

Geo-Spatial Approach for Urban Green Space and Environmental Quality Assessment: A Case Study in Addis Ababa City

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Abstract

Depending on the rapid growth in infrastructural developments along with the increasing of human population, quality of cities is being deteriorated globally. Assurance of environmental quality is essential for urban planning and developments. This paper presents the potential application of urban green areas as an indicator of urban environmental quality in Addis Ababa, Ethiopia based on indicators of natural parameters extracted from remotely sensed images, and socio-economic variables derived from census data. Physical environmental variables such as land-use/land-cover data, surface temperature, normalized difference vegetation index, and transformed remote sensing variables derived from three landsat images of 1986, 2000 and 2015 were analyzed for the present study. Socio-economic variables including population density and greenhouse gas emission in 2012 were used. Regression analysis, factor analysis and overlay analysis were performed after the two groups of variables were integrated. Four factors such as greenness, crowd, heat island and greenhouse gas emission were used for interpretation. By assigning different weights to each of these factors and proportion of green areas, land-use/land-cover map, environmental risk map and environmental quality index map were generated. The results show deterioration of environmental quality in the study area. It is recommended that future studies should include more parameters to provide a holistic view of the changes in greenness of the city and to try to mitigate adverse effects of development activities leading to human density and depletion of green area in the city.

Keywords

GIS, Landsat, NDVI, Spatiotemporal Distribution, Urban Green Space

1. Introduction

Urban environment quality in the developing part of the world is deteriorating day by day. Large cities are reaching human saturation levels, and are unable to cope up with diverse types of human-induced pressures [1] [2]. Greenery is one of the important ingredients for urban planning with a sustainable environmental quality. Urban environmental quality is based on social, economic, cultural, physical and emotional indices [3]. Urban green spaces and vegetation cover play major roles in balancing human biophysical interconnections and in keeping environmental quality. Green space is a basic requirement of any city that makes tremendous contributions aesthetically and ecologically to the city dwellers for better quality of life [4].

Urban greenery is defined as the overall extent of outdoor space with vegetation cover of trees, bushes, ornamental plants, or grass. Examples of such spaces are squares, parks, rows of trees on road sides, groves, and planted spaces in yards of public or private buildings [5]. Parks and open spaces provide greater diversity of green spaces with positive effects on environmental quality in many megacities around the world [6] [7]. Green space is an important part of urban ecosystems that provides environmental, esthetic, recreational and economic benefits to the urban dwellers. Vegetation provides sufficient oxygen through photosynthesis, pleasing temperatures, cooling through shading and enhanced evapotranspiration [8]. The existence of urban green area in a contemporary urban environment is expected to improve air quality, reduce noise and air pollution and enhances aesthetic quality. Development of urban greenery is a key factor of the overall city planning, as its benefits have direct effects on the environment as well as on the quality of life of its residents. Due to its multi-dimensional, multifaceted and multidisciplinary nature, only one indicator alone cannot measure environmental quality. It requires the integration of a variety of elements such as greenery, built up area, carbon emission, temperature, humidity, waste disposal, accessibility to major roads and population density [9]. However, a major challenge in urban environmental quality is the limit to model and to predict the interactions of all these variables.

The integrated framework of Remote Sensing (RS) and Geographical Information System (GIS) techniques greatly reduces time, effort and expenses in using geographical data. Remote sensing with its advantages of spatial, spectral and temporal availability of data coverage of large and inaccessible areas within a short time has become a handy tool in assessing, monitoring and conserving urban greenery [10]. Satellite Remote Sensing, with its repetitive coverage together with multi-spectral scanner (MSS) capabilities is a powerful tool to map and monitor changes in the areas of analysis [11]. Satellite images enable us to better understand some of the intrinsic components of the ecosystem and the interactions within the whole environment. The relevance of remote sensing monitoring in urban environmental quality is further enhanced by GIS, which makes it possible to integrate remote sensing data with socio-economic variables and *in situ* data [3] [12].

In this research, distribution of urban green area and vegetation density were analysed as the major index for air freshening, which generally improves the urban environmental quality. Building density, population density, temperature, humidity, waste disposal, accessibility to major roads and carbon emission were considered as major indices of degradation of city environment. Understanding the causal factors is a prerequisite to assess and maintain sustainable urban environmental quality. The objectives of the present study were to map the urban green space and evaluate environmental quality of the ten sub-sites of Addis Ababa using natural and social parameters, derived from remote sensing satellite imagery and secondary data.

2. Study Area and Methods

2.1. The Study Area

Addis Ababa, the capital city of Ethiopia, is one of the largest urban centers in the Sub-Saharan Africa. It is located between latitudes $8^{\circ}49'N$ - $9^{\circ}5'N$ and longitudes $38^{\circ}38'E$ - $38^{\circ}54'E$, covering a total area of 51,957.92 ha (**Figure 1**). Altitudinal zones of Addis Ababa range from 2054 m to 3023 m asl., situated in the foothills of the Entoto Mountains, spread across many wooded hillsides and gullies, cut through with fast flowing streams. At present, the city is divided

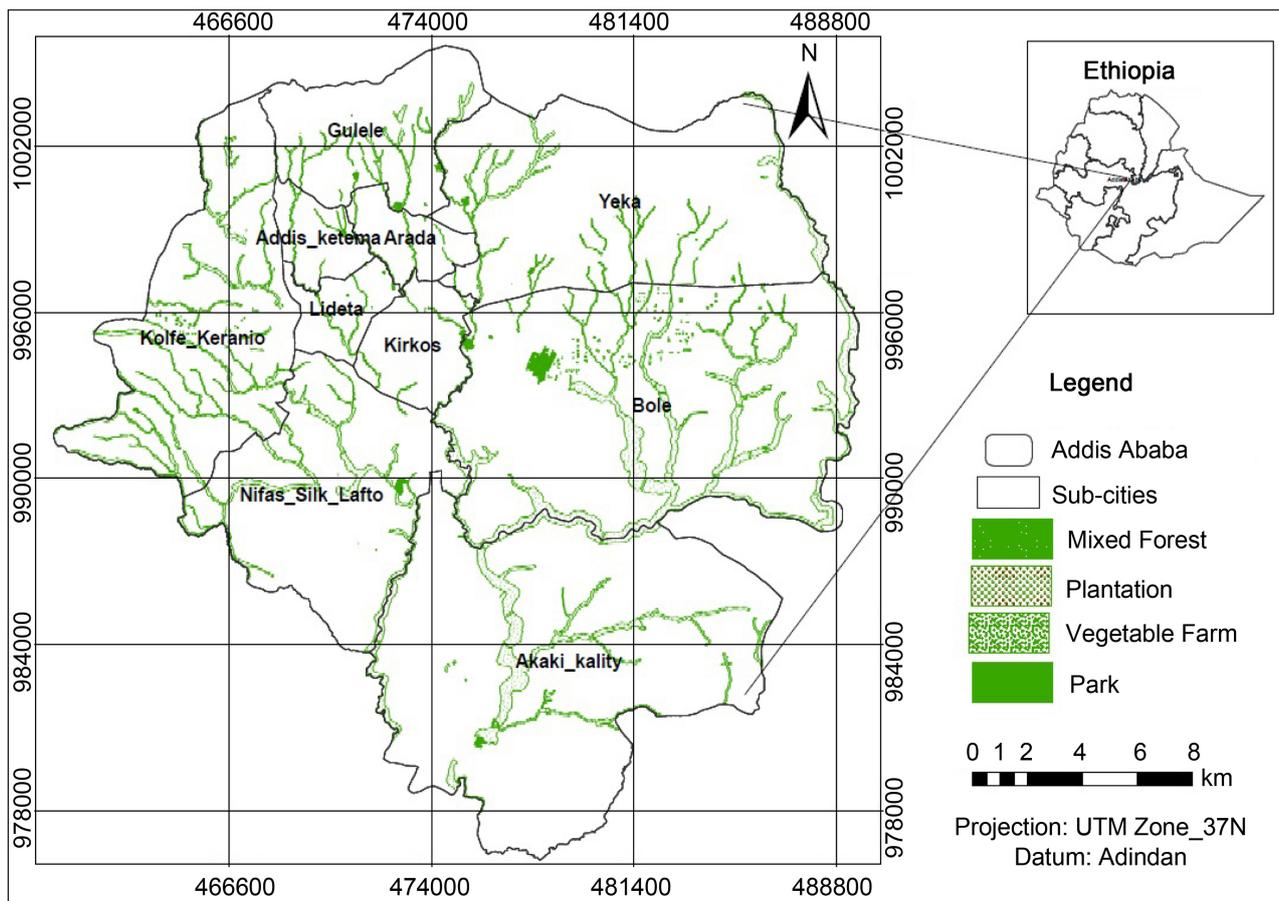


Figure 1. Location map of Addis Ababa.

in to 10 sub-cities and 116 woredas (administrative districts). Long-term mean annual maximum and minimum temperatures of the city are 24.4°C and 7.2°C, respectively. The total population of Addis Ababa is 3,275,348, which is about 60% of the total urban population in Ethiopia [13].

2.2. Methodology

The data sources for this research primarily came from Landsat images. Secondary data were from National Meteorology Agency of Ethiopia, Central Statistical Agency and Addis Ababa Environmental Protection Authority. The population census data were collected from Central Statistical Agency. The three Landsat images included TM 1986, Landsat 2000 and ETM+ 2015. All images were georectified to a common UTM coordinate system. For the image, 250 ground control points were selected to generate coefficients for a first-order polynomial, and a nearest-neighbor method was applied to resample the image according to their original theoretical spatial resolution. The distribution and quantity of land-use/land-cover patterns, distribution and density of vegetation cover Normalized Difference Vegetation Index (NDVI), surface temperature, greenhouse gas emission, built up density and population density were measured, evaluated and compared for each of the sub-cities in Addis Ababa. **Figure 2** shows the general methodology flowchart of the present study.

2.2.1. Normalized Difference Vegetation Index

Normalized Difference Vegetation Index was applied for measurement of vegetation distribution and density. Vegetation has a high reflectance in the Near Infrared Red (NIR) bands of a sensor system because of the internal reflectance by the spongy mesophyll tissue of green leaves [14]. The NDVI separates soil vegetation from other ground cover. Its ratio was calculated through the difference of near infra-red (NIR) and red band (RED), which was normalized by summing up these two bands using Equation (1) [15]:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad (1)$$

2.2.2. Surface Temperature Extraction

The thermal bands of Landsat 8 band 10 and 11 were converted to radiance by calculating the satellite temperature. The satellite temperature was corrected using the emissivity values computed from the NDVI and the satellite temperature was changed to the surface temperature. Basically, the following three steps were involved in the procedure: first, converting the digital number (DN) values of the thermal band into spectral radiance; second, converting the spectral radiance to at satellite brightness temperature, *viz.*, blackbody temperature; and third, adjusting the blackbody temperature to land surface temperature by incorporating emissivity biases due to land-cover differences.

1) Conversion of DN Values to Radiance

Operational land imager (OLI) and Thermal Infrared Sensor (TIRS) band data

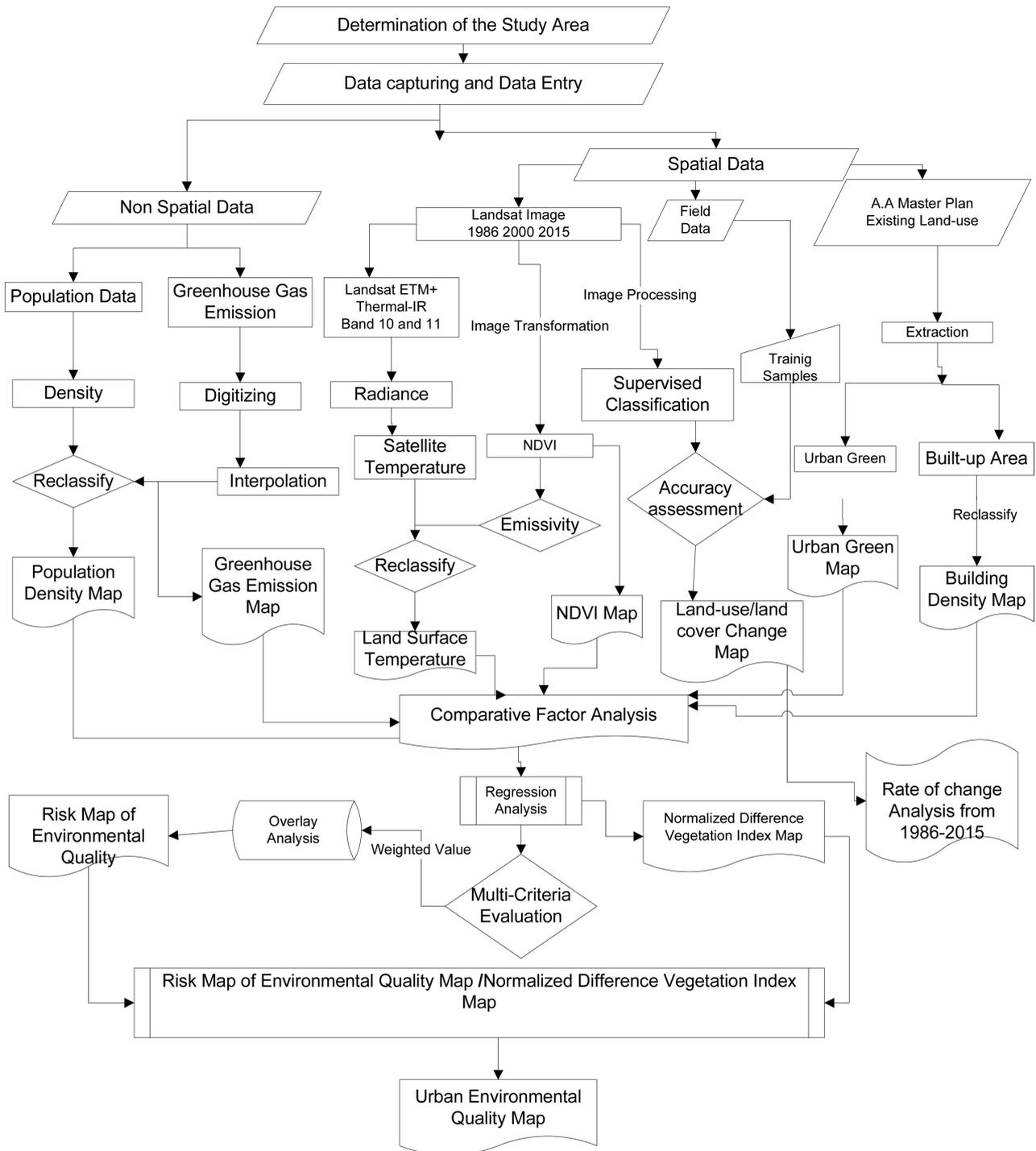


Figure 2. Flow chart of general methodology.

were converted to Top-Of-Atmosphere (TOA) special radiance rescaling factors provided in the metadata file. The first step was conversion of the DN value to the radiance units using Equation (2).

$$L_{\lambda} = M_L * Q_{cal} + A_L \tag{2}$$

where, L_{λ} is the TOA special Radiance(watts/(m² srad μm)), M_L is the Band specific multiplicative rescaling factor from metadata (Radiance_Mult_Band_x

where x is band number), A_L is the Band specific additive rescaling factor from metadata (Radiance_Add_Band_x where x is band number) and Q_{cal} is the Quantized calibrated pixel value in DN's.

2) Conversion of Radiance to at Satellite Temperature

The next step during quantitative analysis was conversion of radiance to temperature. The satellite temperature was calculated under an assumption of unity emissivity using pre-launch calibration constants K_1 and K_2 by the following Equation (3):

$$T = \frac{K_2}{\ln \left[\frac{K_1}{L_\lambda} + 1 \right]} \quad (3)$$

where, T is the satellite brightness temperature (K), K_2 is the calibration constant (K) and K_1 is the calibration constant ($W/m^2 \text{ sr } \mu\text{m}$).

3) Land Surface Temperature

Land surface temperature was computed from calculated emissivity values and calculated temperature at satellite using the following Equation (4):

$$T_{LST} = \frac{T_B}{1 + W * (T_B / \rho) * \ln \varepsilon} \quad (4)$$

where, $T_{LST} \rightarrow$ Surface temperature (K), $T_B =$ at satellite temperature, W is the wavelength of emitted radiance ($11.45 \mu\text{m}$), $\rho = h^* c / k (1.438 \times 10^{-2} \text{ m}\cdot\text{k})$ with $\sigma =$ stefan Boltzmann constant ($1.38 \times 10^{-23} \text{ J/K}$), h is the plank's constant ($6.26 \times 10^{-34} \text{ J}\cdot\text{s}$) and c is the velocity of light ($2.998 \times 10^{-8} \text{ m/s}$).

2.2.3. Regression and Factor Analysis

All the five parameters extracted from the physical and secondary datasets were first entered to run ordinary list square correlation analysis. To shed some light on their qualification on the study, Coefficients have the expected sign, statistically significant, no redundancy among explanatory variables, residuals are normally distributed, residuals are not spatially auto-correlated and strong adjusted r-squared value summarizes their correlation with all the variables that have been evaluated. For land-use/land-cover, the following methods of data analyses were adopted for the study using Maximum Likelihood classification, accuracy assessment with 250 reference points calculation of the area in hectares of the land-use/land-cover types obtained for each study year and subsequently comparing the results and finally annual rate of change ($\text{ha/year} = (\% \text{ of recent land-use/land-cover change} - \% \text{ of previous land-use/land-cover change}) / 100 * \#$ (15 years).

2.2.4. Overlay Analysis

Overlay Analysis tools included in the spatial analyst extension commonly used to solve multi-criteria problems such as optimal site selection or suitability modeling. It is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis [16] to address which locations are

most exposed to environmental degradation. The first step was to model operators using ordinary least squares linear regression to generate prediction to model a dependent variable in terms of its relationships to a set of explanatory variable. Then to generate risk-map of environmental quality, parameter layers were computed by reclassifying as population density, building density, urban heat, greenhouse gas density and land-use/land-cover classification. The overall accuracy for land-use/land-cover of 1986 image classification was 88.80%, of 2000 was 85% and of 2015 was 84.00%. All data groups summarizes as per priority classes, points and influence (weight) values used for weighted overlay to come up with the final environmental risk map of the study area, to show the level of environmental quality of the study area. According to this index, the regions with high greenhouse gas emission, overpopulated, high building density, high heat intensity and low vegetation cover area would get the lowest values, and they will be considered as critical areas. Sparsely populated, low heat, less built-up, low greenhouse gas emission and high vegetation cover areas are considered as environmentally suitable areas.

3. Results

3.1. Findings from Regression Analysis

Table 1 summarizes the correlation with all the variables that have been evaluated. The correlation coefficients inversely correlated with the dependent variable for most of the tested factors. Probability and robust probability asterisk (*) indicate a coefficient is statistically significant ($p < 0.01$). Large variance inflation factor (VIF) values (>7.5) indicate redundancy among the explanatory variables. While there was inflation between population (14) and building (17), variable with a VIF > 7.5 have removed by one. The R-squared measure of model fit/performance values showed 92%.

3.2. Findings from Factor Analysis

The results of 1986, 2000 and 2015 classified images are presented in **Figure 3**. The results show thick vegetation, cropland and bareland have declined whereas the area of settlement has shown increase in extent (**Table 2**). From the land-use/land-cover distribution of the year 1986, 2000 and 2015, a total of 51,957.92 ha of thick vegetation/forest land had declined from the initial 11,040.5 ha in 1985 to 5238.90 ha in 2000 and 2730.42 in 2015. Urban cropland/grassland extent

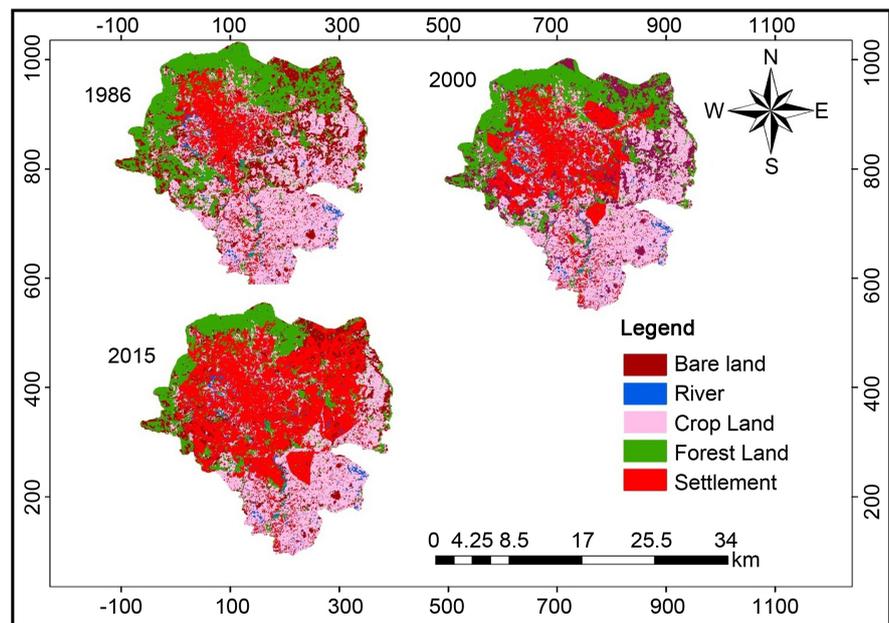
Table 1. Summary of the results of urban environmental quality regression analysis.

Variable	Coefficient	t-Statistic	Probability	Robust-t	Robust-Pr [b]	VIF [c]
Intercept	0.31966	4.195808	0.005943*	7.353267	0.000393*	-
Population	-3.038025	-8.255098	0.000132*	-10.294585	0.000002*	1.923088
Temperature	-0.006742	-2.649933	0.037747	-4.367938	0.004997	1.463664
Greenhouse gas emission	0.000027	2.722399	0.034257	4.62643	0.003897	2.416063

Note: *indicate probability (b) and Robust-pr (b) variable correlation is significant ($P < 0.01$).

Table 2. Land-use/land-cover distribution of the year 1986, 2000 and 2015.

Land-use/land cover category	1986		2000		2015	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Thick vegetation/ forest land	11,040.50	21.2	5238.90	10.08	2730.42	5.26
Urban crop land/ grassland	20,705.40	40	18,835.10	36.25	10,756.70	20.70
Settlement	7005.60	13.4	14,037.60	27.02	25,715	49.49
Water body	4416.84	8.5	5870.10	11.30	6838.6	13.16
Bare land	8789.58	16.9	7976.22	15.35	5919.20	11.39
Total	51,957.92	100	51,957.92	100	51,957.92	100

**Figure 3.** Land-use/land-cover change maps for the years 1986, 2000 and 2015.

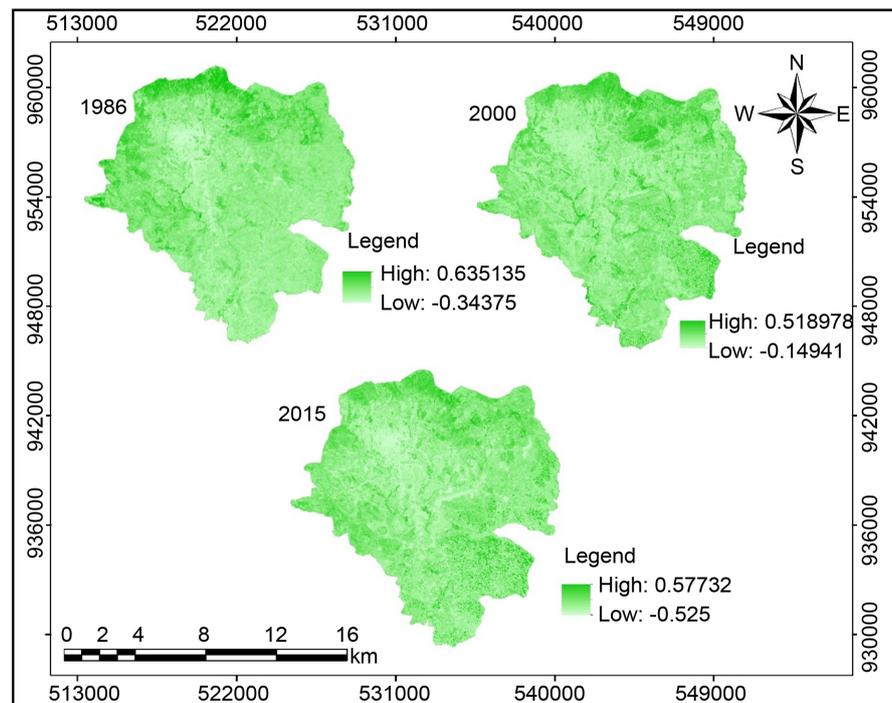
was 20,705.40 ha in 1986, which declined to 18,835.10 ha and 10,756.7 ha in 2000 and 2015, respectively. On the other hand, water body has increased from 4416.84 ha in 1986 to 5870.1 ha in 2000 and to 6836.6 ha in 2015. Settlement area had the highest increase from the initial estimate of 7005.60 ha in 1986. The extent has increased to 14,037.6 ha in 2000 and to 25,715 ha in 2015. This was the most dynamic land-cover in Addis Ababa, which got extended year after year. The extent of bareland showed slight decline from 8789.58 ha to 7976.22 ha and to 5919.2 ha under classification of the years 1986, 2000 and 2015, respectively. The overall accuracy for land-use/land-cover was 88.80% in 1986, 85% for 2000, and 84.00% for 2015. Overall land-use/land-cover changes are given in **Table 3**.

Figure 4 shows the information derived from landsat images. The shades of

Table 3. Assessment of changes of land-use patterns during 1986-2015.

Land-use/ land-cover category	Changes during 1986-2015					
	1986-2000			2001-2015		
	Extent		Rate	Extent		Rate
	(ha)	(%)	(ha/year)	(ha)	(%)	(ha/year)
Thick vegetation/forest land	-5801.6	-11.17	-386.77	-2508.48	-4.83	-167.23
Urban crop land/grass land	-1870.5	-3.59	-124.69	-8078.4	-15.55	-538.56
Settlement	7032	13.53	468.8	11,677.4	22.47	778.49
Bare land	-813.36	-1.57	-54.22	-2057.02	-3.96	-137.13
Water body	1453.26	2.80	96.88	966.5	1.86	64.43

Note: Annual Rate of Change (ha/year) = (% of recent land-use/land-cover change-% of Previous land-use/land-cover change)/100 * # of Study years (15 no of years).

**Figure 4.** Normalized difference vegetation index maps for the years 1986, 2000 and 2015.

white represent man-made surfaces (concrete, roofs and roads) and water bodies. Light green represents grassy fields and dark green represents tree covered areas. The pixel values of 1986 NDVI image ranged from around -0.34 for not very vegetated surfaces to values of 0.63 for vegetated surfaces. For 2000, the pixel values for the NDVI images ranged from -0.14 for not very vegetated surfaces to 0.51 for vegetated surfaces. For 2015, the pixel values for the NDVI image ranged from -0.52 for none and not very vegetated surfaces to 0.57 for vegetated surfaces.

Green area distribution patterns in Addis Ababa city are shown in **Figure 5** and **Figure 6**. Yeka and Gulele sub-cities have only about 0.005% of green area, Akaki-Kality sub-city, Nifassilk-Lafto and Bole have only less than 0.002% green area. Arada Kirkose and Lideta sub-cities hold too low green areas and Addis Ketema sub-city has almost no vegetation cover while Kolfe Keranio has 0.03% green area.

Population density in Addis Ababa city in relation to that of the ten sub-cities indicates that the central region is the densest. Addis Ketema with >350 people/ha is the most populated region in Addis Ababa. Arada and Lideta sub-cities have 300 people/ha, while the Akaki-Kality, Yeka and Bole sub-cities have <17 people/

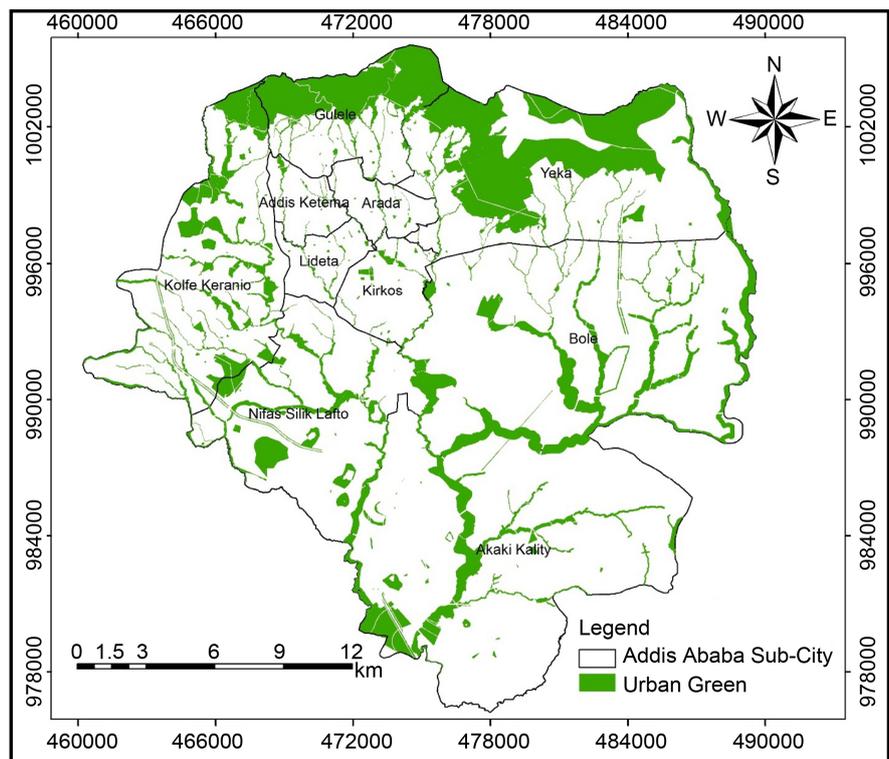


Figure 5. Map of urban green space in Addis Addis Ababa (2015).

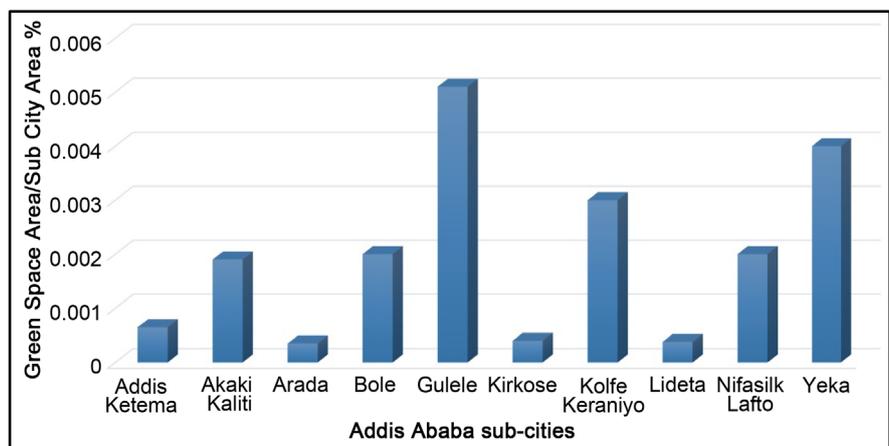


Figure 6. Comparison of urban green space in 10 sub-cities of Addis Ababa.

ha. There is a general increase of surface temperature in the impervious surfaces (building, concrete and asphalt) in comparison with vegetated areas. Maximum average surface temperature recorded was 36.79°C and minimum was 17.40°C. Based on zonal mean statistics, the surface temperature in Akaki-Kality and Bole sub-city was 29°C, followed by Addis-Ketema, Arada, Kirkose, Liedeta and Nifase-Silke (28°C), Yeka (27°C) and Kolfe (26°C), respectively, while Gulele sub-city experienced the lowest surface temperature (24°C) in Addis Ababa.

Greenhouse gas emission data are shown in **Figure 7**. Concentration of greenhouse gas emission was high associated in industrial and residential areas and in major roads. Based on this, the maximum greenhouse gas emission recorded was 1.41 mega tone and the minimum was 0.25 mega tone. Based on the zonal mean statistics, Akaki Kality sub-city was the most polluted (0.24 mega tone), followed by Addis-Ketema and Lideta (0.21 mega tone), Kirkose (0.14 mega tone) Gulele (0.04 mega tone), Kolfe Keranio and Yeka (0.03 mega tone), and Bole, Nifasi-Silke and Akaki-Kality (0.02 mega tone).

3.3. Overlay Model

Based on weighted overlay analysis, there was a need to have a universal integration result of the five parameters (land-use/land-cover, population density, surface temperature, greenhouse gas emission and built-up density) to sum up based on the weighting (**Table 4** and **Table 5**) and to isolate the hotspot areas of environmental deterioration the risk-map generated (**Figure 8**) reclassify as most risk, more risk, risk, marginal and least risk. Based on this classification Addis Ketema belongs its between most risk, Arada more risk, Lideta more risk, Kirkose within risk and Gulele among marginal and least risk and Kolfe, Yeka, Nifas Silke, Bole and Akaki Kality sub-cities belong to least risk. The consistency ratio (CR) indicates the probability that the matrix ratings were randomly generated so that matrices with CR ratings greater than 0.10 should be reevaluated.

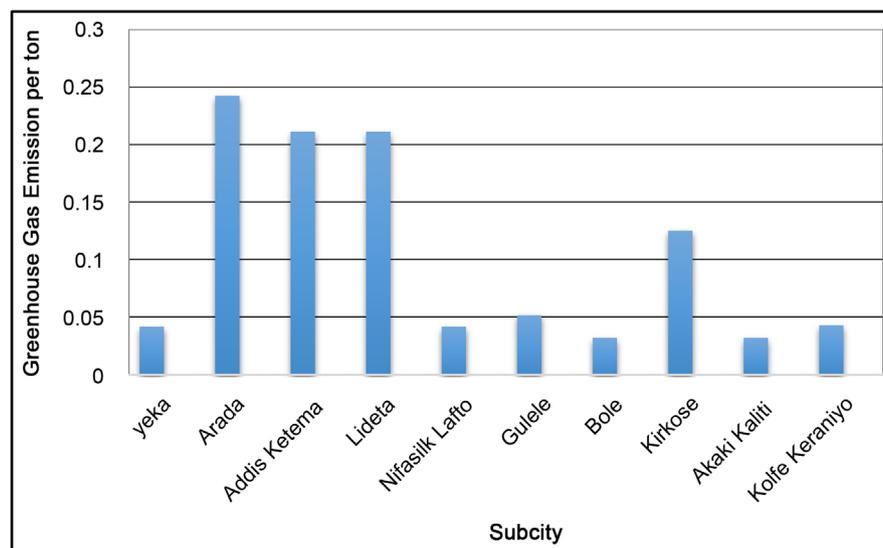


Figure 7. Comparison of greenhouse gas emission in the ten sub-cities of Addis Ababa.

Table 4. Derived factor maps and ranking.

Parameters	Criteria	Unit	Urban environmental quality indicator rating				
			High	Moderate	Marginal	Not suitable	
Land-cover	LU/LC	Class	Forest/ vegetation land	Crop/land/grass land	Water body	Bare land	Settlement
	NDVI	Value	0.22 - 0.52	0.15 - 0.22	0.09 - 0.15	-0.15	-0.01
Existing LU/LC	Built up area	Density	0.05 - 0.08	0.08 - 0.09	0.09 - 0.14	>0.14	
Urban heat	Surface temperature	°C	17 - 24	24 - 27	27 - 29	>29	
Population	Population size	Density	0.0018 - 0.003	0.003 - 0.005	0.005 - 0.006	>0.006	
Green house gas	Carbon emission	Tone	0.02 - 0.03	0.03 - 0.14	0.14 - 0.23	>0.23	

Table 5. Derived factor maps weight.

No	Criteria	Weight %
1	Land-use/land-cover	24
2	Built up density	17
3	Surface temperature	16
4	Population density	21
5	Green house gas emission	22

Consistency Ratio (CR) is 0.02.

However, in this study the CR calculated as 0.02 is acceptable. Based on the urban environmental quality indicator rating (Table 5), sub-cities with fewer green spaces, over polluted, high heat accumulation, high greenhouse gas emission and densely built-up areas were identified as critical areas and those with high vegetation, low greenhouse gas emission, low heat island, low built-up area and sparsely populated locations as environmentally safe areas (Figure 8). Based on these results, sub-cities Arada and Addis Ketema were in the category in between most and more critical, Kirkose and Lideta sub-cities were within critical and marginal and Kolfe, Gulele, Yeka, Nifas Silke, Bole and Akaki Kality were least critical.

4. Discussion

During the present study, a comparison was made between the increase in impervious surface against the reduction in greenness in Addis Ababa city areas that might signify deterioration in the environmental quality of this African city. Vegetation, crop land/grassland, bare land, settlement and water bodies were either increased or decreased in extent in different rates during 1986-2015 in

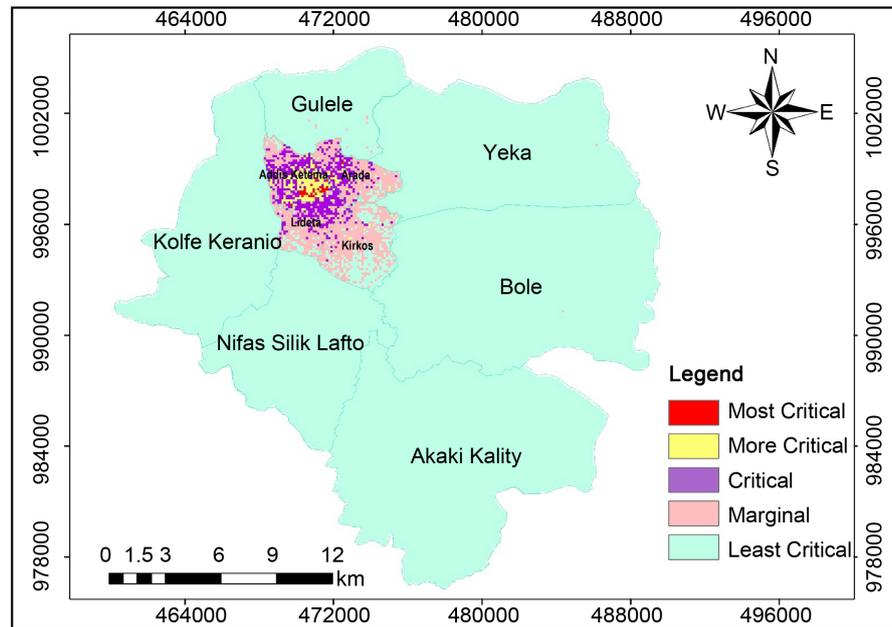


Figure 8. Environmental quality map of Addis Ababa city.

Addis Ababa city area. Greenness of the area serves as a means of urban environmental quality [7] [3] [17]. Information on green area in cities is important for maintaining urban environmental quality. Vegetation is very useful in filtering air, water and sunlight, cooling urban heat, recycling pollutants, moderating local urban climate and providing recreational areas for the people. The ecological functions of vegetation cover in urban parks may filter up to 85% of the air pollutants [9] [18].

Settlement areas increased from the initial estimate of 7005.60 ha in 1986 to 25,715.0 ha in 2015 with the change rate of 468.8 ha/year during 1986-2000 and 778.49 ha/year during 2001-2015. This was the most dynamic land-cover change observed in Addis Ababa city area, the cause of which is none other than urbanization and rapid population growth in the recent past. Unbalanced and uncontrolled urbanization lead to environmental degradation in the quality of urban life [19]. The extent of bareland declined slightly from 8789.58 ha 7976.22 and 5919.2 of the total area under the classification of the year 1986, 2000 and 2015, respectively. This is mainly due to afforestation and rehabilitation conservation programmes. Normalized Difference Vegetation Index is a spectral index that takes into account the amount of infrared rays reflected by plants [20] [21]. Green plants absorb solar radiation, as a source of energy in the process of photosynthesis. The reason for the relationship of NDVI to vegetation is due to the property of green leaves to reflect 20% or less in 0.5 to 0.7 microrange (green to red) and about 60% in 0.7 to 1.3 microrange (near-infrared). Normalized Difference Vegetation Index itself varies between -1.0 and $+1.0$. Negative values of NDVI (values approaching -1) correspond to deep water. Values close to zero (-0.1 to 0.1) correspond to bare land areas of rock and sand. The nature and extent of these changes show variations across time and space. Changes attributed to socio-economic and environmental parameters reflect a host of other factors.

In Addis Ababa city, Yeka and Gulele sub-cities contains about 0.005% of green area, while Kolfe-Keranio cover 0.03% green area and Akaki-Kality, Nifas-silk-Lafto and Bole contain <0.002% green area. Other inner areas in the city such as Arada Kirkose and Lideta hold too low green areas and Addis-Ketema sub-city contains almost zero or no vegetation cover. Green space in Kirkose, Addis-Ketema, Lideta, Arad and kolfe having least green space (4.8×10^{-6} square meter) are the poorest. Gulele and Yeka have $<1.5 \times 10^{-5}$ square meter vegetation area. The suggested standard of green area for cities is 7 to 12 square meters [22]. This indicates that none of Addis Ababa sub-cities contains the required extent of green area to maintain environmental quality. Over all, the results point to a decline in vegetated areas in Addis Ababa city area, and an increase in settlements, cropland, bare land, population explosion, as well as greenhouse gas emission, which act as threat to the environment of the city. There is a need to have a universal integration of the five parameters analyzed. Overall housing density is a more important negative predictor of the extent of green space and tree cover [23]. Weighted overlay methodologies can also be customized for reclassification, and map algebra techniques expand the ability of spatial analyses. The accuracy of the study can be enhanced by using high resolution satellite imagery. Not only the urban environmental quality, but also other subjects important for ecological and environmental impact analysis such as air, water, and noise pollution limitations can also be determined using RS and GIS integration. Environmental risk and quality map are also source of data for city and regional planners.

5. Conclusion

In the light of the present findings, the practical use of geospatial approach involving natural and census data, GIS and remote sensing in tracking urban environment quality change stands appropriate for sustainable environmental planning, considering the little efforts in the past to assess urban environmental quality. Integrated data analysis using remotely sensed satellite imagery and GIS modeling facilitated the analysis of the spatial distribution of environmental changes involving land-use/land-cover classification changes from time to time. Results of this study can influence policy assessments and assist local governments and environmental agencies in monitoring Urban Environmental Quality (UEQ). The UEQ models established in this paper can be applied to assist urban planners not only to evaluate the city's current UEQ condition, but also to devise efficient development polices to construct a more desirable future UEQ environment at the national level. Land-use planners and policy makers can thus make decisions towards a more sustainable city featuring green areas, which correspond well as a key factor in determining a city's UEQ condition.

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