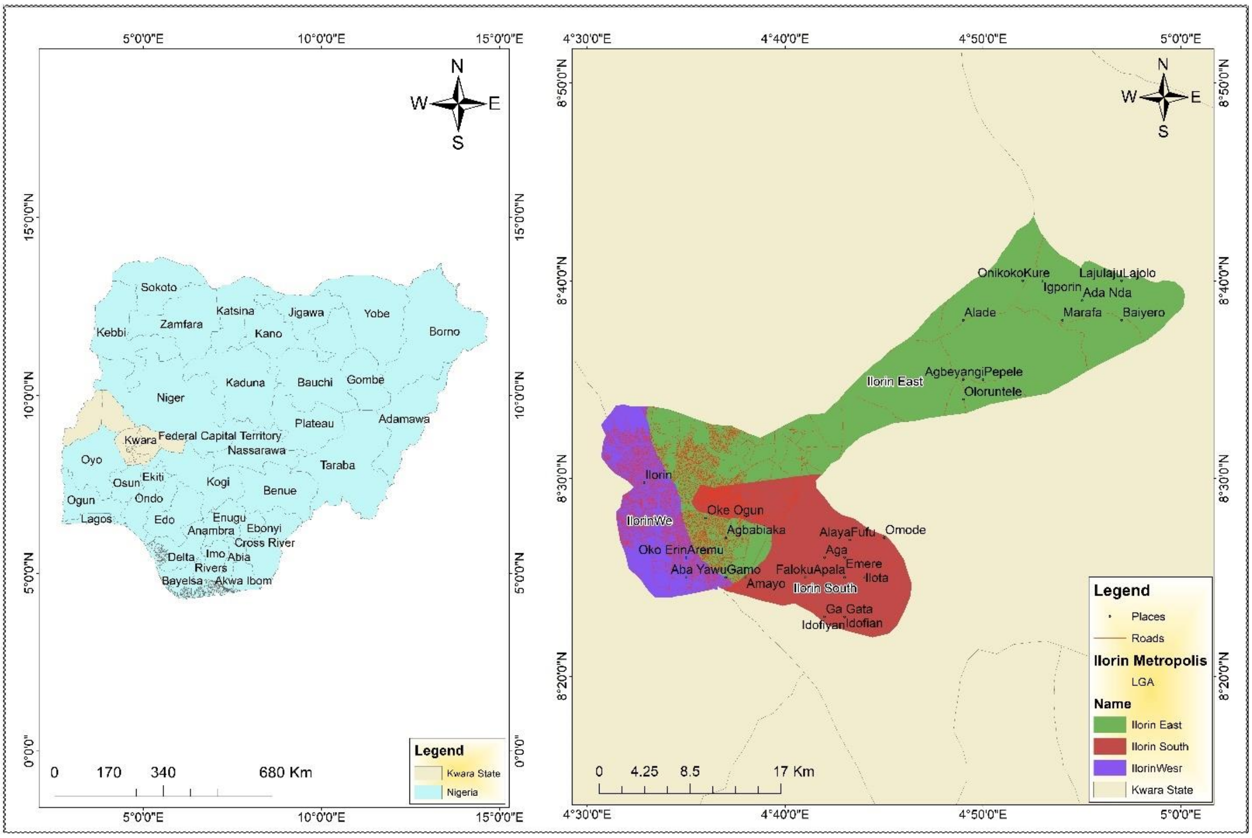

Figure 1: Study Area Map of Ilorin Metropolis

Climate

Ilorin experiences a tropical wet-and-dry climate (Köppen Aw), characterized by distinct wet and dry seasons. The wet season typically extends from April to October, while the dry season lasts from November to March. Mean annual rainfall ranges between 1,000 mm and 1,300 mm, with peak rainfall occurring between June and September (Olanrewaju, 2016). Average temperatures range from 25°C to 33°C throughout the year, with relatively high humidity during the rainy season.

Relief and Drainage

The topography of Ilorin Metropolis is generally undulating, with elevations ranging between 273 m and 333 m above sea level. The terrain consists of gently rolling plains interspersed with isolated inselbergs and low hills (Ifabiyi, 1999). The drainage system is dominated by River Asa and its tributaries, which flow through the metropolis and serve as major sources of surface water.

The nature of the terrain influences surface runoff patterns and pollutant transport, particularly in urbanized areas where impervious surfaces such as roads and buildings reduce infiltration and increase runoff velocity (Taiwo et al., 2014). This contributes to the mobilization of pollutants into the atmosphere and subsequently into rainwater.

Geology and Soils

Ilorin lies within the Nigerian Basement Complex, which is composed mainly of Precambrian rocks such as granite gneiss, schist, and quartzite (Ifabiyi, 1999). These rocks have undergone extensive weathering, resulting in the formation of lateritic soils that are generally well-drained but susceptible to erosion under intense rainfall conditions (Alao, 1982).

Land Use Characteristics
Land use in Ilorin Metropolis is predominantly urban, with major categories including residential, commercial, industrial, institutional, transportation, and agricultural land uses. Residential land use is the most dominant, accounting for over 50% of the total land area (Olanrewaju, 2016). This is followed by commercial and institutional land uses, while industrial and agricultural land uses occupy smaller proportions.

Human Activities and Environmental Implications
Human expansion has intensified anthropogenic activities, including vehicular emissions, generator use, industrial operations, and waste burning. These activities contribute to atmospheric pollution, with emissions such as carbon monoxide, sulphur dioxide, and particulate matter accumulating in the atmosphere. Through wet deposition, these pollutants are incorporated into rainwater, thereby affecting its quality. Consequently, variations in rainwater quality across Ilorin are closely linked to land use patterns and the intensity of human activities in different urban zones (Amodio et al., 2014).
Ilorin Metropolis is therefore an appropriate study area due to its rapid urban growth, diverse land use structure, and increasing environmental pressures, making it suitable for examining the relationship between urban land use and rainwater quality.

METHODOLOGY

This study adopts a quantitative approach to examine the relationship between urban land use and rainwater quality in Ilorin Metropolis. Primary data were obtained through the collection of rainwater samples from selected locations representing major urban land use types: residential, commercial, industrial, institutional, and agricultural areas. A total of five rainwater samples were collected and analysed following standard analytical procedures outlined by APHA (2017) for the determination of pH, turbidity, conductivity, total dissolved solids (TDS), and selected heavy metals.

Descriptive statistics were used to summarize the physicochemical characteristics of the samples, while inferential statistical techniques, including correlation and regression analysis, were employed to examine relationships between land use types and rainwater quality parameters (Field, 2018).

To assess land use dynamics, geospatial analysis was conducted using multi-temporal Landsat satellite imagery for the years 2006, 2013, 2020, and 2025. Image processing was carried out within a Geographic Information System (GIS) environment, involving preprocessing, supervised classification, and accuracy assessment. The Maximum Likelihood Classification algorithm was applied due to its reliability in land use classification (Congalton & Green, 2019). Accuracy assessment was performed to validate classification outputs.

Furthermore, Google Earth Engine was utilized to enhance data processing efficiency and support large-scale geospatial analysis (Gorelick et al., 2017). The integration of statistical and geospatial techniques enabled a comprehensive assessment of land use dynamics and their influence on rainwater quality in the study area.

DISSCUSSION OF FINDINGS

Urban land use in Ilorin comprises residential, commercial, institutional, transportation, industrial, and agricultural categories. Residential areas dominate (52%), followed by commercial (19%) and institutional (12%), while other built-up uses account for 17% (Olanrewaju, 2016). Rapid residential expansion has driven the conversion of farmland, vegetation, and water bodies into built-up areas, intensifying urban agglomeration. This transformation is largely fueled by population migration, resulting in continuous settlement growth and significant alteration of the spatial distribution of natural and agricultural landscapes.

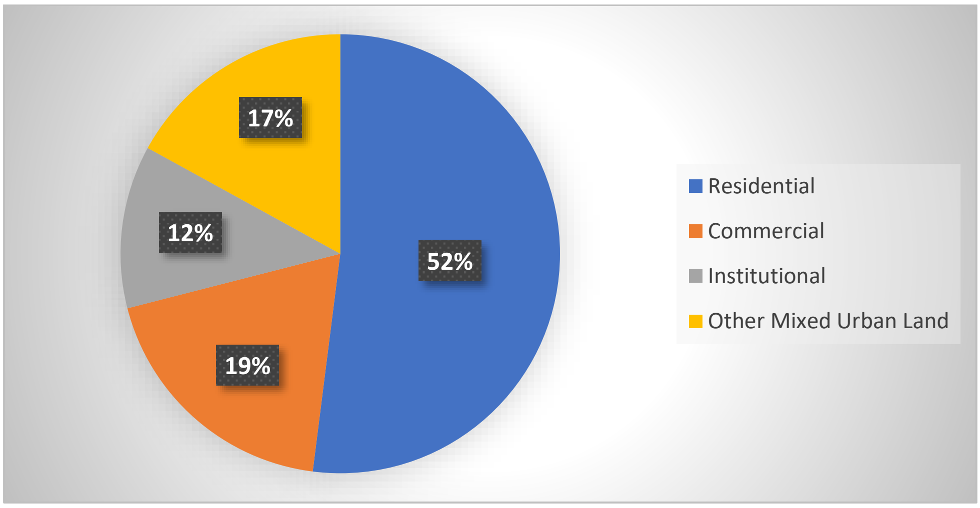

Figure 2: Prominent Urban Land Use Types in Ilorin Metropolis
Source: Adapted from Olanrewaju (2016)

Urban Land Use Changes in Ilorin Metropolis between 2006 and 2025
The classifications of land use in Ilorin Metropolis in 2006 and 2020 are shown in Table 5. Five categories were identified namely; settlement, dense vegetation, vegetation of farmland, rock outcrop and waterbody. As at 2006, forest and other vegetal covers account for over 70% of total land cover of Ilorin. The settlement and water bodies accounted for 13.48% and 0.56% respectively. However, the settlement increased from 13.48% in 2006 to 31.07% in the year 2020. Within the same period, vegetation and farmland decreased with over 15%. No significant change was recorded in other land use patterns.

Table 1: Categorized Land Use Statistics of Ilorin Metropolis in 2006 - 2025

Land Use	2006 km²	2006%	2013 km²	2013%	2020 km²	2020%	2025 km²	2025%
Settlement	97.53	13.48	157.3	21.74	224.79	31.07	236.14	32.64
Dense Vegetation	71.84	9.93	59.16	8.18	30.41	4.2	180.11	24.9
Vegetation/Farmland	512.58	70.85	496.6	68.63	444.14	61.39	266.99	36.9
Rock Outcrop	37.49	5.18	6.34	0.88	20.54	2.84	32.74	4.52
Waterbody	4.07	0.56	4.11	0.57	3.63	0.5	7.54	1.04
TOTAL	723.51	100	723.51	100	723.51	100	723.51	100

Source: Author's Field Compilation, 2025

Table 1 shows land use and land cover dynamics in Ilorin from 2006 to 2025. Settlement expanded from 13.48% to 32.64%, indicating rapid urban growth (AGR 142%). Dense vegetation declined to 4.20% in 2020 before rising to 24.90% in 2025 (AGR 151%). Vegetation/farmland steadily decreased from 70.85% to 36.90% (AGR −48%), reflecting conversion to built-up areas. Rock outcrops and waterbodies showed minor fluctuations. Overall, the trends highlight strong anthropogenic influence and ongoing transformation of natural landscapes, with implications for sustainable land management.

Table 2: Land Use Change and Period Growth Rates in Ilorin Metropolis 2006–2025

Land Use	2006 %	2013 %	2020 %	2025 %	Percentage Point Change 2006–2013	Percentage Point Change 2013–2020	Percentage Point Change 2020–2025	Percentage Point Change 2006–2025	Period Growth Rate (PGR) 2006–2013	Period Growth Rate (PGR) 2013–2020	Period Growth Rate (PGR) 2020–2025	Overall Period Growth Rate (PGR) 2006–2025
Settlement	13.48	21.74	31.07	32.64	8.26	9.33	1.57	19.16	61%	43%	5%	142%
Dense Vegetation	9.93	8.18	4.2	24.9	-1.75	-3.98	20.7	14.97	-18%	-40%	493%	151%
Vegetation /Farmland	70.85	68.63	61.39	36.9	-2.22	-7.24	-24.49	-33.95	-3%	-11%	-40%	-48%
Rock Outcrop	5.18	0.88	2.84	4.52	-4.3	1.96	1.68	-0.66	-83%	223%	59%	-13%
Waterbody	0.56	0.57	0.5	1.04	0.01	-0.07	0.54	0.48	2%	-12%	108%	86%
TOTAL	100	100	100	100	—	—	—	—	—	—	—	—

Source: Author's Field Compilation, 2025

Table 2 summarizes land use percentage changes in Ilorin from 2006 to 2025. Settlement increased steadily from 13.48% to 32.64% (PGR 142%), indicating rapid urban expansion. Dense vegetation declined initially but rose sharply to 24.90% by 2025 (PGR 151%). Vegetation/farmland consistently decreased from 70.85% to 36.90% (PGR −48%), Rock outcrops and waterbodies recorded minor fluctuations, with PGRs of −13% and 86%, respectively. Overall, the trends reflect strong human influence on land transformation and the need for sustainable land management strategies.

In this study, rainwater physicochemical data for the years 2006, 2013, 2020, and 2025 were compiled to enable a consistent temporal comparison between land use change and rainwater quality trends. Direct laboratory measurements were available for 2006 and 2020, while values for 2013 and 2025 were estimated using linear interpolation and linear extrapolation, respectively. The estimation was based on a linear time-weighted model expressed as:

$$X_t = X_1 + \frac{(t - t_1)}{(t_2 - t_1)}(X_2 - X_1)$$

where X_t is the estimated value at time t, X_1 and X_2 are observed values at times t_1(2006) and t_2(2020), respectively. This approach follows standard procedures for estimating intermediate and projected values in environmental time-series analysis (Isaaks & Srivastava, 1989; Burrough & McDonnell, 1998). Measured and estimated values are clearly distinguished in Table 3 to ensure transparency and proper interpretation of results.

Table 3: Urban Land Use and Rainwater Parameters in Ilorin Metropolis (2006, 2013, 2020 and 2025)

Year	Parameter	Unit	Agricultural	Industrial	Institutional	Residential	Commercial	WHO Limit
2006 (Measured / Back-Calculated*)								
2006	pH	—	6.680	5.980	5.990	6.110	5.580	**7.0–8.5**
	Turbidity	NTU	0.036	0.024	0.012	0.036	0.036	**0.5**
	Conductivity	µs/cm	180.275	155.543	107.684	431.130	527.256	**750**
	TDS	mg/l	212.000	150.000	102.000	142.000	242.000	**600**
	Total Hardness	mg/l	1.150	0.550	0.750	0.850	0.550	**200**
	Magnesium	mg/l	2.712	1.960	1.360	1.525	1.140	**3.0**
	Carbon Dioxide	mg/l	29.000	38.200	26.000	30.400	36.400	**50**
	Chlorine	mg/l	6.800	8.700	6.900	7.200	9.500	**20**
	Aluminium (Al^{3+})	mg/l	0.000	0.000	0.000	0.000	0.000	**0.2**
	Copper (Cu^{2+})	mg/l	0.024	0.036	0.060	0.072	0.060	**1.0**
	Lead (Pb^{2+})	mg/l	0.060	0.060	0.000	0.000	0.060	**0.05**
	Nickel (Ni^{2+})	mg/l	0.024	0.012	0.072	0.024	0.012	**0.1**
	Zinc (Zn^{2+})	mg/l	0.072	0.084	0.168	0.084	0.144	**3.0**

Year	Parameter	Unit	Agricultural	Industrial	Institutional	Residential	Commercial	WHO Limit
	Iron (Fe^{2+})	mg/l	0.170	0.085	0.258	0.085	0.170	**0.3**
	Sulphate (SO_4^{2-})	mg/l	71.930	3.200	54.110	72.750	99.500	**250**
	Phosphorus	mg/l	0.050	0.050	0.130	0.070	0.060	**20**
	Potassium (K^+)	mg/l	0.177	0.097	0.192	0.212	0.131	**75**
	Sodium (Na^+)	mg/l	3.870	4.150	3.950	3.970	4.730	**50**
	Nitrate (NO_3^-)	mg/l	23.520	40.320	28.560	31.920	44.240	**50**
	Dissolved Solids	mg/l	212.000	150.000	102.000	142.000	242.000	**500**
2013 (Interpolated)								
2013	pH	—	6.925	6.825	7.580	6.740	7.030	**7.0–8.5**
	Turbidity	NTU	0.033	0.022	0.011	0.033	0.033	**0.5**
	Conductivity	µs/cm	165.472	142.772	98.842	395.730	483.963	**750**
	TDS	mg/l	112.835	82.760	56.665	82.335	171.835	**600**
	Total Hardness	mg/l	1.055	0.505	0.689	0.780	0.505	**200**
	Magnesium	mg/l	2.490	1.799	1.248	1.400	1.046	**3.0**
	Carbon Dioxide	mg/l	26.619	35.064	23.865	27.904	33.411	**50**

Year	Parameter	Unit	Agricultural	Industrial	Institutional	Residential	Commercial	WHO Limit
	Chlorine	mg/l	6.242	7.985	6.334	6.609	8.720	**20**
	Aluminium (Al^{3+})	mg/l	0.000	0.000	0.000	0.000	0.000	**0.2**
	Copper (Cu^{2+})	mg/l	0.022	0.033	0.055	0.066	0.055	**1.0**
	Lead (Pb^{2+})	mg/l	0.030	0.030	0.000	0.000	0.030	**0.05**
	Nickel (Ni^{2+})	mg/l	0.022	0.011	0.066	0.022	0.011	**0.1**
	Zinc (Zn^{2+})	mg/l	0.066	0.077	0.154	0.077	0.132	**3.0**
	Iron (Fe^{2+})	mg/l	0.175	0.207	0.274	0.158	0.200	**0.3**
	Sulphate (SO_4^{2-})	mg/l	53.965	25.100	48.055	58.425	70.550	**250**
	Phosphorus	mg/l	0.190	0.240	0.270	0.230	0.230	**20**
	Potassium (K^+)	mg/l	0.162	0.089	0.176	0.195	0.120	**75**
	Sodium (Na^+)	mg/l	2.215	2.235	2.120	2.125	2.590	**50**
	Nitrate (NO_3^-)	mg/l	27.910	35.660	29.880	29.960	37.270	**50**
	Dissolved Solids	mg/l	194.593	137.684	93.625	130.340	222.129	**500**
2020 (Measured / Projected)								
2020	pH	—	7.170	7.670	9.170	7.370	8.480	**7.0–8.5**

Year	Parameter	Unit	Agricultural	Industrial	Institutional	Residential	Commercial	WHO Limit
	Turbidity	NTU	0.030	0.020	0.010	0.030	0.030	**0.5**
	Conductivity	µs/cm	150.670	130.000	90.000	360.330	440.670	**750**
	TDS	mg/l	13.670	15.520	11.330	22.670	101.670	**600**
	Total Hardness	mg/l	0.961	0.460	0.627	0.710	0.460	**200**
	Magnesium	mg/l	2.267	1.638	1.137	1.275	0.953	**3.0**
	Carbon Dioxide	mg/l	24.238	31.927	21.730	25.408	30.422	**50**
	Chlorine	mg/l	5.683	7.271	5.767	6.018	7.940	**20**
	Aluminium (Al3+)	mg/l	0.000	0.000	0.000	0.000	0.000	**0.2**
	Copper (Cu2+)	mg/l	0.020	0.030	0.050	0.060	0.050	**1.0**
	Lead (Pb2+)	mg/l	0.000	0.000	0.000	0.000	0.000	**0.05**
	Nickel (Ni2+)	mg/l	0.020	0.010	0.060	0.020	0.010	**0.1**
	Zinc (Zn2+)	mg/l	0.060	0.070	0.140	0.070	0.120	**3.0**
	Iron (Fe2+)	mg/l	0.180	0.330	0.290	0.230	0.230	**0.3**
	Sulphate (SO42-)	mg/l	36.000	47.000	42.000	44.100	41.600	**250**
	Phosphorus	mg/l	0.330	0.430	0.410	0.390	0.400	**20**

Year	Parameter	Unit	Agricultural	Industrial	Institutional	Residential	Commercial	WHO Limit
	Potassium (K^+)	mg/l	0.148	0.081	0.160	0.177	0.109	**75**
	Sodium (Na^+)	mg/l	0.560	0.320	0.290	0.280	0.450	**50**
	Nitrate (NO_3^-)	mg/l	32.300	31.000	31.200	28.000	30.300	**50**
	Dissolved Solids	mg/l	177.185	125.367	85.250	118.681	202.259	**500**
2025 (Projected)								
2025	pH	—	7.345	8.274	10.306	7.820	9.516	**7.0–8.5**
	Turbidity	NTU	0.028	0.019	0.009	0.028	0.028	**0.5**
	Conductivity	µs/cm	140.097	120.877	83.684	335.044	409.746	**750**
	TDS	mg/l	0.000	0.000	0.000	0.000	51.552	**600**
	Total Hardness	mg/l	0.893	0.428	0.583	0.660	0.428	**200**
	Magnesium	mg/l	2.108	1.523	1.057	1.186	0.886	**3.0**
	Carbon Dioxide	mg/l	22.537	29.687	20.205	23.625	28.287	**50**
	Chlorine	mg/l	5.284	6.761	5.362	5.596	7.383	**20**
	Aluminium (Al^{3+})	mg/l	0.000	0.000	0.000	0.000	0.000	**0.2**

Year	Parameter	Unit	Agricultural	Industrial	Institutional	Residential	Commercial	WHO Limit
	Copper (Cu^{2+})	mg/l	0.019	0.028	0.046	0.056	0.046	**1.0**
	Lead (Pb^{2+})	mg/l	0.000	0.000	0.000	0.000	0.000	**0.05**
	Nickel (Ni^{2+})	mg/l	0.019	0.009	0.056	0.019	0.009	**0.1**
	Zinc (Zn^{2+})	mg/l	0.056	0.065	0.130	0.065	0.111	**3.0**
	Iron (Fe^{2+})	mg/l	0.184	0.417	0.301	0.282	0.251	**0.3**
	Sulphate (SO_4^{2-})	mg/l	23.168	62.643	37.675	33.868	20.921	**250**
	Phosphorus	mg/l	0.430	0.566	0.510	0.504	0.521	**20**
	Potassium (K^+)	mg/l	0.138	0.075	0.149	0.164	0.101	**75**
	Sodium (Na^+)	mg/l	0.000	0.000	0.000	0.000	0.000	**50**
	Nitrate (NO_3^-)	mg/l	35.436	27.671	32.143	26.600	25.321	**50**
	Dissolved Solids	mg/l	164.751	116.570	79.268	110.353	188.066	**500**

Source: Author’s Field Compilation, (2025)

Table 3 shows variations in rainwater quality across different urban land uses in Ilorin between 2006 and 2025. Most parameters remained within WHO limits, indicating generally safe water quality. However, pH values increased over time, exceeding recommended levels in institutional and commercial areas. A declining trend in conductivity, total dissolved solids, and major ions suggests improving environmental conditions. Heavy metals were generally low, with lead present in 2006 but absent thereafter. Higher concentrations in residential and commercial zones reflect stronger human influence on rainwater quality.

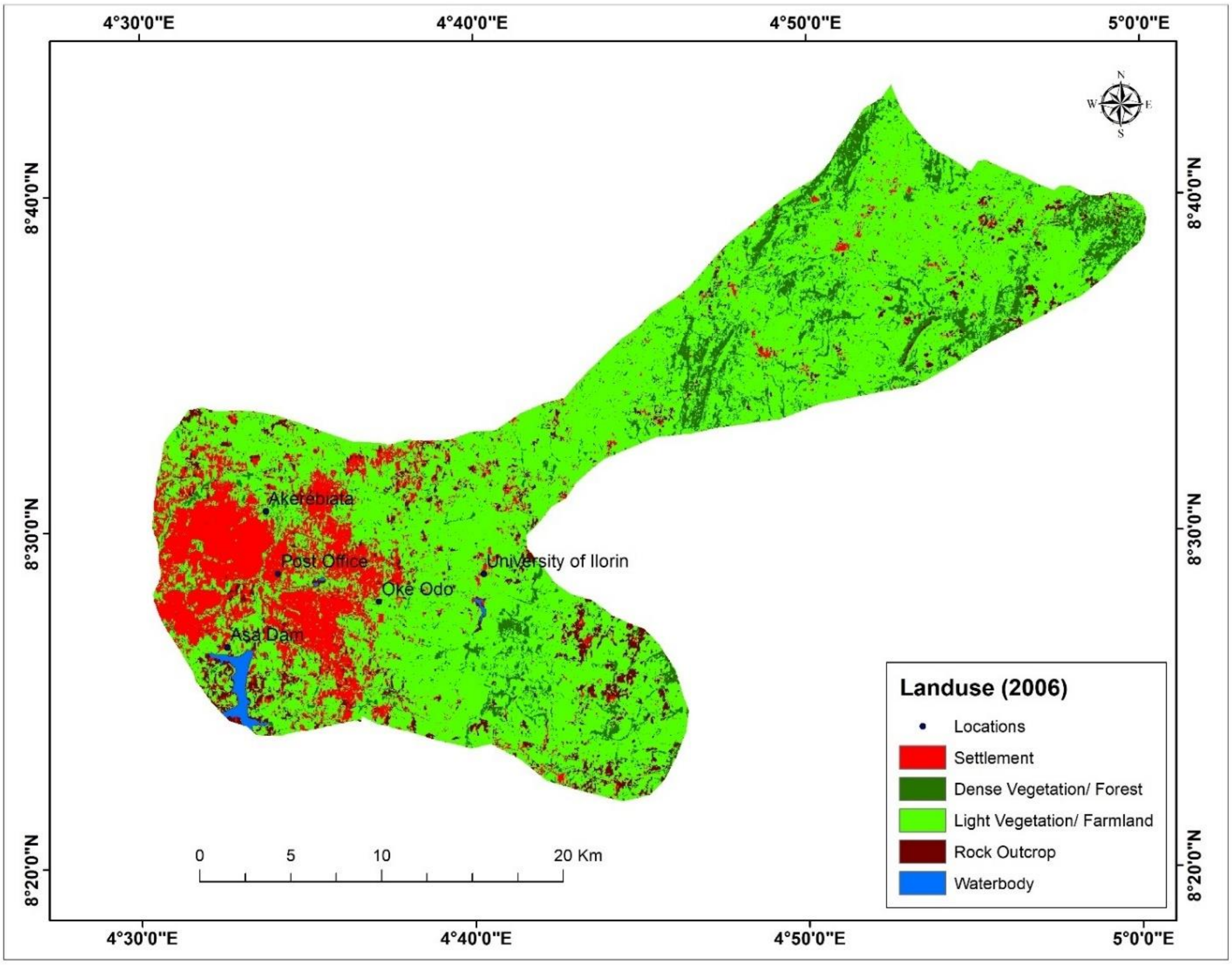

Figure 4: Land Use Map of Ilorin Metropolis in 2006
Source: Landsat imagery USGS) analyzed in ArcGIS, 2025.

Figures 4 - 7 present the classified land use/land cover maps of Ilorin Metropolis for 2006, 2013, 2020, and 2025. The figures indicate an increase in the percentage of settlements and a corresponding decrease in vegetation.

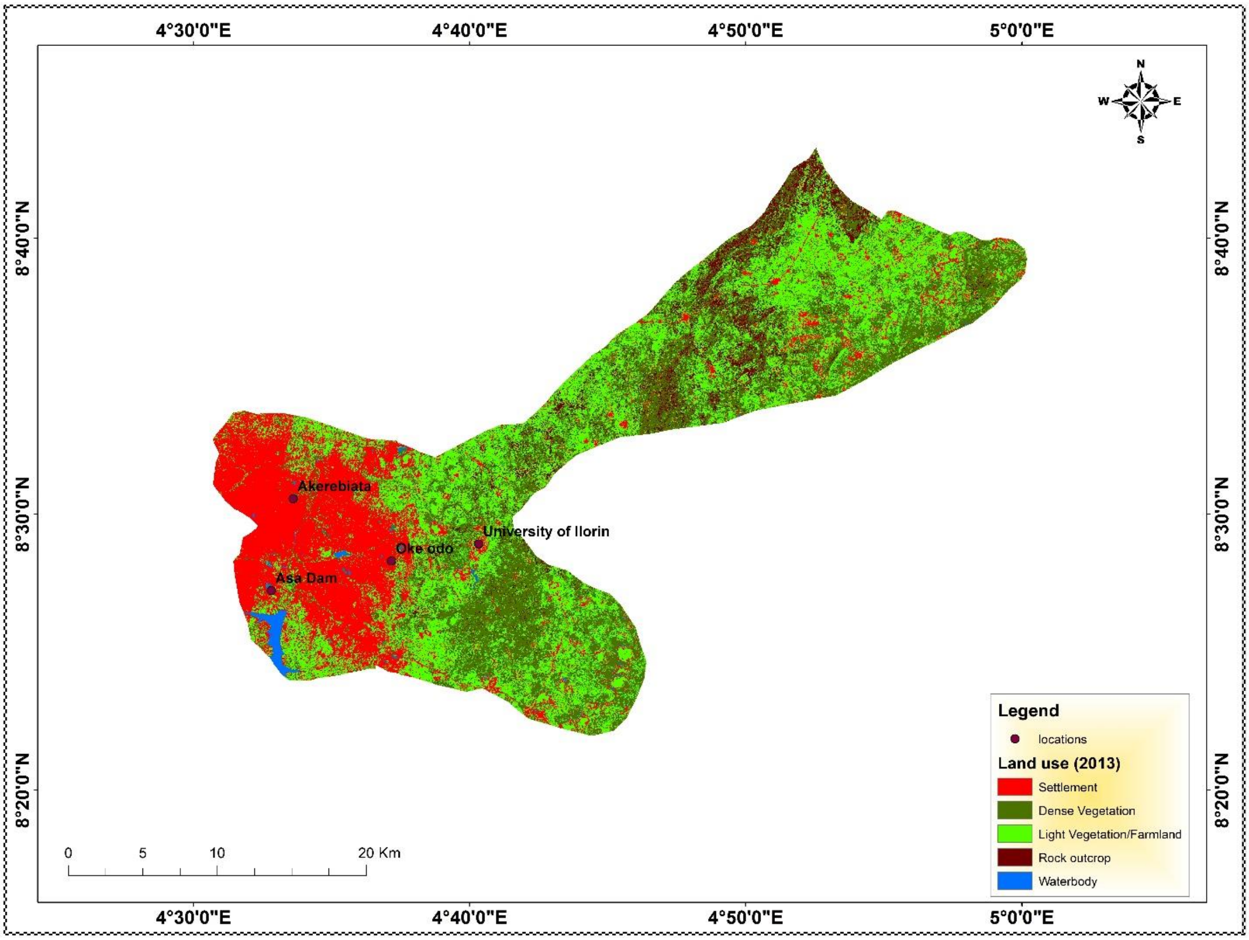

Figure 5: Land Use Map of Ilorin Metropolis in 2013
Source: Landsat imagery USGS) analyzed in ArcGIS, 2025.

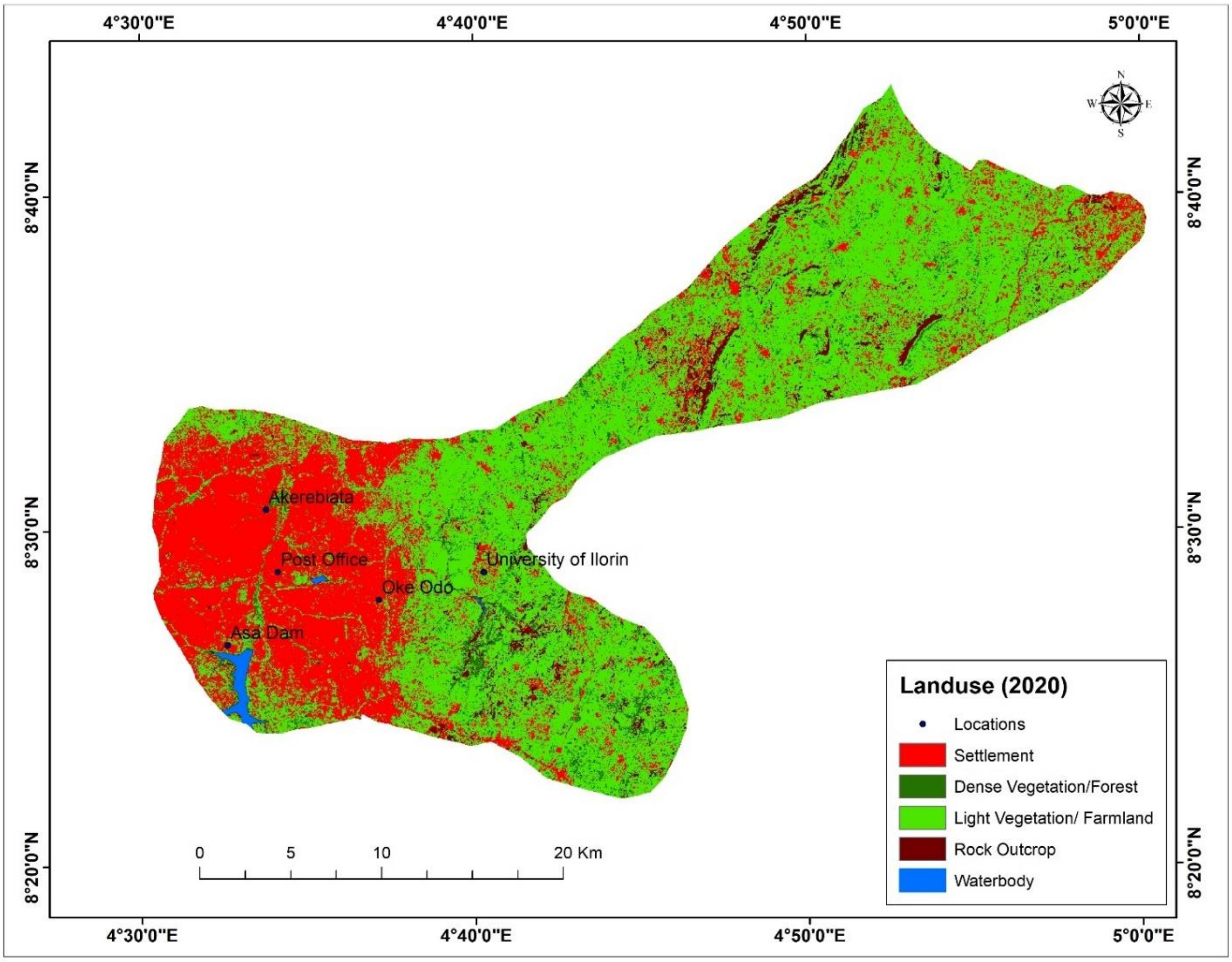

Figure 6: Land Use Map of Ilorin Metropolis in 2020
Source: Landsat imagery USGS) analyzed in ArcGIS, 2025.

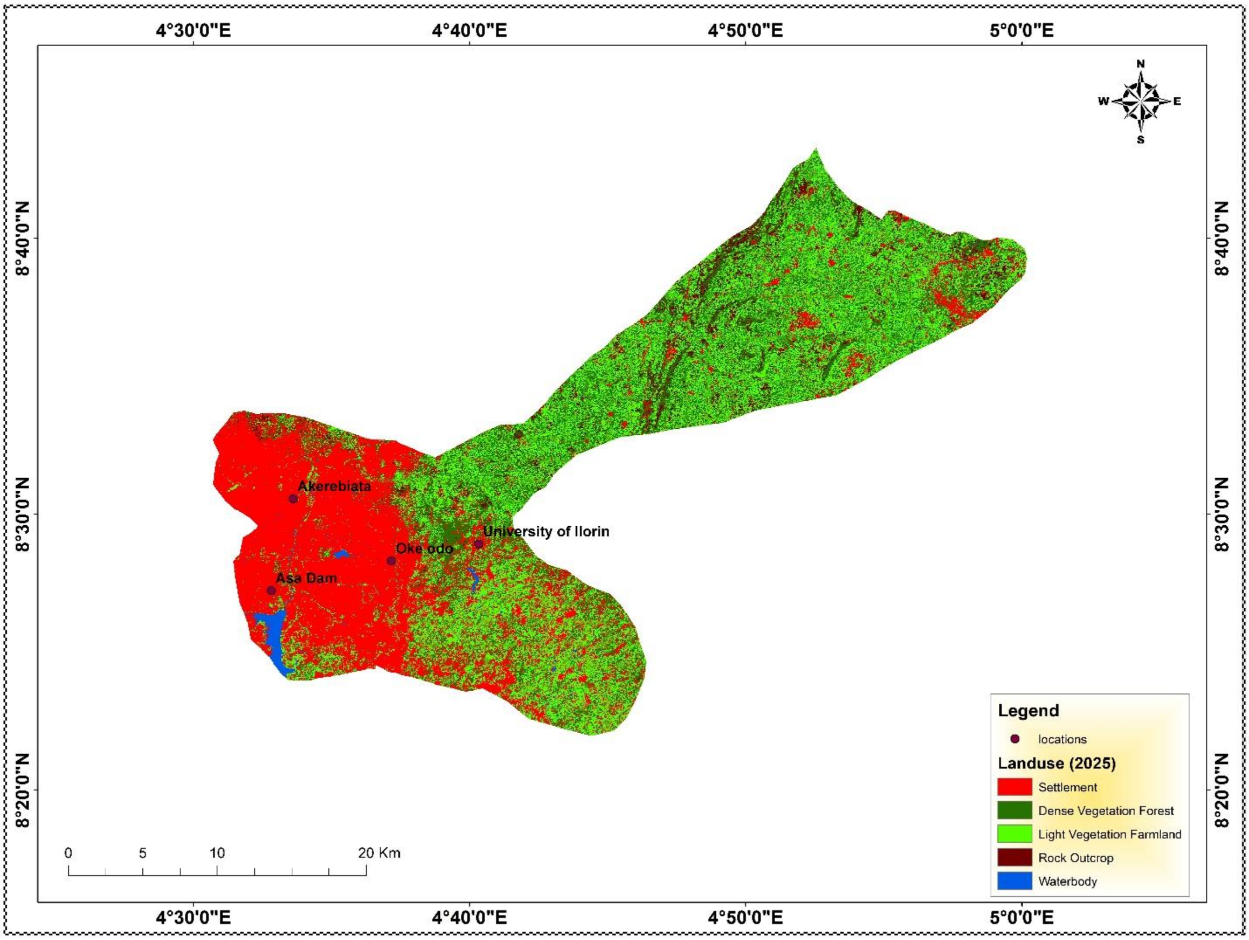

Figure 7: Land Use Map of Ilorin Metropolis in 2025
Source: Landsat imagery USGS) analyzed in ArcGIS, 2025.

Land Consumption and Growth Rate in Ilorin Metropolis between 2006 and 2025
The pace of urban growth in Ilorin Metropolis is historically unprecedented, with rates of growth typically increasing in the late 19th century. The 1991 National Census shows that Ilorin Metropolis had a population of 532,088, while the 2006 census figures shows that the figure had increased to 847,582. Thus, within 15 years the city's population had increased by 75% showing period growth rate of 2.6%, and it is believed that by the year 2020 the population of Ilorin Metropolis will reach 1,272,908 (Ibrahim *et al.*, 2014). Land consumption rate is a measure of the amount of land area utilized per person within a given population at a specific point in time. It provides an indication of the efficiency of land use relative to population growth and is particularly useful for understanding the pressure that urban expansion places on available land resources. In the case of Ilorin Metropolis, the total study area of 723.51 km² is divided by the projected population of 1,272,908 for the year 2020 to derive the land consumption rate, as shown below:

$$\text{Consumption Rate} = \frac{723.51}{1,272,908} = 5.684\times10^{-4}$$

An important aspect of land use change analysis is to identify the nature and direction of transitions between land use categories, that is, to determine which land use types are being converted and what they are being converted into. This information will reveal both the desirable and undesirable land use changes that are relatively stable over time, and will also serve as a vital tool in land use management decisions. Looking at the nature of land use change under stability, that is, land use areas with no change, and instability, represented by loss or gain by each class between 2006 and 2025, stability seems to be a relative term as no land use is actually stable during this period except when observed from the percentage change.

The introduction of the 2013 and 2025 data points provides a fuller and more comprehensive picture of the trajectory and pace of land use transformation in Ilorin Metropolis across nearly two decades. Between 2006 and 2013, settlement coverage increased from 13.48% to 21.74%, representing a percentage change of 8.26% and a 7-year cumulative growth rate of 61% for that period. This growth accelerated further between 2013 and 2020, with settlement rising to 31.07%, a further change of 9.33%, at a 7-year cumulative growth rate of 43%. By 2025, settlement had reached 32.64%, recording an additional change of 1.57% over the five-year period at a 5-year cumulative growth rate of 5%, culminating in an overall percentage change of 19.16% and a total cumulative growth rate of 142% across the full 2006–2025 period. This progressive and sustained expansion of settlement clearly reflects the rapid and unrelenting urbanization trajectory of Ilorin Metropolis.

Correspondingly, dense vegetation declined from 9.93% in 2006 to 8.18% in 2013, and further to 4.20% by 2020, with the rate of decline accelerating markedly in the second period, from 18% between 2006 and 2013 to 40% between 2013 and 2020. Vegetation/farmland followed a consistent declining trend from 70.85% in 2006 to 68.63% in 2013 and 61.39% in 2020, with the steepest rate of loss recorded in the 2020–2025 period at 40%, as vegetation/farmland declined sharply to 36.90% by 2025, representing an overall percentage change of -33.95% and an overall annual growth rate of -48% across the study period. Rock outcrop exhibited a notable decline from 5.18% in 2006 to 0.88% in 2013, likely due to land clearing for construction activities, before showing a partial recovery to 2.84% in 2020 and 4.52% by 2025, recording an annual growth rate of 59% in the 2020–2025 period. Waterbody remained relatively stable across the first three periods, with small change between 2006 and 2020, before recording a modest increase to 1.04% in 2025, representing an annual growth rate of 108% for that period. The progressive urbanization of Ilorin Metropolis across the study period is directly reflected in the evolution of rainwater physicochemical parameters across all land use types. pH values increased across all land use types between 2006 and 2020, rising from 6.68 to 7.17 in agricultural areas, from 5.98 to 7.67 in industrial areas, from 5.99 to 9.17 in institutional areas, exceeding the WHO upper limit of 8.5, from 6.11 to 7.37 in residential areas, and from 5.58 to 8.48 in commercial areas, with interpolated 2013 values confirming the steady progression of this trend. Iron concentrations increased notably in industrial areas from 0.085 mg/l in 2006 to 0.330 mg/l in 2020, surpassing the WHO permissible limit of 0.300 mg/l, while 2025 value of 0.417 mg/l indicates continued deterioration consistent with expanding industrial activity. Sulphate concentrations showed a general decline across most land use types between 2006 and 2020, with agricultural areas recording 71.93 mg/l in 2006, declining to 53.97 mg/l in 2013 and 36.00 mg/l in 2020, and projected to further decline to 23.17 mg/l by 2025, remaining within WHO limits throughout. Nitrate concentrations, however, showed a progressive increase in agricultural areas, from 23.52 mg/l in 2006 to 27.91 mg/l in 2013, 32.30 mg/l in 2020, and a projected 35.44 mg/l by 2025, reflecting the intensification of agricultural chemical inputs alongside urban expansion. Phosphorus levels increased consistently across all land use types throughout the study period, with commercial areas recording 0.060 mg/l in 2006, rising to 0.230 mg/l in 2013, 0.400 mg/l in 2020, and projected at 0.521 mg/l by 2025, a trend attributable to increased detergent and wastewater discharge associated with growing commercial activity. Sodium concentrations declined across all land use types between 2006 and 2020, from 3.87 mg/l to 0.56 mg/l in agricultural areas and from 4.73 mg/l to 0.45 mg/l in commercial areas, remaining well within WHO limits. Lead concentrations, which were recorded at 0.060 mg/l in agricultural, industrial, and commercial areas in 2006, exceeding the WHO limit of 0.050 mg/l, declined to 0.000 mg/l across all land use types by 2020, suggesting improvement in fuel combustion standards and reduced leaded emission sources over the study period.

Thus, between 2006 and 2025, settlement increased greatly at an overall annual growth rate of 142%, vegetation and farmland decreased by 48%, rock outcrop decreased by 13%, and waterbody recorded a marginal overall increase of 86% from its very low base. The four-period dataset spanning 2006, 2013, 2020, and 2025 confirms that the transformation of Ilorin Metropolis from a predominantly vegetated landscape to an increasingly urbanized one was not a sudden shift but a continuously increasing process. This is compelling evidence of rapid and sustained development in Ilorin Metropolis and directly explains why residential land use in the metropolis consistently records the poorest rainwater quality, as the abrupt and sustained growth in settlement, accompanied by the progressive decline in vegetation cover, has significantly reduced natural filtration capacity and increased impervious surface runoff, thereby degrading rainwater quality progressively across the study area.

Rainwater quality is widely recognized as an indicator of atmospheric conditions, where lower concentrations of physicochemical parameters generally correspond to better water quality (Amodio et al., 2014; Dami et al., 2012). The findings of this study reveal clear spatial variations in rainwater quality across different urban land use types in Ilorin Metropolis. Among the land use categories examined, institutional areas exhibited the least overall contamination based on aggregate ANOVA significance values, followed by industrial and agricultural zones, while commercial and residential areas recorded relatively poorer rainwater quality.

Table 4: One-Way ANOVA Significance Values for Rainwater Quality Parameters by Land Use Type, Ilorin Metropolis

Land Use Type	**Significance Value (p)**	**Interpretation**
Institutional	0.014	Significant ($p < 0.05$) — least contaminated
Industrial	0.035	Significant ($p < 0.05$)
Agricultural	0.044	Significant ($p < 0.05$)
Commercial	0.585	Not significant ($p > 0.05$)
Residential	0.724	Not significant ($p > 0.05$) — most contaminated

Source: Author's Field Analysis, 2025

As presented in Table 4, the statistical analysis revealed significance values of 0.014, 0.035, and 0.044 for institutional, industrial, and agricultural land uses respectively, all below the 0.05 threshold, indicating statistically significant relationships between these land use types and relatively better rainwater quality. Conversely, commercial (0.585) and residential (0.724) land uses exceeded the significance threshold, indicating weaker statistical relationships and higher levels of rainwater contamination (Igbinosa and Aighewi, 2017; Atedhor et al., 2019).

The observed variations are closely linked to the structure and dynamics of land use in Ilorin Metropolis. Residential land use dominates the urban landscape, accounting for approximately 52% of total land area, followed by commercial (19%) and institutional (12%) uses. Over the study period (2006–2025), a consistent and extensive expansion of settlement areas was recorded, increasing from 13.48% in 2006 to 32.64% in 2025, representing an overall growth rate of 142%. This rapid urban expansion occurred alongside a significant decline in vegetation and farmland, which decreased from 70.85% to 36.90%, reflecting an overall reduction of 48%. Dense vegetation also declined sharply before experiencing a partial recovery in 2025, while rock outcrops and water bodies showed relatively minor fluctuations. These findings align with global observations that rapid urbanization leads to the conversion of natural landscapes into built-up environments, thereby altering environmental quality and atmospheric composition (Seto et al., 2012).

The transformation of land use patterns in Ilorin is directly reflected in the temporal evolution of rainwater physicochemical characteristics. Notably, pH values increased across all land use types between 2006 and 2020, with institutional and commercial areas exceeding the World Health Organization (WHO) recommended upper limit of 8.5. This trend suggests increasing alkalinity in rainwater, likely resulting from intensified anthropogenic emissions such as industrial discharges, vehicular exhaust, and construction activities. Similar trends have been reported in rapidly urbanizing environments, where atmospheric pollutants alter the chemical composition of precipitation (Wang et al., 2020).

Other parameters such as turbidity, conductivity, and total dissolved solids (TDS) remained within WHO permissible limits across all land use types, indicating relatively low particulate and dissolved matter contamination. However, spatial differences were evident, with higher conductivity values recorded in residential and commercial areas, reflecting increased anthropogenic inputs. The observed decline from 2006 to 2025 in TDS and conductivity over time may indicate improvements in environmental regulation or changes in emission sources, although this trend requires further investigation.

Heavy metal concentrations showed mixed patterns. Lead, which exceeded WHO limits in 2006, declined to undetectable levels by 2020 across distinct land use types, suggesting improvements in emission control measures, particularly the phasing out of leaded fuels. In contrast, iron concentrations increased notably in industrial areas, exceeding WHO permissible limits by 2020 and projected to rise further by 2025. This trend is consistent with the expansion of industrial activities and highlights the continued influence of localized pollution sources. Other metals such as copper, nickel, and zinc remained within safe limits, indicating minimal contamination from these elements.

Nutrient parameters also exhibited important trends. Nitrate concentrations increased steadily in agricultural areas, reflecting the intensification of fertilizer use and agricultural practices, while phosphorus levels rose across all land use types, particularly in commercial and industrial zones. These increases are likely associated with wastewater discharge, detergent use, and surface runoff in densely populated areas. Despite remaining within WHO limits, the upward trends suggest growing anthropogenic pressure on atmospheric quality.

Overall, the findings demonstrate that rapid urban expansion is a key driver of declining rainwater quality in Ilorin Metropolis. The substantial increase in settlement areas has intensified anthropogenic activities, including vehicular emissions, waste burning, and industrial operations, all of which contribute to atmospheric pollution. The distribution of physicochemical parameters across land use types revealed distinct contamination patterns rather than a uniform dominance of residential and commercial areas. Institutional and commercial land uses consistently recorded the highest pH values, with pH exceeding the WHO permissible limit of 8.5 in institutional areas by 2020 and in commercial areas by the projected 2025 period. Iron concentrations were highest in institutional areas during 2006 and 2013, while industrial areas recorded the highest concentrations in 2020 and 2025, exceeding the WHO guideline value of 0.300 mg/l. Nitrate concentrations were initially highest in commercial and industrial areas but later became most pronounced in agricultural areas, reflecting increasing agricultural inputs. Similarly, conductivity and total dissolved solids were highest in commercial areas, followed by residential areas, indicating greater anthropogenic influence. These findings suggest that rainwater quality deterioration in Ilorin Metropolis is driven by land-use-specific activities, including industrial emissions, commercial activities, agricultural inputs, and urban development, rather than by residential expansion alone, consistent with previous studies (Igbinosa & Aighewi, 2017; Atedhor et al., 2019).

In summary, the study establishes a strong relationship between land use dynamics and rainwater quality in Ilorin Metropolis. The continuous conversion of vegetation and farmland into built-up areas has reduced natural filtration capacity while increasing pollutant emissions, leading to progressive deterioration in rainwater quality. These findings underscore the need for sustainable urban planning and effective environmental management strategies to mitigate the adverse impacts of urbanization on atmospheric and water quality.

CONCLUSION AND RECOMMENDATIONS

The findings of this study indicate that most physicochemical parameters of rainwater in Ilorin Metropolis conform to World Health Organization water quality standards, with the exception of iron, which exceeded the recommended limit of 0.3 mg/l in industrial and institutional areas. Rainwater quality was highest in institutional zones, followed by industrial, agricultural, commercial, and residential areas. A significant relationship was observed between the dominant urban land use types residential, commercial, industrial, institutional, and agricultural) and rainwater quality. Spatial analysis revealed that settlement areas increased by 17.59 percentage points between 2006 and 2020, from 13.48% to 31.07%, reflecting a total period growth rate of 126% over the 14-year period, highlighting the rapid urban expansion in the metropolis.

The persistence of rainwater contamination in urban centers underscores the need for comprehensive management strategies. It is recommended that national and state environmental agencies develop and enforce stricter policies, standards, and monitoring frameworks to protect rainwater quality. Systematic monitoring of rainwater pollutants and greenhouse gases should be established, complemented by continuous public education campaigns to raise awareness of health risks. Sustainable urban planning, including green housing, adequate waste management, and effective sewage systems, is essential to mitigate pollution. Furthermore, improved electricity supply, vehicle emission control, and strict adherence of industries to atmospheric pollution regulations are critical for reducing sources of contamination. Collectively, these measures will support public health, environmental sustainability, and the long-term resilience of urban ecosystems in Ilorin Metropolis.

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