

INFLUENCE OF STUDY CENTERS ON ENVIRONMENTAL PERFORMANCE OF KOTA CITY: A SPATIO-TEMPORAL ANALYSIS USING REMOTE SENSING AND GIS

¹Arisha Hussain, ²Dr. Seema Chauhan

¹PhD Research Scholar, ²Professor

¹Department Of Geography,

¹University of Kota, Kota, India

Abstract : This study examines the environmental performance of Kota Municipal Area, Rajasthan widely recognised as India's 'coaching capital' — through the application of GIS-based methods and time-series satellite data. Kota has undergone a distinct form of urbanisation termed as 'studentification' driven by the migration of students due to the presence of the country's most significant coaching institutes. Satellite imagery from Landsat 5 TM (2000) and Landsat 8 OLI (2020) were examined to measure the effects of this student-led urbanization in Kota city. Land Use Land Cover (LULC) classification by employing the IsoCluster Unsupervised algorithm and Normalized Difference Vegetation Index (NDVI) analysis were performed over the study period. The analysis reveal that Urban Built-up area grew by 44.2% (from 52 km² to 75 km²), while total vegetation cover shrank by 36.5% (from 91.32 km² to 57.95 km²). Dense Vegetation lost 43.8%. Scrubland dominates more than 75% of all buffer zones, and a proximity buffer analysis surrounding 12 major coaching institutes at 500m, 1km, and 2km radii indicated that the near environs of coaching institutes are defined by severely low vegetation cover. With important ramifications for the planning of urban green infrastructure in Kota and other developing educational cities in India, these findings demonstrate a measurable connection between student-fueled urbanisation and environmental deterioration.

Index Terms: Studentification; LULC change detection; NDVI; Urban vegetation loss; Remote sensing; GIS; Kota; Coaching institutes; Buffer analysis; Environmental degradation

1. Introduction

Urbanisation in many developing regions has emerged as a key factor driving changes in land use and land cover (LULC), along with associated vegetation decline and environmental degradation in the twenty-first century (Mondal et al., 2015; Singh et al., 2017). Although a significant portion of the existing literature emphasises industrialisation and population growth as principal catalysts of urban expansion, the influence of specialised economic activities, such as education-driven urbanization, has garnered relatively insufficient scrutiny (Bose, 2017; Guin and Das, 2015). Kota, a Tier-II city in Rajasthan, India, is a unique and understudied example of urban change mostly driven by the growth of the private coaching institute industry.

Over the past thirty years, Kota has become India's leading "coaching capital," drawing more than 250,000 students each year to study for the extremely competitive IIT-JEE and NEET engineering and medical entrance exam. This unprecedented concentration of students has given rise to a phenomenon described in urban studies literature as 'studentification' — the transformation of urban spaces, land use patterns, and social structures in response to large-scale student in-migration (Smith and Holt, 2007; Chatterjee, 2022). According to Bose (2017), Kota's built-up footprint increased by more than 111% between 1990 and 2015, mostly at the expense of open space, bodies of water, and vegetation.

Despite the growing body of literature on urbanisation and environmental change in Indian cities, the specific environmental consequences of studentification-driven urbanisation in Kota remain inadequately quantified. Remote sensing and GIS have together become indispensable for tracking shifts in land use and land cover and unpacking the environmental consequences of those changes (Hussain et al., 2013; Mondal et al., 2015). The Computed from multispectral satellite bands, the Normalized Difference Vegetation Index (NDVI) gives a well-validated, quantitative reading of canopy condition and vegetation density (Rouse et al., 1974; Tucker, 1979). Additionally, buffer analysis allows for the evaluation of spatial environmental gradients surrounding urban land uses. This study addresses the following research questions: (1) How has LULC changed in the Kota Municipal Area between 2000 and 2020? (2) How has vegetation cover, as measured by NDVI, changed over the same period? (3) What is the spatial pattern of vegetation cover in the immediate vicinity of coaching institutes? (4) What are the implications of these findings for green infrastructure planning in studentification-dominated urban areas? The research makes a novel contribution by developing a quantitative and GIS-based body

of evidence of the environmental impacts of studentification in an Indian city and suggests spatially sensitive remedial recommendations for green infrastructure.

2. Literature Review

2.1 Urbanisation and LULC Change in Indian Cities

Land use and land cover change detection employing remote sensing and GIS techniques have been extensively used to monitor and estimate the rate and pattern of urban growth in Indian cities. Multi-temporal Landsat images were used in the study of LULC dynamics in the Barrackpore Subdivision, West Bengal, which reported that vegetation shrank by 23 percent, cropland by 7 percent, and wetlands by 6 percent, whereas built-up and fallow land together expanded by 32.2 percent (Mondal et al., 2015). The authors noted that rapid urban development presents very significant environmental and social issues, especially in smaller Indian cities without proper databases to analyze spatiotemporal factors. By applying Cellular Automata–Markov Chain (CA–Markov) models, Singh et al. (2015) demonstrated that both spatial and decadal changes in LULC can be predicted. Their findings suggest that urbanisation-driven LULC changes tend to follow identifiable spatial patterns, making them useful for future planning and projection.

Within the case of Rajasthan in particular, the Kota Master Plan (Government of Rajasthan, undated) has shown high levels of land use pressures due to the coaching industry, but these have not been quantified in detail using remote sensing. Mehra and Swain (2024) performed a geospatial evaluation of urban sprawl in the Western Himalayan City of Dharamshala using Landsat 8 OLI imagery and the Maximum Likelihood Classification technique to create LULC thematic maps and post-classification correction measures — a methodology very similar to the one used in the current research. A spatio-temporal examination of the impact of urbanisation in the city of Aligarh was carried out by Khan et al. (2024) where land use and land cover dynamics were recorded and their effects on land surface temperature were studied. Their results aligned with global evidence that urban growth is accompanied by decrease in area under vegetation and increase in impermeable surface with cascading effects on thermal environments. The trends in Aligarh, which is also typified by a single-sector economy (textiles), serve as an effective comparative tool for the examination of Kota's transformation under the influence of coaching.

2.2 Remote Sensing Indices for Environmental Assessment

NDVI remains the most broadly applied index for vegetation monitoring. Its values span from -1 to $+1$, derived from the NIR-to-red reflectance ratio with higher scores corresponding to denser, more vigorous plant cover (Rouse et al., 1974). A scientometric analysis of remote sensing vegetation mapping by Mhangara et al. (2024) determined that NDVI is the predominant index employed irrespective of spatial scale and sensor type, and that NDVI change is a legitimate method for detecting land cover alterations, including deforestation, urbanisation, and agricultural expansion.

Singh and Punithavathi (2019) documented the shift from agricultural to urban land use and its effects on the environment in the Hubli-Dharwad region using NDVI-based change detection. The buffer analysis approach in this work is informed by the findings that urban sprawl routinely lowers NDVI values in peri-urban areas. Thakur et al. (2025) investigated spatio-temporal LULC dynamics in the Thambarbarani River Basin, India, integrating NDVI, Land Surface Temperature (LST), and soil temperature data from Landsat 8 and Sentinel-2. The study documented significant proportions of developed and desolate land, with NDVI analysis indicating that vegetation was under stress in urban and degraded areas — a trend that closely resembles the Kota case.

Ramaiah and Avtar (2019) investigated urban environmental degradation utilising NDVI and LST as environmental indicators, establishing significant correlations between LULC change and the decline in environmental quality in Indian cities. Shukla and Jain (2021) used an integrated environmental quality index (IEQI) analysis on the city of Bhopal from 2000 to 2020 — a method first of its kind to use remote sensing data to assess the environment using multiple indicators. The Bhopal experiment indicated a consistent increase in environmental degradation from 2000 to 2020, with IEQI ranges expanding from 0–28 to 13–57, attributed to unplanned rapid urbanisation.

2.3 Buffer Analysis and Urban Green Space Assessment

Buffer analysis is an established GIS method of evaluating the spatial impact of land uses on their immediate neighbourhood. In green space research, buffer distances of 300 m, 500 m, 1 km, and 2 km are commonly applied to assess vegetation exposure in urban areas (Mears et al., 2024; Nguyen et al., 2021). After a comprehensive review of previous studies by Nguyen et al. (2021) reported that While buffers of less than 500m best predicted vegetation conditions at the neighbourhood level, buffers of 1000–1999m appeared to provide the most reliable health-relevant vegetation exposure prediction.

Mears et al. (2024) used NDVI values derived from Landsat data within 1km buffers around urban centres in Great Britain and found

that buffer-based NDVI analysis is a useful and spatially explicit indicator of urban green infrastructure quality. Their conclusions that urban centres have lower NDVI values than surrounding areas closely resembles what one would anticipate in the Kota coaching hub. In Chinese cities, Guan et al. (2022) observed a clear fragmentation of green spaces along the urban fringe and reported a decline in total vegetation extent from 359.57 km² to 213.46 km² over the study period. This trend is comparable to the vegetation loss identified in the present study.

A thorough review of NDVI-based greenness exposure measures as urban policy interventions by Martinez and Labib (2023) identified NDVI as a policy-relevant, scalable, and standardised measure of green infrastructure. Their contribution justifies the utilization of NDVI as the key indicator of environmental performance in the given work and underpins the framework of the spatial strategy suggested for the coaching hub areas of Kota.

2.4 Studentification and the Kota Educational Economy

Studentification, first conceptualised by Smith (2005) in the context of UK towns and later developed by Smith and Holt (2007), refers to the transformation of urban spaces driven by a concentration of students. This process brings about cultural, economic, social, and physical changes, and can, in some cases, lead to the displacement of long-term residents. Smith and Holt (2007) define studentification within the overall conceptual umbrella of gentrification, noting that both processes provoke social segregation and concentration, territorial ownership of space and housing, and enhancement of social-spatial polarisation. Their model defines four fundamental consequences of studentification: capital reinvestment in affected areas; social repositioning of neighbourhoods through incoming student demand; visible landscape alteration; and the gradual or abrupt displacement. Studentification through coaching institutes in the Indian context is a qualitatively different form of this phenomenon, which takes place at a city rather than neighbourhood scale and is motivated by the economics of examination preparation rather than higher education expansion (Nair, 2015).

Nair (2015) examined how Kota was re-made into an educational city, tracing its transformation into an education hub through a shadow education economy and neoliberal restructuring of urban spaces. The paper documents the spatial change of Kota since the 1980s, identifying the shift of industrial land to coaching institute campuses, and the growth of hostel complexes, businesses and service facilities. Bose (2017) also reported that over 1990–2015, the built-up area of Kota increased by 111.55%, resulting in loss of open land, bodies of water, and area under vegetation, mostly in the southern section of the city where coaching institutes are clustered.

Although radical spatial and environmental changes have been recorded in these works, no systematic, remote sensing-based account of LULC change and vegetation loss that could be directly linked to the studentification process in Kota has been found in the literature. This gap is filled by the present study, which provides the first multi-temporal NDVI and LULC change analysis of the Kota Municipal Area during 2000–2020, with a proximity buffer analysis of the environmental impact of coaching institutes.

3. Study Area

The study area is Kota (24°52'–26°32' N; 74°36'–76°13' E), a Tier-II city in the southeastern part of Rajasthan, India (Figure 1). Kota lies along the banks of the Chambal River between northeastern Madhya Pradesh and southwestern Haryana. It is the District headquarters and has a population of roughly 1.2 million, placing it third among Rajasthan's cities by size, after Jaipur and Jodhpur. The study area is bounded by the limits of Kota Municipal Corporation, spread over an area of 320 km².

Kota is located in the northwest of the state, with a semi-arid climate characterised by hot summers and mild wet winters, and most rainfall during the monsoon season. The city receives an average of 750mm of rainfall per annum, with the Chambal River as the primary perennial watercourse, originating from Madhya Pradesh and flowing from north to south through the city before turning eastwards. The largest water body is Kishore Sagar Lake, an artificial lake. Dry deciduous scrub dominates the landscape, with scattered tree cover where forests have not been cleared.

Historically, Kota had a heavy industrial base with major companies in petrochemicals, fertilizers, and precision instruments manufacturing. However, from the late 1980s onwards, education services became the major economic activity. The bulk of coaching institutes are clustered in the IPIA (Indraprastha Industrial Area), Indra Vihar, Jawahar Nagar, and Vigyan Nagar areas. Talwandi area is a more recent addition to this coaching hub. More than 250,000 students from across the country flock to Kota every year, leading to intense urbanization in the southern and central parts of the city limits.

4. Data and Methodology

4.1 Satellite Data Acquisition and Pre-Processing

Multi-temporal Landsat scenes for both reference years were retrieved from the USGS Earth Explorer platform

(earthexplorer.usgs.gov). Image used for 2000 was Landsat 5 Thematic Mapper (TM) imagery (Path/Row: 146/043, acquisition date: 3rd February 2000). For 2020, Landsat 8 Operational Land Imager (OLI) imagery (Path/Row: 147/042, acquisition date: 17th February 2020) was used. Both products were Collection 2 Level 2 Surface Reflectance, which corrects for the effects of the atmosphere and enables radiometric consistency. February acquisition dates were chosen to avoid cloud cover and, where possible, to maintain similar phenology between the two time periods.

Each scene was spatially subset to the study area boundary by applying the Extract by Mask function in ArcGIS, using the Kota Municipal Corporation administrative shapefile as the mask. Before calculation of surface indices, surface reflectance scaling was applied according to the USGS Collection 2 scaling factor (multiplier: 0.0000275, offset: -0.2), in order to convert digital numbers into physically meaningful observations of surface reflectance.

4.2 LULC Classification

The IsoCluster unsupervised classification method available in ArcGIS Spatial Analyst was used to classify land use and land cover. The analysis was based on band composites from Bands 1–5 and 7 for Landsat 5, and Bands 1–7 for Landsat 8. Seven spectral groups were generated and labelled as: Water Body, Open Areas, Vegetation/Forest, Agricultural Land, Urban Built-up Area, Scrubland, and Barren Land — defined using visual interpretation and spectral analysis. Salt-and-pepper noise was reduced by applying a majority filter (8-neighbourhood rule) to both classified outputs. Area estimates were expressed in km² by multiplying pixel counts with Landsat pixel area (0.0009 km² for 30m resolution).

4.3 NDVI Computation and Classification

For each image, NDVI was derived using the conventional normalised-difference expression: $(NIR - Red) / (NIR + Red)$. For Landsat 5 (2000), Bands 4 (NIR) and 3 (Red) were used; for Landsat 8 (2020), Bands 5 (NIR) and 4 (Red) were used. The NDVI rasters were classified into five classes: Water Body (< -0.5), Scrub Land (-0.5 to -0.2), Bare Soil (-0.2 to 0), Sparse Vegetation (0 to 0.15), and Dense Vegetation (0.15 to 0.52). These thresholds are defined from established remote sensing literature and were further validated using visual interpretation against the LULC classification outputs.

4.4 Change Detection

The classified 2000 LULC raster was subtracted from the 2020 classified LULC raster in ArcGIS Raster Calculator to perform change detection, resulting in a change detection map with class numbers ranging from -6 to +6, representing the direction and magnitude of class number change. The change detection output was passed through a Majority Filter twice for improved spatial coherence. The final change detection map was classified into: Major Loss, Moderate Loss, Minor Loss, No Change, Minor Gain, Moderate Gain, and Major Gain.

4.5 Buffer Analysis

Based on validated address data, point shapefiles of locations of 12 major coaching institutes were created in ArcGIS. The ArcGIS Buffer tool, applied with the Dissolve All parameter to merge overlapping buffers, generated buffer zones of 500m, 1km, and 2km radius around all coaching institute points. NDVI rasters for each year were masked, reclassified to the five vegetation classes, and statistics of pixel counts from the output attribute tables summarised within each buffer zone using Extract by Mask.

5. Results

5.1 LULC Change (2000–2020)

Time-series Land Use and Land Cover (LULC) classes of the Kota Municipal Area were analysed from 2000–2020 and various types of changes in land cover were observed (Table 1; Figures 1–3). The greatest alteration was noted for Urban Built-up Area, which grew by 23 km² (+44.2%), from 52 km² to 75 km². The biggest relative change was a 25 km² (-38.5%) drop in Vegetation/Forest cover, going from 65 km² to only 40 km². Agricultural Land increased by 23 km² (+54.8%) — mostly in the northern fringe of the municipal border — and Scrubland increased by 19 km² (+39.6%). Barren Land exhibited a net decrease of 26 km² (-59.1%), indicating conversion to other land uses, mostly agriculture and urbanization. The area of Open Areas decreased by 11 km² (-19.3%).

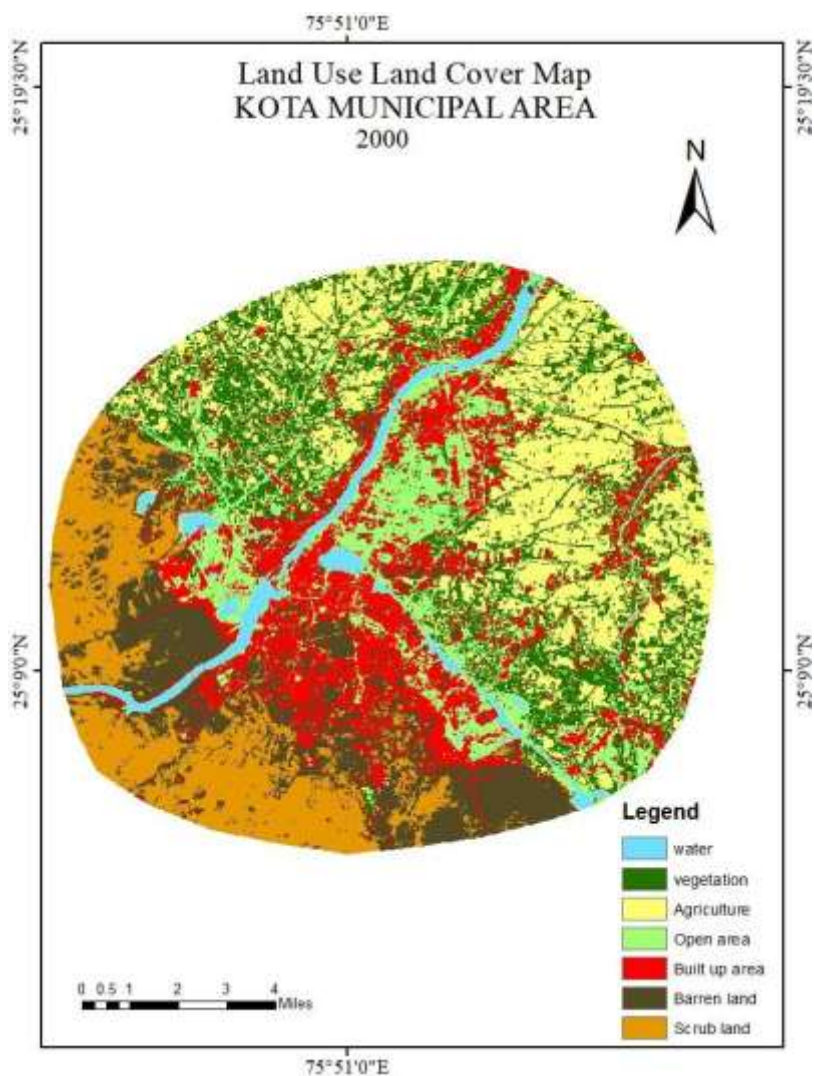


Figure 1: LULC Classification Map — Kota Municipal Area, 2000

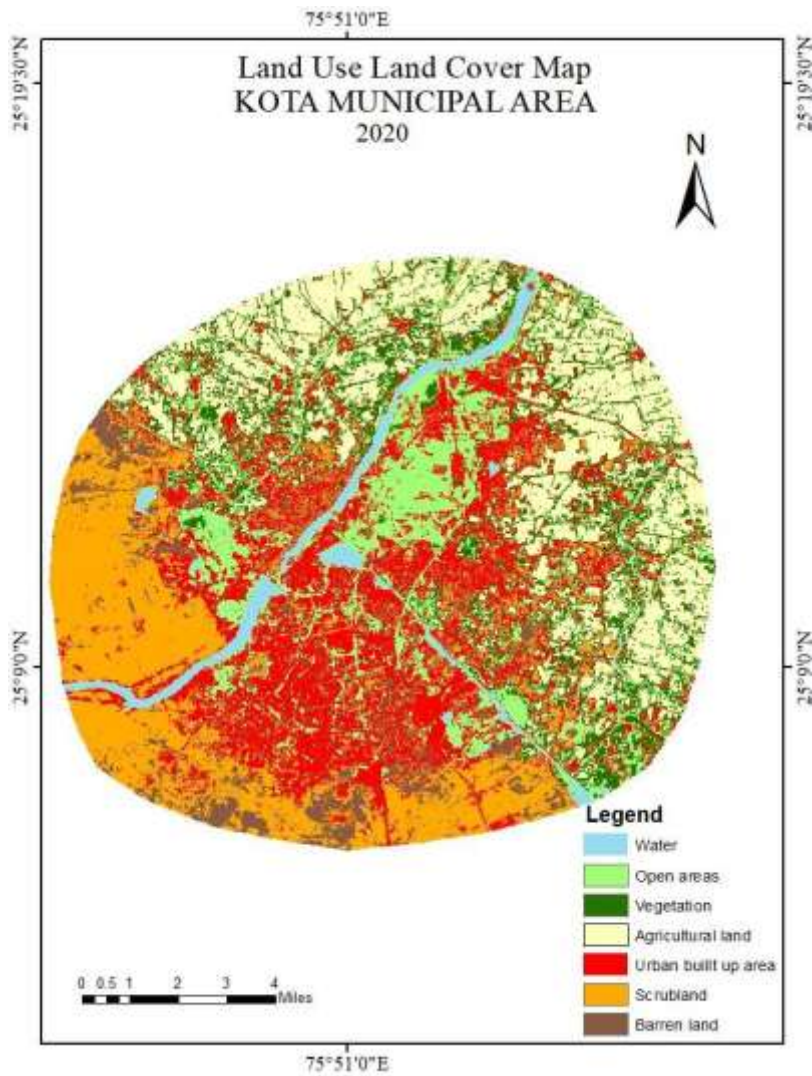


Figure 2: LULC Classification Map — Kota Municipal Area, 2020

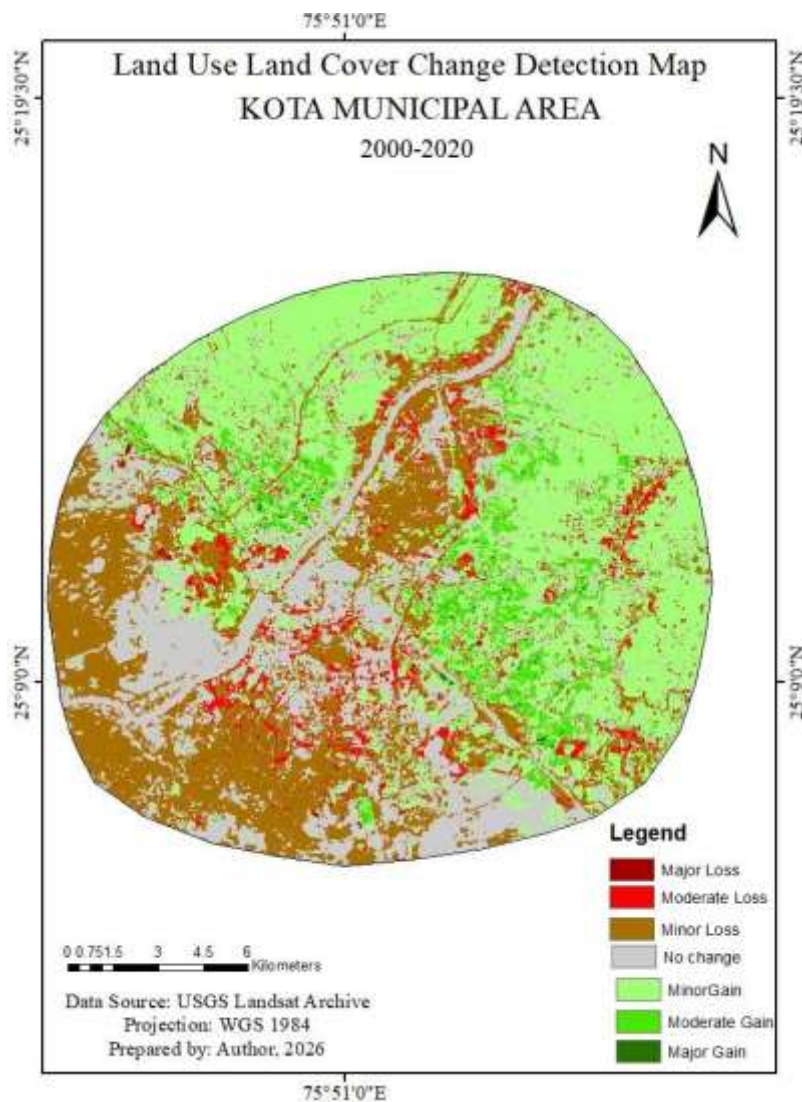


Figure 3: LULC Change Detection Map — Kota Municipal Area, 2000–2020

Table 1: LULC Area Statistics — Kota Municipal Area (2000 vs. 2020)

LULC Class	Area 2000 (km ²)	Area 2020 (km ²)	Change (km ²)	Change (%)
Water Body	10	9	-1	-10.0
Open Areas	57	46	-11	-19.3
Vegetation / Forest	65	40	-25	-38.5
Agricultural Land	42	65	+23	+54.8
Urban Built-up	52	75	+23	+44.2
Scrubland	48	67	+19	+39.6

Barren Land	44	18	-26	-59.1
TOTAL	318	320	+2	—

Source: USGS Landsat Archive; Analysis by Author using ArcGIS 10.x.

5.2 NDVI-Based Vegetation Change

The NDVI analysis showed a significant decline in vegetation cover in the Kota Municipal Area over the study period (Table 2; Figures 4–5). Total vegetation cover (NDVI > 0) declined from 91.32 km² in 2000 to 57.95 km² by 2020 — a reduction of some 33.37 km² (–36.5%). Dense Vegetation (NDVI > 0.15) had the greatest reduction, decreasing by 25.77 km² (–43.8%), from 58.81 km² to 33.04 km². Sparse Vegetation also decreased significantly by 7.60 km² (–23.4%). Additionally, there was a notable 7.60 km² (–23.4%) drop in sparse vegetation. On the other hand, Scrub Land and Bare Soil grew by 7.76 km² (+6.0%) and 4.11 km² (+8.2%), respectively, suggesting a slow shift from vegetated land to cover types with lower productivity.

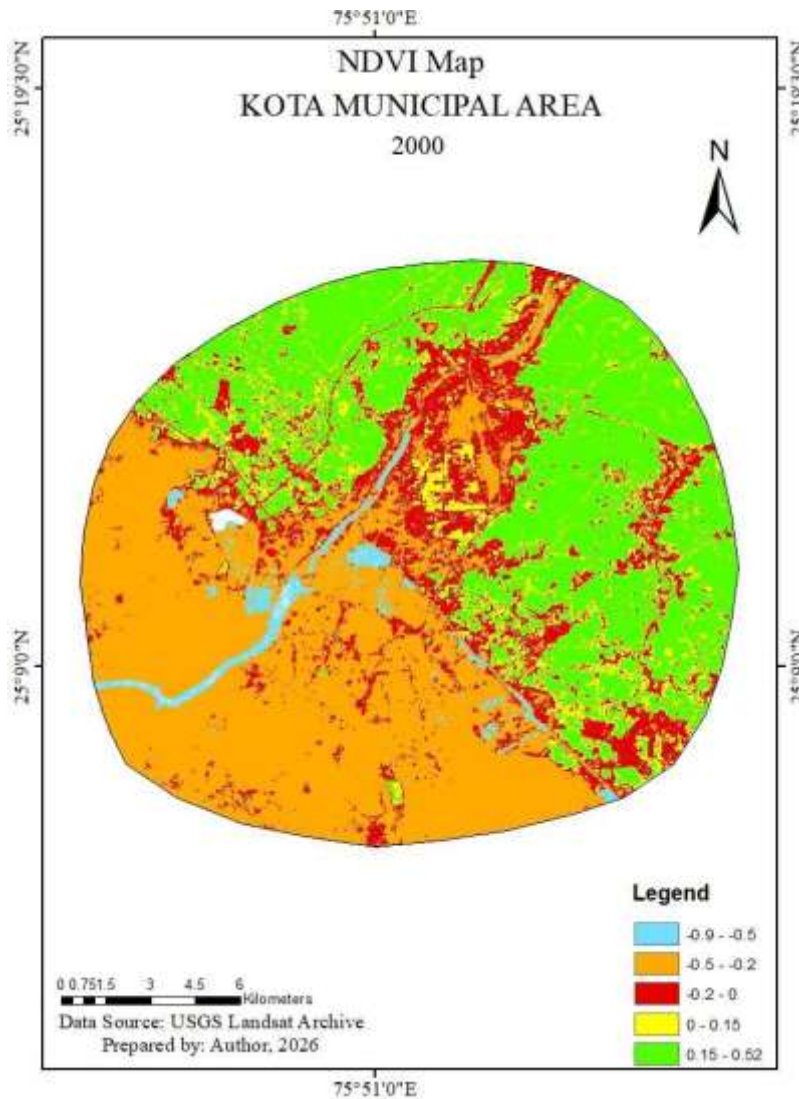


Figure 4: NDVI Classification Map — Kota Municipal Area, 2000

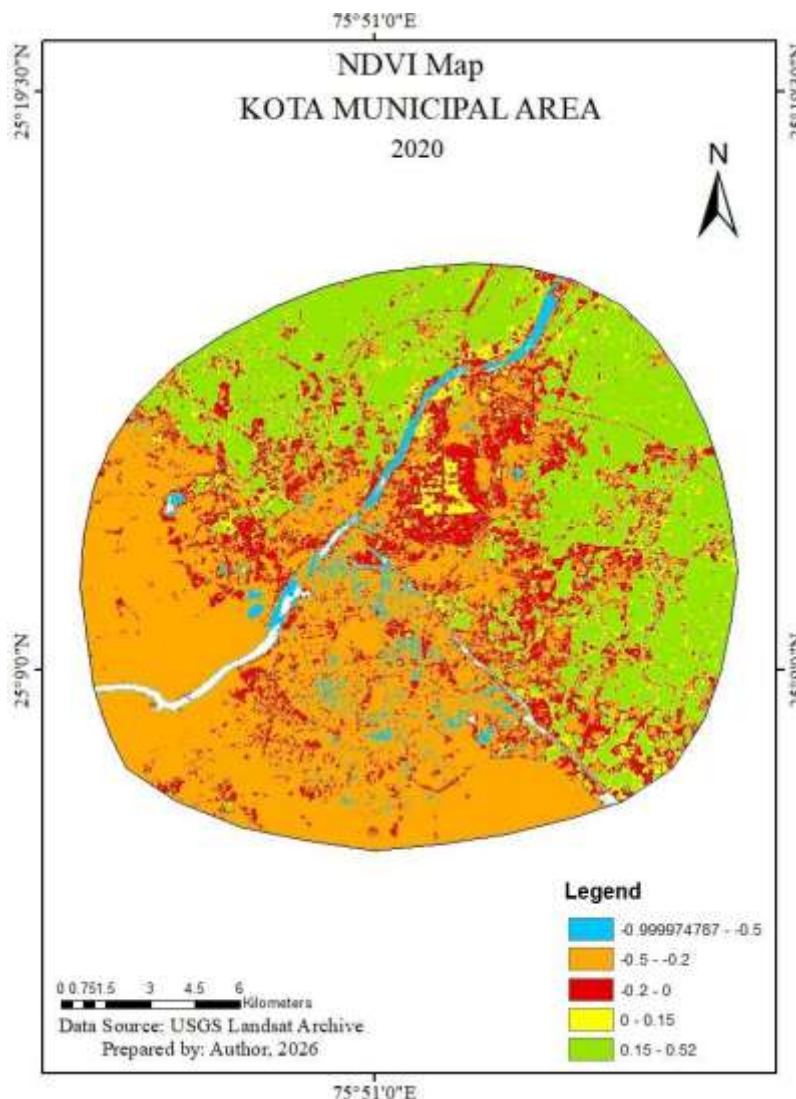


Figure 5: NDVI Classification Map — Kota Municipal Area, 2020

Table 2: NDVI Area Statistics — Kota Municipal Area (2000 vs. 2020)

NDVI Class	Range	Area 2000 (km ²)	Area 2020 (km ²)	Change (km ²)	Change (%)
Water Body	< -0.5	6.95	7.61	+0.66	+9.5
Scrub Land	-0.5 to -0.2	129.12	136.88	+7.76	+6.0
Bare Soil	-0.2 to 0	49.95	54.06	+4.11	+8.2
Sparse Vegetation	0 to 0.15	32.51	24.91	-7.60	-23.4
Dense Vegetation	0.15 to 0.52	58.81	33.04	-25.77	-43.8
Total Vegetation	> 0	91.32	57.95	-33.37	-36.5

Source: USGS Landsat Archive; Analysis by Author using ArcGIS 10.x.

5.3 Buffer Analysis Results

Buffer analysis performed on 12 major coaching institutes revealed that vegetation cover in the zones of coaching institute influence is very low across both study years (Table 3). Scrub Land is the dominant land cover category for all buffer zones in both 2000 and 2020, making up more than 75% of surface area for the 500m and 1km buffers. Less than 0.1 km² of vegetated area (NDVI > 0.1) is present within a 500m buffer around coaching institutes in either year, confirming the persistent absence of relevant green cover near the coaching centres. While Scrub Land remains the single largest land cover at more than 70% across the 2km buffer, Total Vegetation increased only marginally by 0.21 km² (from 0.88 km² to 1.09 km²) over the study period.

Table 3: NDVI Vegetation Statistics within Coaching Institute Buffer Zones (2000 vs. 2020)

Buffer Zone	Dominant Cover (Both Years)	Total Veg 2000 (km ²)	Total Veg 2020 (km ²)	Veg Change (km ²)
500m	Scrub Land (>75%)	0.03	0.06	+0.03
1km	Scrub Land (>75%)	0.05	0.23	+0.18
2km	Scrub Land (>70%)	0.88	1.09	+0.21

Source: USGS Landsat Archive; Buffer analysis performed using ArcGIS 10.x. Institutes included: Allen Career Institute, Resonance, Bansal Classes, Career Point, Vibrant Academy, Motion Education, Aakash Institute, FIITJEE, Narayana IIT Academy, RAO IIT Academy, Brilliant Tutorials, Etoos Education.

6. Discussion

6.1 LULC Dynamics and Studentification

The LULC outcomes corroborate and significantly build upon earlier investigations by Bose (2017) on the environmental transition of Kota. The 44.2% growth of Urban Built-up Area between 2000 and 2020 aligns spatially with the geographic distribution of coaching institutes presented by Nair (2015), which recorded maximum urban increase in the central and southern segments of the municipal area, exactly where coaching institutes, student hostels, and related commercial infrastructure are most heavily concentrated. This observation is in accordance with Khan et al. (2024), who document similar patterns of sector-driven urban expansion in North Indian cities.

The 38.5% fall in Vegetation/Forest cover (25 km²) indicates a massive loss of ecological function. This observation follows the global trends of urbanisation-driven vegetation loss documented by Mondal et al. (2015) and Singh et al. (2015), but the decline in Kota is significantly steeper than the trend reported for Indian cities of comparable size. The concomitant increase in Scrubland (+39.6%) implies that the transformation of vegetated land to urban space is frequently a dual stage process, with an intermediate scrubland state where land is initially degraded through informal occupation before formalised development.

The rapid growth of Agricultural Land (+54.8%) in the northern periphery emphasises a lowland–upland dualism where the Chambal canal irrigation system continues to be productive, presenting a spatial pattern distinct from urban-dominated southern city regions. This bifurcated trajectory — agricultural intensification in the north, urban expansion in the south — is an idiosyncratic aspect of Kota's spatial structure that can be traced back to the geographic concentration of coaching institutes in the southern part of the city.

6.2 NDVI Trends and Environmental Performance

The NDVI analysis revealed a 36.5% loss in total vegetation cover, during the study period which quantitatively shows the environmental degradation going in Kota. The loss of 33.37 km² (3,337 ha) of vegetated area will have direct effects on services provided by ecosystem such as air quality regulation, carbon sequestration and microclimate amelioration. These results confirm the trends of environmental degradation for Bhopal city reported by Shukla and Jain (2021) during 2000–2020, as well as the general patterns of urbanisation-related NDVI decline seen in global urban remote sensing literature (Thakur et al., 2025; Singh et al., 2019).

The tendency for NDVI declines to be steepest in densely concentrated residential coaching areas immediately south of the river, while the northern agricultural belt retains relatively high vegetative values, establishes a spatially interpretable pattern whereby studentification-led urbanisation is identified as the largest contributor to vegetation loss in Kota. This spatial pattern is supported by buffer analysis results demonstrating highly suppressed vegetation cover within 500m and 1km buffer distances from coaching institutes.

6.3 Buffer Analysis and Spatial Environmental Impact

The findings of the buffer analyses — that over 75% of the area within 500m and 1km of coaching institutes is Scrub Land in both 2000 and 2020 — imply that this zone has been environmentally degraded throughout the duration of this study, predating the most rapid phase of growth for Kota's coaching industry. The result is a consistent deficit of vegetation within the coaching hub area that mirrors the history of industrial land-use transformation around the RIICO Industrial Estate phase documented by Nair (2015), and which has been exacerbated over time through continued intensification of coaching industry-driven development.

The methodological framework applied in this study — NDVI buffer analysis of selected urban land uses — is consistent with those widely adopted in the domain of research investigating non-built environments (Mears et al., 2024; Nguyen et al., 2021; Martinez and Labib, 2023). The application of 500m, 1km, and 2km buffer distances is in accordance with the empirically-validated distances identified by Nguyen et al. (2021) as most relevant for capturing neighbourhood-level vegetation exposure. The fact that vegetation cover in the 500m buffer is below 0.1 km² for both years confirms how poorly students and residents from the nearby coaching hub must be accessing green space, with concomitant negative effects on wellbeing, air quality, and thermal comfort.

6.4 Implications for Green Infrastructure Planning

The combined findings of LULC change, NDVI decline, and buffer analysis point to an urgent need for targeted green infrastructure interventions in the coaching hub areas of Kota. Guan et al. (2022) showed that the fragmentation of urban periphery green space dramatically lowers the value of services provided by ecosystem, and Martinez and Labib (2023) introduced NDVI as a policy-relevant indicator for assessing and tracking urban green infrastructure improvements. Both frameworks are applicable to the Kota context.

Based on the spatial distribution analysis carried out in this study, three target scales for green infrastructure intervention are identified: (1) greening at the building scale (rooftop gardens, vertical vegetation within coaching institute campuses and hostels); (2) greening at the street scale (systematic tree planting along major roads of the coaching hub); and (3) greening at the neighbourhood scale (pocket parks and green corridors within the 1km buffer zone). These findings are in line with the green space planning strategies implemented by Martinez and Labib (2023) as well as the suitability guidelines for optimal green space assignment in urban communities with deficient NDVI values identified by Matewera and Odera (2024).

7. Conclusion

This study presents a novel, multi-temporal remote sensing and GIS-based analysis of environmental change associated with studentification-driven urbanisation in the Kota Municipal Area. The key findings are: (1) The extent of built-up area expanded by 44.2% from 2000 to 2020, while area under vegetation/Forest decreased by 38.5%, with a clear spatial and temporal correlation between coaching industry-driven urbanisation and vegetation loss; (2) overall NDVI-based vegetation cover decreased by 36.5% during the study period, with Dense Vegetation experiencing the greatest decline of 43.8% among all land cover classes; and (3) the buffer analysis confirmed that persistently low vegetation cover characterises the immediate surrounds of coaching institutes, with Scrubland covering more than 75% of all buffer zones across both study years.

These insights provide a numerically credible evidence baseline for assessing the environmental impacts of studentification in Kota, contributing to the wider international knowledge on education-economy-led urbanisation and its impact on natural systems. Additionally, the study demonstrates Landsat multi-temporal analysis and NDVI buffer analysis as cost-effective, scalable methodological tools for assessing environmental performance in rapidly changing Indian cities.

Urban planners and the Kota Municipal Corporation should prioritise integrating mandatory green space standards into coaching hub development regulations, while the Rajasthan Urban Development Authority should add spatially targeted green infrastructure strategies as described in this study to the upcoming revision of the Kota Master Plan.

References

- [1] Bose, R. (2017). Industrial Town to Educational Hub: Transformation of Kota. JIGYASA, ISSN 0974-7648, Vol. XI, No.3, July 2018.
- [2] Census of India (2011). Primary Census Abstract, Kota District, Rajasthan. Office of the Registrar General & Census Commissioner, Government of India, New Delhi.
- [3] Chatterjee, R. and Majumdar, S. (2022). Urbanization and the Urban Heat Island Effect. Environmental Science and Engineering Series, Springer.
- [4] Government of Rajasthan (undated). Kota Master Plan (2001–2023). Jaipur: Town Planning Department, Government of Rajasthan.
- [5] Guan, Y., Li, X., Li, S., Sun, H., and Liu, H. (2022). Effect of urban fringes green space fragmentation on ecosystem service value. PLOS ONE, 17(2): e0263452. <https://doi.org/10.1371/journal.pone.0263452>
- [6] Guin, D. and Das, D. N. (2015). New census towns in West Bengal: Census activism or sectoral diversification? Economic and Political Weekly, 50(14), 68–72.
- [7] Hussain, M., Chen, D., Cheng, A., Wei, H., and Stanley, D. (2013). Change detection from remotely sensed images: From pixel-based to object-based approaches. ISPRS Journal of Photogrammetry and Remote Sensing, 80, 91–106.
- [8] Khan, D., Bano, S., and Khan, N. (2024). Spatio-temporal analysis of urbanization effects: unravelling land use and land cover dynamics and their influence on land surface temperature in Aligarh city. Geology, Ecology, and Landscapes, September 2024, 1–25. <https://doi.org/10.1080/24749508.2024.2398419>
- [9] Martinez, A. I. and Labib, S. M. (2023). Demystifying normalized difference vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening. Environmental Research, 220, 115155. <https://doi.org/10.1016/j.envres.2022.115155>
- [10] Matewera, M. and Odera, P. A. (2024). Identification of optimal locations for green space initiatives through GIS-based multi-criteria analysis and the Analytical Hierarchy Process. Environmental Systems Research, 13, 45. <https://doi.org/10.1186/s40068-024-00377-0>
- [11] Mears, M., Brindley, P., and Jorgensen, A. (2024). Urban centre green metrics in Great Britain: A geospatial and socioecological study. PLOS ONE, 17(11): e0276962. <https://doi.org/10.1371/journal.pone.0276962>
- [12] Mehra, N. and Swain, J. B. (2024). Geospatial assessment of urban sprawl using remote sensing and GIS: a case study of Western Himalayan City of Dharamshala, Himachal Pradesh, India. IOP Conference Series: Earth and Environmental Science, 1327(1), 012031.
- [13] Mhangara, P. (2024). Advances in vegetation mapping through remote sensing and machine learning techniques: a scientometric review. Geocarto International, 39(1). <https://doi.org/10.1080/22797254.2024.2422330>
- [14] Mondal, M., Sharma, N., Kappas, M., and Garg, P. (2015). Land use land cover change detection and monitoring of urban growth using remote sensing and GIS techniques: A micro-level study. GeoJournal. <https://doi.org/10.1007/s10708-020-10359-1>
- [15] Nair, P. (2015). Production of an 'Educational' City: Shadow Education Economy and Re-structuring of Kota in India. In: Knowledge and the City, Springer. https://doi.org/10.1007/978-3-319-40317-5_24
- [16] Nguyen, P. Y., Astell-Burt, T., Rahimi-Ardabili, H., and Feng, X. (2021). Within what distance does 'greenness' best predict physical health? A systematic review of articles with GIS buffer analyses across the lifespan. International Journal of Environmental Research and Public Health, 18(3), 1233. <https://doi.org/10.3390/ijerph18031233>
- [17] Ramaiah, M. and Avtar, R. (2019). Urban green spaces and their need in cities of rapidly urbanizing India: A review. a. Urban Science, 3(3), 94. <https://doi.org/10.3390/urbansci3030094>
- [18] Rouse, J. W., Haas, R. H., Schell, J. A., and Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. Proceedings of the Third Earth Resources Technology Satellite-1 Symposium, 1, 309–317. NASA, Washington, DC.
- [19] Shukla, A. and Jain, K. (2021). Urban environmental degradation and its associated determinants: A geostatistical approach towards sustainable urban planning and management in an Indian city. Journal of Environmental Management. <https://doi.org/10.1016/j.jenvman.2025.031627>

- [20] Singh, P., Kikon, N., and Verma, P. (2017). Impact of land use change and urbanization on urban heat islands in Lucknow city, Central India. A remote sensing-based estimate. *Sustainable Cities and Society*, 32, 100–114. <https://doi.org/10.1016/j.scs.2017.02.018>
- [21] Singh, S. K., Mustak, S., Srivastava, P. K., Szabó, S., and Islam, T. (2015). Predicting spatial and decadal LULC changes through cellular automata Markov chain models using Earth observation datasets and geo-information. *Environmental Processes*, 2, 61–78. <https://doi.org/10.1007/s40710-014-0062-2>
- [22] Smith, D. P. (2005). 'Studentification': the gentrification factory? In R. Atkinson and G. Bridge (Eds.), *Gentrification in a Global Context: The New Urban Colonialism* (pp. 72–89). Routledge, London.
- [23] Smith, D. P. and Holt, L. (2007). Studentification and 'apprentice' gentrifiers within Britain's provincial towns and cities: extending the meaning of gentrification. *Environment and Planning A*, 39(1), 142–161. <https://doi.org/10.1068/a38204>
- [24] Thakur, S., Maity, D., and Mondal, I. (2025). Spatio-temporal analysis of land use transformations and their environmental implications in the Thamirabarani River Basin, India. *Frontiers in Remote Sensing*, 5, 1732414. <https://doi.org/10.3389/frsen.2025.1732414>
- [25] Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8(2), 127–150. [https://doi.org/10.1016/0034-4257\(79\)90013-0](https://doi.org/10.1016/0034-4257(79)90013-0)
- [26] USGS (2020). Landsat Collection 2 Level-2 ScienceProduct Guide. U.S. Geological Survey. <https://www.usgs.gov/landsat-missions/landsat-collection-2-level-2-science-products>

Copyright & License:

© Authors retain the copyright of this article. This work is published under the Creative Commons Attribution 4.0 International License (CC BY 4.0), permitting unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.