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ASSESSING THE IMPACT OF LAND USE CHANGES ON AIR POLLUTION REMOVAL CAPACITY: A THREE-DECADE ANALYSIS APPLYING THE I-TREE ECO MODEL

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ABSTRACT

Urban vegetation is a greenery and plant found within urban areas. It encompasses a diverse range of flora, including trees, shrubs, grasses, flowers, and other forms of vegetation that thrive amidst the concrete and infrastructure of urban environments. But urban growth continuously removes this and causes atmospheric pollution in third world countries like Pakistan. Therefore, being the most rapidly growing city in Pakistan, Lahore was selected as a study area to analyze the air pollution removal capacity from 1990 to 2020. For this, Landsat images of 1990, 2000, 2010 and 2020 were used by applying the I-Tree Eco Model and found that the study area lost 2934.06 tons in pollutants removal capacity from 1990 to 2020 at 94.65 tons/year. Therefore, it is suggested that urban vegetation should be preserved and maintained as a primary pillar of urban society. As cities continue to grow and urbanization intensifies, there is a time to understand the significance of urban vegetation becomes increasingly critical.

KEYWORDS: Air Pollution, Land Use Changes, Pollutant Removal Capacity, Urban Vegetation

1. INTRODUCTION

Urban trees and vegetation help remove air pollutants and contribute to improved air quality for better public health. Urban vegetation is the cheapest and most natural air filter. They have the ability to remove air pollution (Abhijith & Kumar, 2019; Jabbar & Yusoff, 2022; Kumar et al., 2019). Vegetation reduces air pollution by providing a buffer zone between humans and pollutant sources (Hagler et al., 2012). The characteristics of vegetation, like the height of plants and vegetation thickness, help reduce air pollutants. For instance, a tall, thick, and complete canopy-covered area reduces downward pollution because the canopy acts as a buffer zone (Brantley et al., 2015). Vegetation is a significant feature of the environment, and even roadside vegetation is a significant source of pollutant removal and improves human health by providing clean air for breathing (Deshmukh et al., 2019). Some observational studies demonstrated mixed findings on the relationship between urban trees and air pollution. A lower level of NO_2 was found under Quercus ilex canopy than in open areas of Siena in Italy (Fantozzi et al., 2015) and three Spanish sites (García-Gómez et al., 2016). In Shanghai, lower concentrations of NO_2 are found in parks with tree cover areas than tree cover (Yin et al., 2011). In Sydney, Australia, there were no discernible patterns in NO2 concentration variations between areas with high traffic and those with abundant green spaces. However, certain field-based investigations, such as the one conducted by Irga et al. in 2015, did observe reductions in PM levels in areas with more canopy coverage. Consequently, it is important to recognize that the mitigation of air pollution by vegetation should be managed not only at a local level but also at the neighborhood and municipal scales. This is particularly crucial because the capacity of specific plant species to remove pollutants may be influenced by various external factors, including wind conditions and local concentrations of air pollution (Jabbar et al., 2021; Audi & Ali, 2023). So, it can be analyzed that the loss of urban vegetation in the study area positively impacts air pollution. The study analysis supports that the loss of trees is one of the significant causes of air pollution in the study area.

A study conducted the first-ever evaluation of the impact of multiple i-Tree Eco projects. The study's results highlight that comprehensive ecosystem assessment and valuation tools like i-Tree Eco can be valuable resources for environmental decision-makers and managers. i-Tree Eco offers a wide-ranging assessment of urban forests, encompassing their composition, structure, and overall condition, with a particular focus on the local level. The

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process of quantifying and assigning value to crucial ecosystem services aids in guiding management choices, such as the selection of tree species, and reinforces the argument for investing in urban forests. These i-Tree Eco initiatives have played a significant role in shifting the perspective of local governments from viewing trees primarily as expenses and potential liabilities to recognizing their inherent value and benefits (Raum et al., 2019).

Another study focused on estimating the current and potential tree cover and its contributions to ecosystem services. It concluded that i-Tree Eco contributes to tree cover benefits by reducing air pollution (Wu et al., 2019), managing stormwater, conserving building energy, and mitigating carbon emissions in London. The present estimated value of urban tree benefits across ten megacities includes $482 million per year from reduced levels of CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$, $11 million per year from the avoidance of stormwater processing costs by wastewater facilities, $0.5 million per year from energy savings related to building heating and cooling, and $8 million per year from CO_2 sequestration. Expanding tree planting efforts in areas with the potential for tree cover could nearly double the benefits derived from urban forests (Endreny et al., 2017).

Urban vegetation plays a crucial role in ventilating densely populated areas. A study was conducted to evaluate and quantify the present and future biophysical and economic value of the regulatory ecosystem service offered by urban forests in Tabriz, Iran. The findings indicate that, in 2015, trees and shrubs collectively removed 238.4 tons of pollutants annually, indicating a relatively modest capacity for air purification when compared to other cities worldwide. However, implementing appropriate yet feasible urban forest management and development practices could potentially enhance this capacity, resulting in a cumulative removal of up to 814.46 tons over the next two decades (Parsa et al., 2019). These approaches for evaluating air pollution removal capacity lay the foundation for quantitatively assessing and optimizing the future status of urban ecosystem services (Jabbar et al., 2021; Audi & Ali, 2023).

So, according to the above cited literature, urban vegetation is a significant pillar of a safe and sustainable city. The vegetation is a sign of better health for the city and its residents. However, the situation in most of the urban areas is adverse due to the rapid increase of built-up areas, which is one of the significant causes of atmospheric pollution. Similarly, Lahore is one of the most rapidly growing cities in Pakistan and losing its vegetation swiftly. Therefore, the study aims to analyze the air pollution removal capacity of the city from 1990 to 2020.

2. METHODOLOGY

2.1. THE STUDY AREA

Lahore, the study area, is the capital of the Punjab province, and it can be observed between 31° 15' to 31° 43' N and 74° 10' to 74° 39' E in the world map as shown in figure 1.

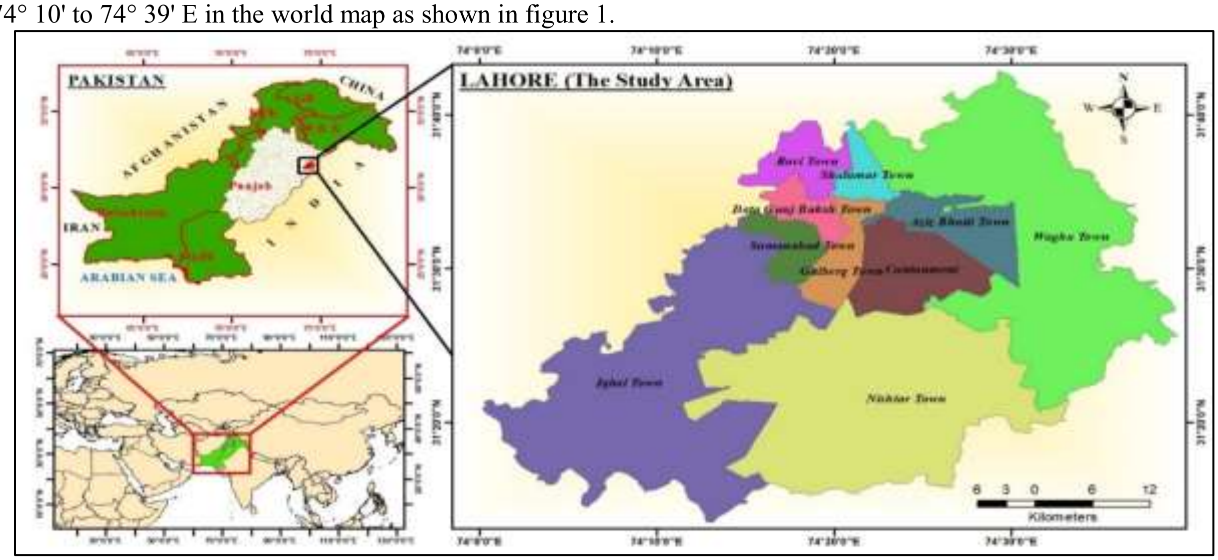

Figure 1: Location Map of the Study Area

2.2. DATA COLLECTION

The study used i-Tree Eco, a software program developed by the United States Forest Service that helps communities assess the structure and functions of their urban forests. It is used to quantify the economic, environmental, and social benefits of trees and forests in urban areas. i-Tree Eco utilizes a combination of field data collection and computer modelling to estimate various aspects of urban forest health and value. Therefore, the field data collected about the urban vegetation, such as tree species, size, condition, and location. This data can be collected through remote sensing techniques.

2.3. DATA INPUT

The collected data was entered into the i-Tree Eco software. This data forms the foundation of the analysis. i-Tree Eco uses various algorithms and models to analyze the data and estimate a wide range of urban forest attributes. The following key factors were assessed:

- Tree species diversity and distribution.
- Tree health and condition.
- Carbon sequestration by trees.
- Air quality improvement through tree canopy.
- Energy conservation due to tree shading and windbreak.
- Stormwater runoff reduction.
- Economic benefits, such as property value increase.
- Aesthetic and social benefits.

2.4. SAMPLING

The study used Landsat Images of 1990, 2000, 2010 and 2020 to evaluate land use changes, as given in Appendix A. Similarly, the study collected 500 samples of each Landsat Image on the same sites, as shown in figure 2.

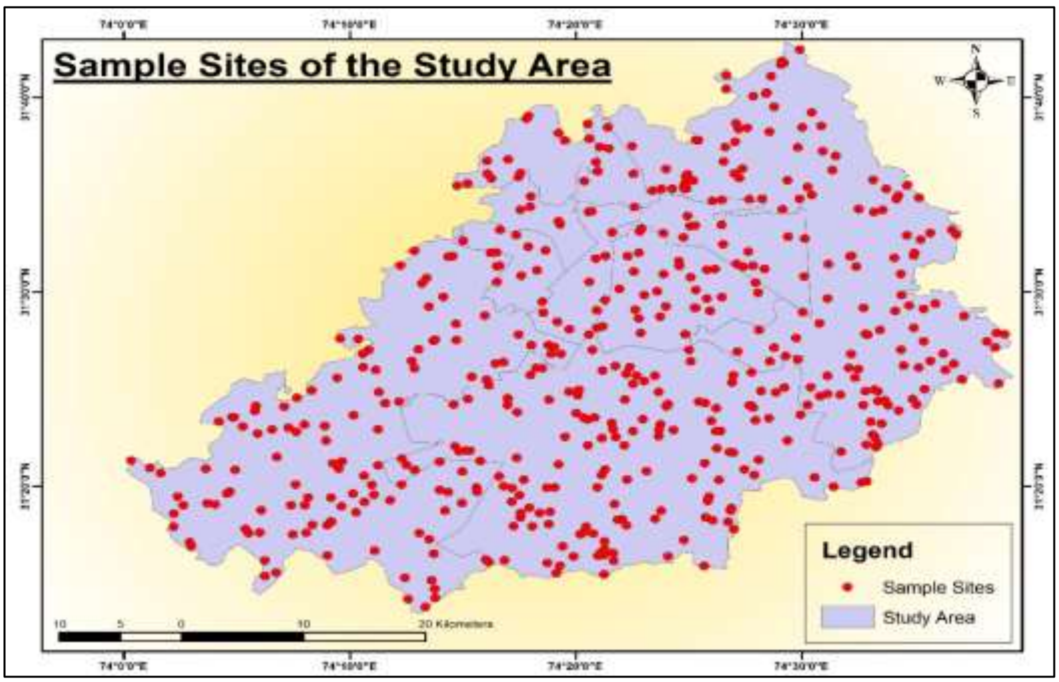

Figure 2: Sample Sites of the Study Area

2.5. REPORTING

The software generated detailed reports that provide information on the assessed urban vegetation's current state and the benefits it provides to the community in the form of the capacity of pollutant removal or sequestration of pollutants. The role of urban vegetation in removing air pollution was computed using the i-Tree Eco Model software. After that, the changes that occurred in the last three decades were calculated based on land use changes from 1990 to 2020 as shown in Appendix A. As the Forest Land of the study area has been decreasing with land use changes, the capacity of urban vegetation for air pollution removal also decreased. So, the changes in air pollution removal were computed based on changes in urban vegetation. In this way, the obtained results are given below in detail.

3. RESULTS

3.1. POLLUTANT REMOVAL CAPACITY

The capacity of pollutants (CO, CO_2, NO_2, O_3, SO_2, $PM_{2.5}$, PM_{10}) removal in the study area from 1990 to 2020 is shown in figure 3. According to the figure, the study could remove pollutants: 6004.05 tons in 1990, 4439.57 tons in

2000, 3795.82 tons in 2010, and 3070 tons in 2020. In this way, the study found a decrease of 2934.06 tons in the pollutants removal capacity of the study area from 1990 to 2020 at 94.65 tons/year.

Similarly, the study analyzed the air pollutants removal capacity of the study area and found that it has lost its 2934.06 tons of air pollutants removal capacity from 1990 to 2020. Similarly, the study area has lost 2660 kilotons of storage capacity of CO, and 9621 kilotons of CO_2, as well as the study has lost 104.41 kilotons sequestering of CO and 383.16 kilotons sequestering of CO_2 capacity from 1990 to 2020. So, the study area is losing its pollutant removal capacity with the loss of its green cover.

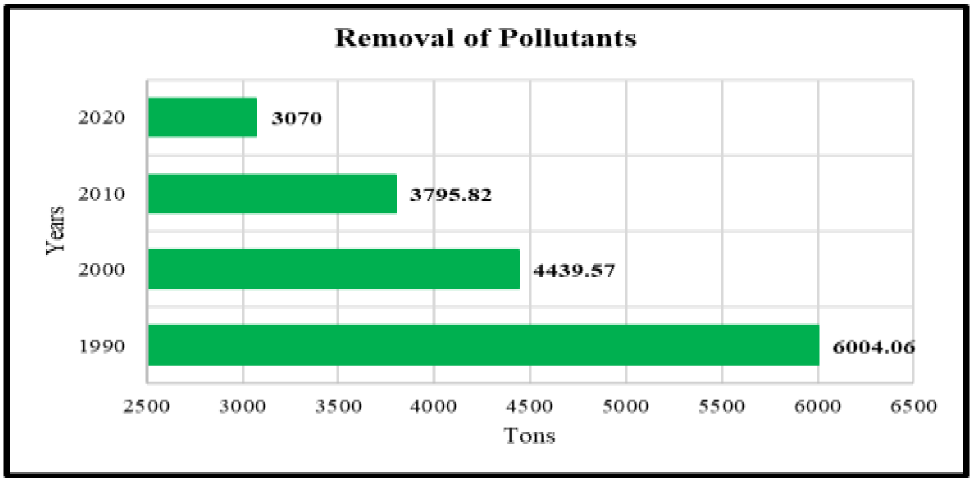

Figure 3: Annual Pollutant Removal Rate of Vegetation in the Study Area

Similarly, this study assesses how trees of the study can remove air pollution and how it was in the past, which will help urban management for future planning. The study provides the capacity of air pollution removal and the economic value of the tree services. It is easy to understand the green economy of the study area for community awareness and future management through environmental valuation. The study findings are expected to be beneficial for air pollution control planning in the future. It is not commonly known that trees are essential for us, especially because of their environmental cost. Therefore, the environmental valuation may benefit the study area's healthy environmental future.

3.2. AIR QUALITY

Clean air is characterized by minimal levels of solid particles and chemical pollutants, and it is referred to as good air quality. Conversely, poor air quality is marked by elevated pollutant levels, often resulting in a cloudy and harmful environment for both human health and the ecosystem (Source: "What Is Air Quality? | Center for Science Education, n.d."). To assess air quality, the Air Quality Index (AQI) is employed. It quantifies the concentration of pollutants present in the air within a specific region, offering a measure of air quality. Figure 4 illustrates the air quality in the studied area.

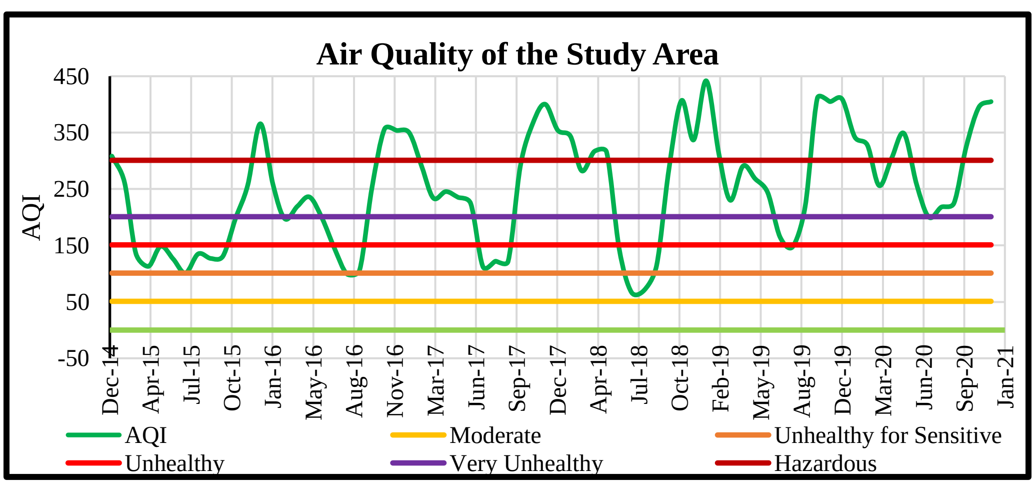

Figure 4: Air Quality of the Study Area

According to the figure, the air quality of the study area is found above Good AQI according to PEQS. In the whole year's air quality, only June, July, and August were found within Moderate to Unhealthy for the sensitive group (51 to 150 AQI), whereas autumn (September and October) and spring (March and April) seasons months found within Unhealthy to Very Unhealthy (151 to 300 AQI) in the study area. Winter (December, January, and February) is the most polluted season for the study area in which AQI keeps a Hazardous (above 300 AQI) zone. So, the study area found Unhealthy and Very Unhealthy air quality on maximum days of the year and Hazardous in every winter (December, January, and February).

4. DISCUSSION

Urban green spaces are the cheapest and most natural air filters. They can reduce air pollution (Abhijith & Kumar, 2019; Kumar et al., 2019). Vegetation reduces air pollution by providing a buffer zone between humans and pollutant sources (Hagler et al., 2012; Ali et al., 2022). The characteristics of vegetation, like the height of plants and vegetation thickness, help reduce air pollutants. For instance, a tall, thick, and complete canopy-covered area reduces downward pollution because the canopy acts as a buffer zone (Brantley et al., 2015). Vegetation is a significant feature of the environment, and even roadside vegetation is a significant source of pollutant removal and improves human health by providing clean air for breathing (Deshmukh et al., 2019; Ali et al., 2021). Some observational studies demonstrated mixed findings on the relationship between urban trees and air pollution. A lower level of NO_2 was found under Quercus ilex canopy than in open areas of Siena in Italy (Fantozzi et al., 2015) and three Spanish sites (García-Gómez et al., 2016). In Shanghai, lower concentrations of NO_2 are found in parks with tree cover areas than tree cover (Yin et al., 2011). In Sydney, Australia, there were no discernible patterns in NO_2 concentration variations between locations with high traffic and those with abundant green spaces. However, certain field-based studies, such as the one conducted by Irga et al. in 2015, did observe reductions in PM levels in areas with more tree canopy coverage. Consequently, it is important to recognize that the effectiveness of vegetation in removing air pollution should be managed not only at a local level but also at the neighborhood and municipal scales (Gómez-Moreno et al., 2019). This is particularly crucial because the capacity of specific plant species to remove pollutants can be influenced by various external factors, such as wind conditions and the local concentration levels of air pollution (Hanif et al., 2023). So, it can be analyzed that the loss of urban vegetation in the study area positively impacts air pollution. The study analysis supports that the loss of trees is one of the significant causes of air pollution in the study area.

Urban vegetation, including trees, shrubs, and grasses, can help remove various pollutants from the atmosphere. Trees and plants can capture airborne particles through their leaves and branches. This includes both PM_{10} (coarse particles) and $PM_{2.5}$ (fine particles), which are harmful to human health (De Carvalho & Szlafsztein, 2019). Nitrogen Dioxide (NO_2): Trees can absorb and store NO_2 in their leaves, reducing the concentration of this harmful gas in the air (Van Ryswyk et al., 2019). Trees absorb CO_2 as part of photosynthesis, helping to mitigate greenhouse gas emissions (McPherson et al., 2003). Trees release volatile organic compounds that can react with and neutralize certain harmful VOCs in the air (Badach et al., 2020). While high levels of ozone can damage trees, they can also help reduce ground-level ozone concentrations by absorbing some of them (Linden et al., 2023). Therefore, the findings of the above cited studies support the results of this study.

5. CONCLUSION

It is concluded that the study area is rapidly losing its vegetation cover, which is the primary cause of atmospheric pollution in the study area. Air pollution removal capacity has been decreasing with the reduction of urban green cover; therefore, the study area has to face hazardous atmospheric conditions. Most of the time, the quality of the study area is found in an Unhealthy air quality zone. The summer season is mainly found within the Moderate to Unhealthy for the sensitive group, whereas the autumn and spring seasons keep within the Unhealthy and unhealthy air quality zones. Winter is the most polluted season for the study area, which faces Hazardous air quality. In this way, the study area has converted from an Unhealthy and Very Unhealthy place. So, the data reports generated by the study can be used by urban planning, policymaking, and community organizations to make informed decisions about managing and preserving urban forests. It helps them prioritize tree care and conservation efforts based on the economic and environmental benefits.

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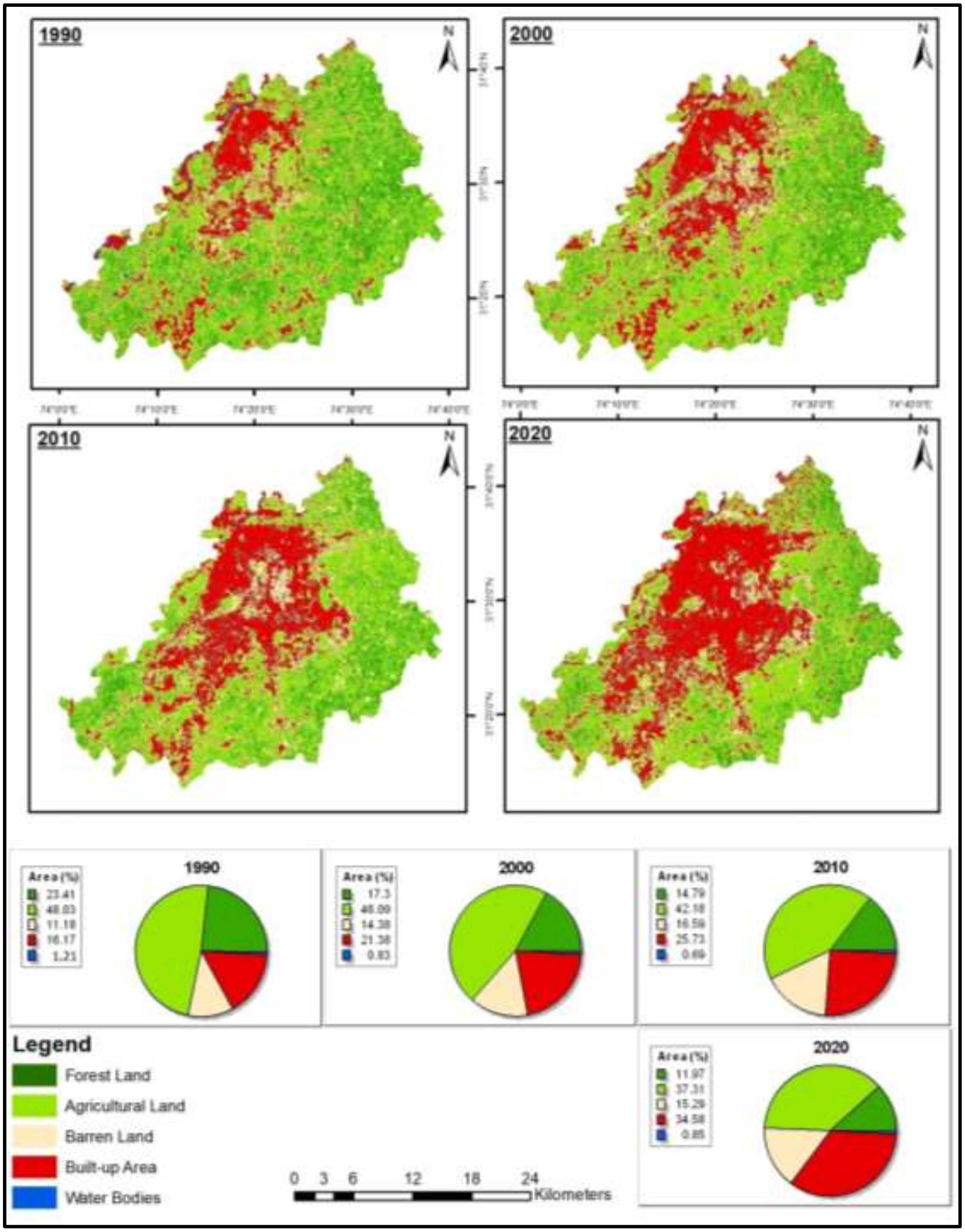
APPENDIX-A


1990
2000
2010
2020
N
Area (%)
23.41
48.03
11.18
16.17
1.21
17.3
46.09
14.38
21.38
0.83
14.79
42.18
16.59
25.73
0.69
11.97
37.31
15.29
34.58
0.85
Legend
Forest Land
Agricultural Land
Barren Land
Built-up Area
Water Bodies
0 3 6 12 18 24
Kilometers