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Assessing Land Use and Land Cover Change and Its Correlation with Air Pollutants in Kabul City

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Abstract: ***Land use transformations have substantially altered the natural environment in which humans live and in urban areas, the declining air quality poses a large threat to human health. To investigate the relationship between land use, land cover change and air pollutants, a non- segregated approach was used in combining remote sensing techniques with Geographical Information System. The land use and land cover in this study were categorized into the following; Water Bodies, Bare Land, Vegetations and Built-up area. The pollutants considered are; $PM_{2.5}$, SO_2, NO_2 and CO. The annual average for 2021 was observed to be 47.46 µg/m³ which exceeded the threshold value of EPA 15µg/m³. Understanding the effect of pollutants on land use and land cover using Pearson correlation, it was observed that PM2.5 had a negative correlation of (-0.921) on water. Results also indicated that SO_2 had a positive correlation (0.91) with vegetation, while CO indicated a positive correlation of (0.31) on bare land. In addition, NO_2 had a negative correlation of (-0.62) on built-up area, and a positive correlation on Bare land. Analysis indicated an increase of (0.86%) in vegetation and (66%) in built-up area. While registering a simultaneous decrease of (39.9%) in water bodies and (15%) in bare land from 2001 to 2021. The findings from this observation constitute and suggest a valuable benefit of knowledge of regulations aimed at improving, safeguarding, and monitoring air quality. These outcomes may be used to inform land-use in making planning decisions in a comprehensive way and will be an empirical tool for LUCC rationalization and control strategies.***

Keywords: Correlation, air Pollutants, $PM_{2.5}$, air quality, Kabul city, land use change

1. Introduction

Land use (LU) and land cover (LC) change studies at global level are becoming paramount to international climate and environmental change since the launch of land use and land cover concerns. These two terms (Land use and Land Cover) have now become synonymous. Meanwhile, they can be used interchangeably. Land cover refers to the physical features of the earth's surface including water, vegetation, soil, and other physical characteristics while land use is the manner in which land has been used by humans and usually for economic benefits (Liping et al., 2018). Land use change is a global and inevitable phenomenon. According to Sanga et al. (2021) these current change rates and intensities of LU and LC are well beyond the changes ever experienced and is causing detrimental impacts on the ecosystem and other environmental processes. Understanding LU change and its relationship with air pollutants ($PM_{2.5}$, SO_2, NO_2 and CO) will help in sustainable development and management of natural resources such as water, land and vegetation.

Land use and land cover does not only impact land and ecosystem but also affect the concentration of pollutants in the atmosphere which leads to climate change, global warming and negatively affect the human health. Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere (Sicard et al., 2021). These contaminants are referred to as air pollutants. Air pollution can have detrimental impacts on both the environment and human health. It causes damage to the ecosystem, crops and trees leading to reduced agricultural and commercial crop yield. Not only that, exposure to high levels of air pollution can cause a variety of adverse health outcomes. It increases the risk of respiratory infections, heart disease and lung cancer. Both short- and long-term exposure to air pollutants have been associated with health impacts. Research shows that air pollution and development go hand in hand. Therefore, with continuous development and urbanization the air pollution emissions also increase.

Previous researches have also shown a close relationship between air pollution and LU and LC change. In addition, understanding land use change features will help in policy making and urban planners to optimally organize and use land accordingly (Z. Zhu et al., 2019). To the best of our knowledge, there had been no research as relate to LU, LC and how it affect the concentration of air pollutants in Kabul, Ag. Therefore, this study aims to examine the relationship of LU, LC and Air pollutants. The main objectives of this study were 1) Derive LU and LC maps and quantify the changes in various LU and LC classes using

GIS. 2) To evaluate the changes in LU and LC from 2001 to 2021 and provide suggestion to better understand the Land use and land cover progresses.

2. Study Location

2.1 Methodology

Kabul is the administrative capital and largest city of Afghanistan, located in the eastern part of the nation and laying between 34.55°N and 69.20°E. It is located high up on the narrow valley between the Hindu Kush Mountains and bounded by Kabul River. It bounds a total area of 1028Km^2 and consists of 22 districts with a population of 4.3 million in 2021 (https://en.wikipedia.org/wiki/Kabul). The climate of Kabul is an arid to semiarid, characterised by cold winters and hot summer. The winter (December to March) are very cold, snowy and partly cloudy with temperatures reaching as low as -4ºC and highs of 7.0ºC while the summer (May to September) are very hot, dry and clear. The average temperature in summer is approximately 35^{O}C and the lowest temperature is 17^{O}C (https://weatherspark.com/y/106802/Average-Weather-in-Kabul- Afghanistan-Year-Round). Kabul records an average annual precipitation of 367mm. We selected Kabul city as the region of interest because it is an indicative as well as a characteristic city to evaluate and analyse growth indicators such as population, transformation, rapid urbanization and air pollution in the country. Despite the unfortunate events caused by the decades-long war and conflicts, Kabul seems to still maintain a stable urban growth. The economy of Kabul has been growing steadily and seems to be moving in the right trajectory. The location of the study area is as shown in the figure below.

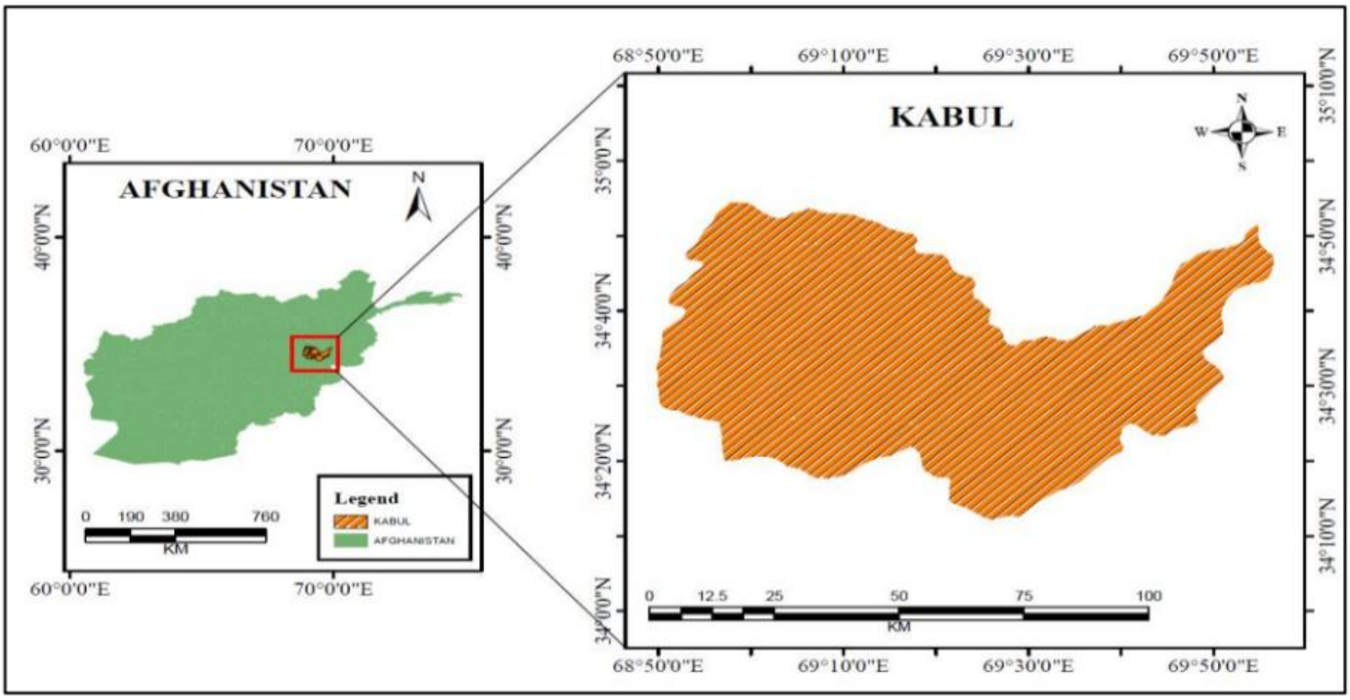

Figure 1: Area of interest (study area)

Study period and Data Source

The investigation period chosen for this study was from 1st of Jan 2001 to 31st December 2021. In this study we obtained secondary data from satellite observation United States Geological Survey (USGS) and Environmental Protection Agency (EPA). Precisely air pollution data was retrieved from EPA and geospatial data from (USGS). The geospatial data used include two multispectral satellite images from Landsat 5 (TM) and Landsat 8 (OLI) to evaluate LU and LC changes between the year's 2001 to 2021 respectfully.

Data Analysis

In this section, we analyzed air pollutants mentioned previously and the concentration of each individual pollutant was considered, we also analyzed LU and LC geospatial data. The geospatial images were analysed over a 20-year period between 2001 and 2021 as it is expected that major changes with regard to land use and land cover occurred during this period. Data analysis was carried out by IBM SPSS (version 19.0), ArcGIS and Excel. IBM SPSS software was used to evaluate the correlation between the air pollutants and the LU and LC, ArcGIS was used to establish the changes in LU and LC. Meanwhile, excel was used for annual average concentration of individual pollutants. Using these mean values, we were able to scrutinize the status and variations in air quality during the 2-decade period.

LU and LC Analysis

The data for LU and LC change was analysed using ArcGIS software. Landsat 8 OLI and Landsat 5 TM were adopted for the analysis of 2021 and 2001 respectfully. By stacking these multispectral images into one, a composite image with a false color composition was developed. This was later going to be the basis on which the classification was to be conducted. Spectral signatures were then collected and fed into a training sample (Nazari & Fei, 2020). The training sample was then introduced into a supervised classifier and quantified the land use and land cover changes throughout the study, using images that were obtained. All spatial data was prepared into ArcGIS and re-sampled using the same resolution and projection. In addition, all datasets were geometrically registered using the World Geodetic System (WGS_1984_UTM_Zone_36N) coordinate system of the used Landsat projection. In additional to all that, data was prepared in raster format, 30 × 30 meters cell size, the spatial resolution of Landsat was classified. ArcGIS was also used to map out the LU and LC because of its versatility to organize, visualize and analyze different layers of data and scenes. The land was divided into four categories i.e., Built up area, Bare land, Vegetation and Water Bodies. The (Table 1) below explains and describes exactly these categories.

Table 1: Description for the classified categories

S. No	Classification	Description
1	Built Up Area	Land altered by people, for example, residence, modern and mining region, transportation
2	Vegetation	Agricultural area, forest, Shrubs and grassland
3	Bare Land	Regions with under 10% vegetation contains rocks, sands, stone and hard soil.
4	Water Bodies	Visible Water surface, lake and dam.

Analysis for Air Pollution

The pollutants considered in this paper are; PM_2, SO_2, NO_2 and CO. Pollutants data was categories in to four (2) sections for analysis namely; annual means, seasonal and weekly concentration variation.

LU, LC and Air Pollutants Analysis

In this part of the study, we analyzed the correlation between the concentration of air pollutants and the LU and LC. Following the methodology of previous studies, the correlation between air pollutants concentration, LU and LC was analyzed to understand and established the true relationship between pollutants, LU and LC.). The correlation in this study was evaluated in IBM's SPSS, a statistical and analysis software and using the bivariate mode, the results were collected and are explained later in this study. Correlations between LU, LC and concentrations of pollutants were quantified based on the Pearson correlation coefficient. The equation involved is (Z. Zhu et al., 2019).

$$\rho_{x,y} = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \tag{1}$$

Here $\rho_{x,y}$ is the covariance between the two variables, σ_x is the standard deviation of land use type, σ_y represents the standard of air pollutant and σ_{xy} the product of the standard deviation of the two parameters. The correlation analysis conducted in here is a bivariate type of correlation. A correlation value of 1 indicated that the variables were significant positively correlated, a value of -1 indicated a significant negative correlation between the variables, and a value of 0 indicated no significant relationship between the variables. Parameters that have a correlation of 1 implies that two parameters are in perfect correlation.

3. Results and Discussion

LU and LC distribution for 2001

In order to understand the dynamic phenomena of development and growth, we require identifying sprawl patterns and analyse LU and LC change. These are fundamental inputs in urban planning and management. In this section we examine the GIS results of land use and land cover obtained from ArcGIS. Based on the GIS results (Fig 2), the changes in LU and LC varies from year to year depending on the rate of development. GIS results of 2001 and 2021 was obtained and then compared to find how the change was registered overtime. These changes can either be positive or increment over time (Sanga et al., 2021). The results in (Table 2) show that bare land had the largest coverage of 350 square kilometers and registered 34 percent of the total land area. water bodies had the second largest land area of about 230 square kilometers and attributed a 22 percent. Built-Up and vegetation both had 230 and 226 respectfully. Figure 2 below shows the distribution of each land use and land cover for the year 2001.

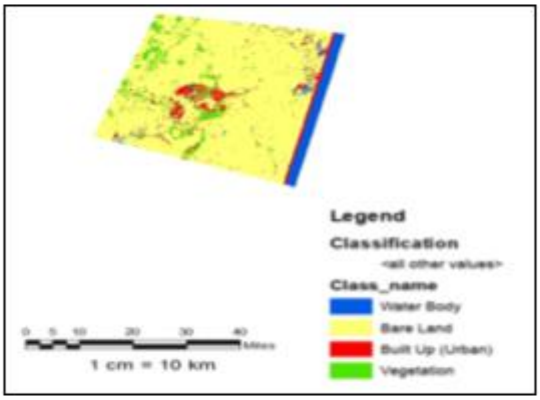

Figure 2: LU and LC change maps for 2001

Land use and land cover change over time

Shown in (figure 3), we see how the land use and land cover is distributed and spread over the study area, it was clearly shown that massive changes were recorded over a period of 2 decades from 2001 to 2021. It was also shown that there is a significant urban growth in terms of built-up area. From (Table 3), we see that built-area increased substantially and covered a total area of 367 square kilometers, attributing to a percent change of 66 percent, this high percentage could be due to transition of political instability to stability that led to significant socio-economic growth that leading to the high infrastructure development among four. In 2021, Bare land decreased notably, registering an area of 294 square kilometers a percent decrease of 15 percent. This land area conversion is likely transferred to Built-Up and is alluded to a massive urbanization that took place during this time. These results corroborated the results obtained by (Hidayat & Kajita, 2019) who conducted a case study on the rapid urbanization and management in Kabul. Vegetation increased substantially from 2001 to 2021, a percent increase of 0.86 percent. This is because of the afforestation policies put in place during this time period.

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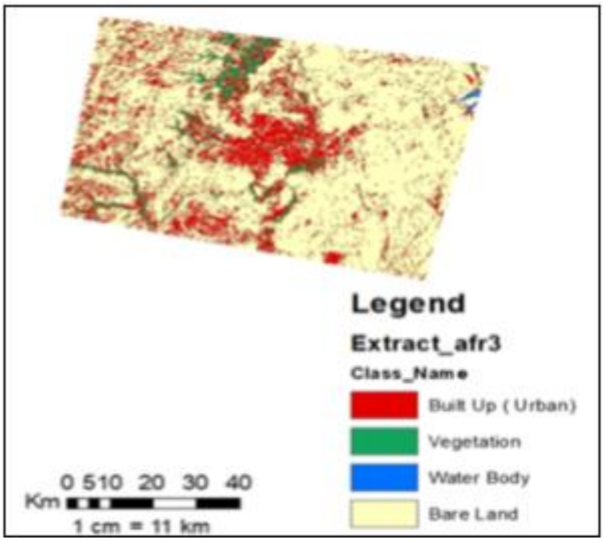

Distribution of land type

Shown in (Fig 4), land use and land cover over the period of 2 decades. From the (Fig 4), we can clearly observe that LU and LC have a comparable change seen over the study period. Built-up area was higher with a value of 366 km^2 as compared to the 220.57 km^2 observed in 2001. This was due to the rapid development and urbanization over the study period that led to infrastructure growth. Water bodies indicated a decrease in 2021, this conversion was transferred to built-up area and vegetation. Bare land also indicated a decrease while vegetation registered a minimal.

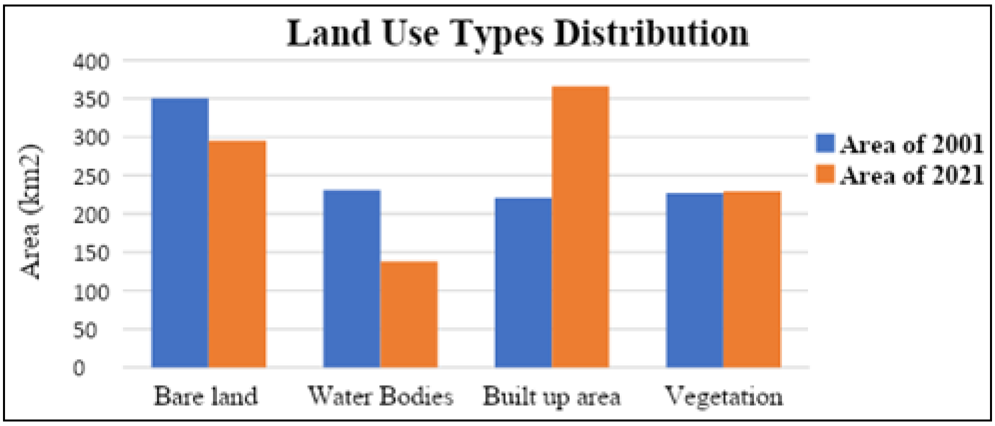

Figure 4: Graphical representation of LU and LC

Air pollutants trend

The city of Kabul experiences poor air quality and congestion. As of late, the ambient air quality in the city has deteriorated such that it tends to be ranked among the polluted urban areas in the world. From (Fig 5), it is observed that the annual averages of 2021 were high than that of 2001. As seen, the average yearly concentration of PM2.5 in 2021 was calculated at 47.46$\mu g/m^3$ which is two and half times the standard annual values of EPA of 15$\mu g/m^3$. In both 2001 and 2021, nitrogen dioxide pollutant recorded the highest value as seen in (Fig 5). The high concentration could be due to an increase in vehicle ownership and biomass burning. In addition, there are many other factors that can be attributed to such occurrences. Among them include; increase in generation of electricity from diesel engines, burning of tires for cooking and heating. In research from (Esmatullah Torab, 2016), the value of annual $PM_{2.5}$ exceeded the acceptable national limit of 35 $\mu g/m^3$ making it one of the unsafe air qualities in the world.

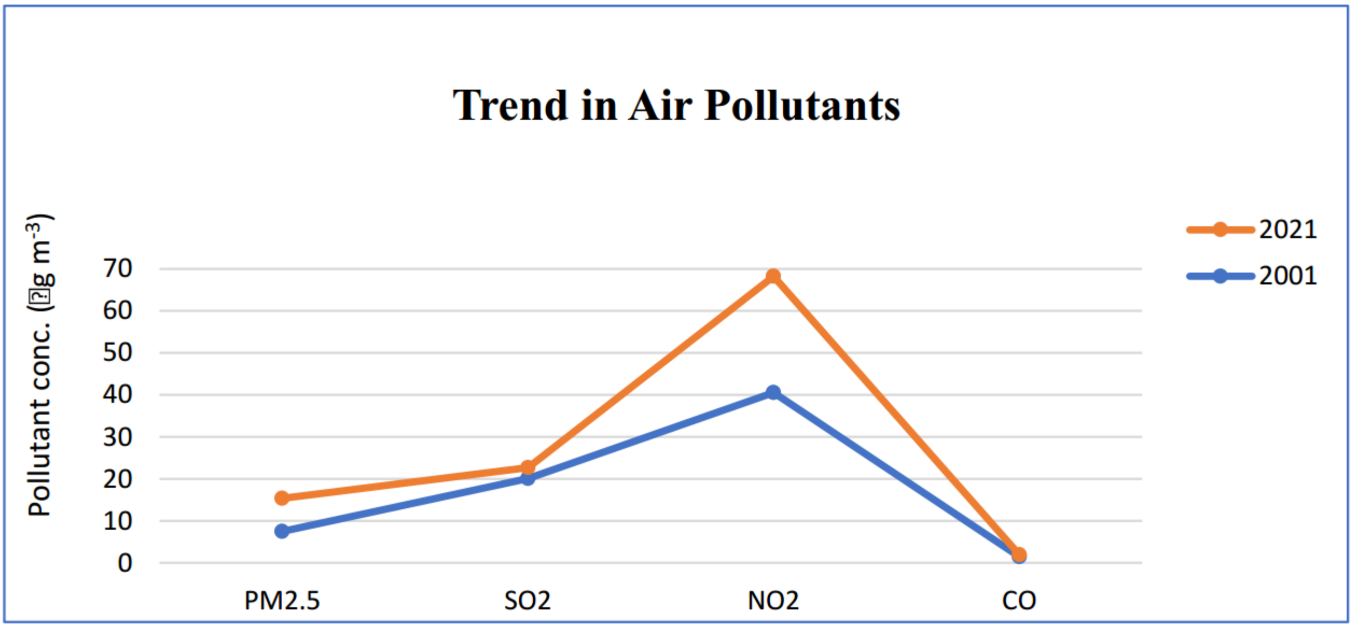

Figure 5: Air Pollutant Trend for 2001 to 2021

Relationship of LU, LC and air pollutants

In our analysis, it was found that air pollutant concentration was affected by land use. It was observed that PM2.5 was negatively correlated (-0.92) with water and SO2 correlated with vegetation positively (0.97). This concurs with the study conducted by (Yang & Jiang, 2021) who studied the influence of land use on particulate matter in the Shanxi Province of China. From (Table 5), we see that built-up area negatively correlated with PM2.5 but positively with bare land and vegetation. We can also observe that built-up area was significantly and positively correlated (0.308) with CO which indicates that vehicles emission was higher during this period. Meanwhile, NO2 was negatively correlated (-0.621) with built-up but positively correlated (0.79) with bare land vegetation (0.56). This can be attributed to increasing burning fire and the use of coal combustion for energy production.

4. Conclusion

In this paper, we analyzed the relationship of the relationship between land use and land cover types and air pollutant concentration of Kabul city (study area). We first evaluated and computed the LU and LC of the study area using ArcGIS and the results showed that built-up area increased substantially in the two decades registering an increase of about 66% - the highest among all categories. Vegetation was found to have increased at the value of (0.86%), this is alluded to the tremendous afforestation campaigns undertaken by the afghani government. Meanwhile, water bodies and bare land decreased at the values of 39.9% and 15% respectfully. For air pollutant, PM2, SO2, NO2 AND CO were considered as they are the main pollutants found in the area. By using the Pearson correlation, we were able to map out the exact relationship. The results showed that the 2021 air quality was worser than that of 2001. It was also revealed that PM2.5 was negatively (-0.921) correlated with water and SO2 correlated with vegetation positively (0.965). This could likely have been due to the afforestation activities undertaken to curb the air pollution issues in the city. Calculations show dangerous levels of PM2.5, SO2, NO2 and CO and the numerical values obtained for air pollutants in the study ought to help the policymakers, urban planners and the international organizations engaged with the reconstruction of Afghanistan. These results show that changes in land use may directly or indirectly impact the air quality and to ensure a healthier environment in which people can live, actions such as afforestation should be implemented and policed. This study will hopefully facilitate the officials of the Afghan government in comprehending the magnitude of deterioration of ambient air quality in Kabul. There were some limitations that we encountered. For example, we were only able to classify the land in four categories. This doesn't give a proper and unbiased finding. In order to overcome this, and with sufficient resources, in further research, refining and narrowing down the classification to more granular categories should be emphasized. This will ensure more comprehensive and accurate findings.

Appendices

Table 2: Land use for 2001

Land Use Type	Land Area Coverage (Km^2)	Percent of Total area (%)
Built-Up area	220.57	21.4
Bare Land	350.37	34.0
Vegetation	226.715	22.1
Water Bodies	230.715	22.5
Land Use	1027.43	100

Table 3: Land use for 2021

Land Use Type	Land Area Coverage (Km^2)	Percent of Total area (%)
Built-Up area	366.15	35.62
Bare Land	294.70	28.66
Vegetation	228.70	22.24
Water Bodies	138.42	13.46
Land Use	1027.43	100

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Table 5: LUCC and air pollutant correlation relationship

Air pollutant	Land Use type			
	Built-up Area	Bare land	vegetation	Water bodies
PM2.5 (μg/m^3)	-0.376	0.8130	0.880	-0.921*
SO2(μg/m^3)	-0.214	0.767	0.965*	-0.994
NO2(μg/m^3)	-0.621	0.794	0.558	-0.929
CO(μg/m^3)	0.308	0.825	0.968*	-0.929

** means the correlation is significant at 0.01 (two-tailed);
* Means significant at 0.05 level (two-tailed)

Table 4: Change rates in land use and land cover

Land use type	Land coverage in 2001 (Km^2)	Land coverage in 2021 (Km^2)	Percentage change (%)
Built-Up Area	220.57	366.15	66.0
Bare Land	350.37	294.70	15
Vegetation	226.715	228.7	0.86
Water Bodies	230.715	138.4	39.9

Author's contribution M.K: data organizing, formal analysis, investigation, writing-original draft. E. J. D: writing-review and editing, S.S: data organizing, O.A.H: data organizing, K.A: Supervision

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Author Profile

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Muna Kabamba is an engineer who just completed his Bachelor of technology (B. Tech) in civil engineering. Mr. Muna Kabamba is a junior researcher in both civil and environmental engineering with a focus in land use land changes, air pollution and air quality control.