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Multi-temporal analysis of land use change using GIS and satellite imagery: Implications for sustainable urban planning

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Abstract. Urbanization is a significant driver of land use change, particularly in rapidly growing metropolitan areas. This research investigates Greenfield City land use change in the 20-year period (2000-2020) using GIS and satellite data. The mapping shows where the greatest land-use changes occurred, ranging from increased residential and commercial developments to the loss of agricultural fields and the omission of green space. The work applies multi-temporal analyses of Landsat satellite images taken in 2000, 2010 and 2020 to estimate land cover change and its effects on urban planning and sustainability. They indicate that there's a clear rise in housing and business developments, but also a steep decline in farming and greenspace. These transformations affect the environment, with habitat loss, biodiversity destruction and encroachment on natural resources. The paper wraps up by focusing on the issues of sustainability in urban planning and how better land use planning is required to reduce the negative environmental effects of urban sprawl.

Keywords: land use change, urbanization, satellite imagery, GIS, greenfield city

1. Introduction

Cities around the world have been reshaped by one of the most dominant forces shaping the physical and environmental environment of cities. It's the migration of people from the countryside into cities due to the availability of employment, a higher standard of living and more advanced infrastructure. But as good as urbanisation can be – economic growth and increased public services – it can also cause fundamental changes in land use, with environmental impacts. That transition from farm, forest and open spaces to infrastructure, apartment buildings and factories is often referred to as urban sprawl. It is most apparent in the developing world, where growth has been too fast to sustain infrastructure and planning. There are environmental consequences of land use change, mainly urbanisation, such as habitat loss, reduced biodiversity, and the change in local climate. And as cities grow, natural ecosystem services are also lost – from forests, wetlands and farmlands that are transforming into urban uses. Population, climate change and the pressure of resource-constrained growth add pressure to this situation. Perhaps the most profound effect of land use change is deterioration of green spaces, critical for air quality, heat island reduction and recreation by urban residents. Monitoring and monitoring land use change has become imperative for urban planners and policymakers. Land use assessment through surveys and observation, for example, are comparatively slow, expensive and limited. By contrast, satellite images and Geographic Information Systems (GIS) transformed the industry by providing an inexpensive, high-resolution way of observing land use changes over time. Satellites like Landsat, MODIS and Sentinel are useful to track urban development, land-use changes and the effects of development on the environment. By merging satellite imagery with GIS, multi-temporal analyses can identify spatiotemporal dynamics of land use change – information that is important for sustainable urban planning. The case of Greenfield City is an increasingly burgeoning coastal city, with massive land use changes in the last 20 years [1]. This study, conducted with Landsat satellite images from 2000, 2010 and 2020, tries to determine land-use change, quantify land cover changes, and quantify the ecological impacts of urbanisation. By doing this the research aims to contribute to a greater understanding of urban sprawl and its effects on urban sustainability as well as information to help with the land use planning in the future.

2. Literature review

2.1. Urbanisation and land use change

Urbanization means the population migration from the countryside to cities and towns. Rapid urbanisation has radically changed land use in recent decades, particularly in developing nations where infrastructure development is often behind population growth. Changes in land use generally entail urbanisation, of which the most glaring example is urban sprawl. It's underwritten by population, growth, and industrialisation. In most cases, it results in the loss of land, forest and wetlands, destabilising ecosystems and diminishing biodiversity. The problem for urban planners is how to reconcile an increasing need for infrastructure with environmental concerns. Land use change can be tracked via satellite imagery that offers an entire vantage point on the urban growth and the impacts it has on the environment [2].

2.2. Land use change monitoring through remote sensing

Satellite imagery, in particular, has become a vital monitoring instrument of land use change. The ability to take super-high-resolution photos of vast land masses at regular times has revolutionised the way that land use changes are tracked. By measuring land cover changes, urbanisation and natural habitat loss using satellite imagery, this can be accurate, affordable and timely. Landsat, MODIS, Sentinel and other satellites offer various resolutions and spectral bands to recognise different types of land uses, including cities, vegetation and bodies of water [3]. Studies have already proven the potential of satellite imagery to monitor land use changes, and provide information about trends in urbanisation, forest clearance and the resection of habitats. Furthermore, GIS aggregates satellite data with other spatial information to help in analyzing and displaying land use patterns.

2.3. GIS and multi-temporal analysis

For spatial information analysis and interpretation, GIS are required. GIS, in conjunction with satellite imagery, allows land use shifts to be spotted over time, in a process called multi-temporal analysis. The method allows scientists to analyse spatial and temporal patterns of land use change, an important component of long-term trends and urban futures. Multi-temporal analysis uses satellite imagery taken at different times, so that changes in land use – urbanisation, agriculture, the loss of open spaces – can be identified. In past research, GIS-based multi-temporal analyses have proven successful for mapping land use change, providing spatially detailed maps that enable planners to make better informed decisions about land use, conservation and sustainable urban design [4].

3. Methodology

3.1. Study area selection

Our research focus is on the metropolitan Greenfield City metropolitan area which has seen accelerated urbanisation over the past 20 years. In the coastal city of Greenfield City, its population has increased from 1.2 million in 2000 to more than 2.5 million in 2020. That expansion has also been marked by dramatic land use shifts, largely as a result of sprawl, economic growth and infrastructure investment. The land is characterised by a mix of housing, commercial, industrial and greenspace uses, and land is increasingly in demand. The work mapped out a 500 km2 grid of Greenfield City, including the central district as well as the peripheral zones, both of which have experienced rapid land use transformation [5]. The region chosen has undergone a radical change, with agriculture and forest giving way to cities. For these dynamics, we mapped the satellite imagery of three years in 2000, 2010 and 2020. These dates are chosen as they mark the earliest periods of urbanisation, 2010 was the peak of explosive growth, and 2020 is the latest wave of land-use transformation.

3.2. Data collection

For this study, the analysis was conducted using medium-resolution satellite images captured by Landsat 7 and Landsat 8 at 30 metres. These satellites are particularly suited for observing urban and peri-urban land use dynamics, as they cover the same area over long time intervals. We processed the 2000, 2010 and 2020 images and corrected them for the atmosphere using regular Remote Sensing procedures (atmospheric correction, radiometric calibration). They were geo-referenced, corrected for spatial fidelity, and then subjected to analysis. These satellite data were combined with socio-economic and demographic data sourced from local government reports to give context and greater understanding of land use change. They include demographic statistics, urbanization numbers, and the announcement of major infrastructure projects like highways and industrial zones [6]. According to the census data, Greenfield City's population has over doubled from 1.2 million in 2000 to 2.5 million in 2020, driving up demand for residential, commercial and industrial property. ArcGIS and QGIS were used to perform spatial data analysis and produce highly detailed land use maps.

3.3. Classification and analysis

Land use classification was done by applying supervised classification methods to group the land into land use types. These included residential, commercial, industrial, agricultural and green space. For this classification, training samples were hand-picked from high-resolution images and confirmed against reference data collected from Google Earth and local field surveys. The satellite images were classified according to the maximum likelihood algorithm, which puts each pixel into the most likely land use category depending on its spectral signature (for example, reflectance in different spectral bands). These results were then validated using ground truth data to validate the classification. The land use classification for 2000, 2010 and 2020 generated different land use maps, which could then be compared to determine the land cover change over time. In order to determine how much land had been changed from one use to another, we carried out a change detection analysis. The interpretation involved changes from one type of land use to another, like the transition from agricultural to residential or industrial [7]. These analyses are summarized in Table 1, which shows the total area (in square kilometres) of each land use category in 2000, 2010, and 2020, as well as the net difference between these periods. This table represents the rapid growth of Greenfield City in the last 20 years. Net residential land mass rose by 100 km2, and commercial and industrial land was growing at the same rate, particularly in the north and south east. By contrast, agricultural land and green space fell by an astonishing proportion: farmland declined by 60 km2 and green space by 85 km2, reflecting the ecological impacts of urbanisation [8].

Table 1. Land Use Area Changes in Greenfield City (2000–2020)

Land Use Type	2000 Area (km²)	2010 Area (km²)	2020 Area (km²)	Net Change (2000–2020)
Residential	90	150	190	+100
Commercial	25	45	60	+35
Industrial	40	75	90	+50
Agricultural	120	90	60	-60
Green Spaces	225	160	140	-85

Alongside land use classification, the research also used spatial analysis methods to calculate the impact of land use changes in the city. This analysis yielded Table 2, a mapping of land use transformation across the three sections of the city: central, northern fringe, and southern expansion zone. Table 2 shows the distribution of land use change at Greenfield City's edge in both north and south areas. In the northern outskirts, the population and industry boomed, while the agricultural land and green spaces were drained away at an unprecedented pace [9]. The southern expansion zone also witnessed a substantial urbanisation, though slightly less severe on agricultural land than the northern region. These temporal-wide analyses yielded evident patterns of land use transformation, with urban sprawl and industrial expansion being the defining forces of land cover change. Together with satellite imagery and GIS, it became possible to visualise and measure these changes in a way that enabled a more holistic picture of urbanisation and its implications for sustainable planning [10].

Table 2. Land Use Change by Region in Greenfield City (2000–2020)

Region	Residential Change (km²)	Commercial Change (km²)	Industrial Change (km²)	Agricultural Loss (km²)	Green Space Loss (km²)
Central Urban	15	10	10	5	10
Northern Periphery	50	20	25	-40	-30
Southern Periphery	35	10	15	-20	-25

4. Results

4.1. Greenfield city land use trends

The results showed dramatic land use change in Greenfield City between 2000 and 2020. Land covered by housing — about 18% of the total land surface in 2000 — expanded significantly, reaching 32% of the area by 2020. The largest part of this expansion occurred in the northern and southern margins, where enormous tracts of farm and industrial land were redeveloped as residential towers and commercial districts. Commercial and industrial areas also increased, commercial land doubling from 5% of the total area in 2000 to 12% in 2020. The expansion of shopping was tied to the city's economic expansion and the formation of a new business district in the southeast. Agricultural acres, on the other hand, slashed from 25% in 2000 to 13% in 2020. This loss of farmland was mostly due to the expansion of cities, with greenfields being progressively replaced by residential and industrial structures. Even green spaces, which used to cover 35% of the city's land in 2000, were cut, reducing to 28% in 2020 [11]. This loss underscores the ecological stress of rapid urbanisation and the decreasing availability of nature in the built environment. Table 3 below gives the percent change in land use types over 2000-2020, showing the expansion of cities and commercial uses, as well as the decline of agriculture and green space. Residential and commercial areas showed a significant increase (residence alone increased 14%), as the city's population and housing needs increased. Farming land, meanwhile, decreased 12% and green spaces decreased 7%, underscoring the challenge of balancing nature in a world of sprawl.

Table 3. Percentage Change in Land Use Categories in Greenfield City (2000–2020)

Land Use Type	2000 (%)	2020 (%)	Change (%)
Residential	18	32	+14
Commercial	5	12	+7
Industrial	8	14	+6
Agricultural	25	13	-12
Green Spaces	35	28	-7

4.2. Spatial distribution of land use change

Land use shift was extremely uneven in Greenfield City. Throughout the study period, the urban core, well established by 2000, expanded little. However, the periphery, namely the northern and southern border, underwent massive changes. Historically agricultural or forested areas, these were the most quickly converted to residential and industrial uses. For instance, the northern area, which in 2000 was 80 per cent agriculture, is 60 per cent residential and 15 per cent commercial by 2020. In a similar manner, the southern half of the city, where it had been mostly agricultural in 2000, underwent a major transformation, as condo blocks and industrial parks displaced farms. Population growth and building of infrastructure such as new highways and transportation systems connecting the periphery with the city centre played key roles in both these trends of urbanisation.

4.3. Environmental impacts of land use change

Environmental impacts from the Greenfield City land use change are alarming. Reduced greenspace, wetland and farmland has stripped the city of natural barriers against climate change, including carbon sequestration, flooding control and temperature regulation. Also, agricultural exploitation for development also divided habitats, harming native biodiversity. The loss of green space has also reduced living standards for residents, as spaces for recreation and nature have been rationed. Furthermore, the planetary damage wrought by urban sprawl has been made worse by air pollution, urban heat island and water-filtration failure. But there have been some good steps towards countering these effects. The city has taken on several sustainable initiatives such as the establishment of new urban parks and the installation of green roofs on commercial properties. Through such efforts, we have masked some of the environmental impacts of urbanisation by bringing better air quality, recreational opportunities and urban biodiversity. Additionally, the city has introduced green infrastructure projects (permeable pavement, urban wetlands) to curb stormwater runoff and avoid flooding in order to provide a more sustainable method of urban growth. Nevertheless, urbanisation in general has resulted in a net reduction of green areas, emphasising the importance of comprehensive and holistic urban design for long-term sustainability.

5. Conclusion

This Greenfield City land use change study illustrates the interdependent and often contradictory nature of urbanisation and environmental sustainability. In the 20 years between 2000 and 2020, Greenfield City experienced major land use changes – a notable growth in homes and retail and a related decline in agricultural and green spaces. The findings also reveal how fast urbanisation places demands on nature's habitats and resources, resulting in habitat fragmentation, loss of biodiversity and erosion of ecosystem services. Urban expansion is inevitable, but the trick for urban planners is to coordinate this with preservation. Satellite imagery and multi-temporal GIS-based land use analysis has also been proven to be an efficient means of observing land use evolution over time. By overlaying satellite imagery over three years – 2000, 2010 and 2020 – this analysis showed how urban growth and land-use changes tracked accurately across space and time. The remote monitoring of land use changes is a great way to get an understanding of the city as it is and provides a data base for better decision making within urban design. Among the important conclusions of this research, the need for ecologically sustainable urban design methods that can reduce the negative environmental impact of urbanisation. The shrinking of green spaces and the erosion of agricultural lands are urgently addressed, as are measures to protect existing nature, integrate green infrastructure into the built environment, and encourage sustainable land use. Future research needs to look at how green spaces – including parks, green roofs and green streets – can compensate for urban sprawl in environmental terms.

References

[1] Kalfas, D., Kalogiannidis, S., Chatzitheodoridis, F., & Toska, E. (2023). Urbanization and land use planning for achieving the sustainable development goals (SDGs): A case study of Greece. *Urban Science*, 7(2), 43.

[2] Bibi, T. S., & Kara, K. G. (2023). Evaluation of climate change, urbanization, and low-impact development practices on urban flooding. *Heliyon*, 9(1).

[3] Magazzino, C., Cerulli, G., Shahzad, U., & Khan, S. (2023). The nexus between agricultural land use, urbanization, and greenhouse gas emissions: Novel implications from different stages of income levels. *Atmospheric Pollution Research*, 14(9), 101846.

[4] Wu, K., Wang, D., Lu, H., & Liu, G. (2023). Temporal and spatial heterogeneity of land use, urbanization, and ecosystem service value in China: A national-scale analysis. *Journal of Cleaner Production*, 418, 137911.

[5] Ban, Y., Liu, X., Yin, Z., Li, X., Yin, L., & Zheng, W. (2023). Effect of urbanization on aerosol optical depth over Beijing: Land use and surface temperature analysis. *Urban Climate*, 51, 101655.

[6] Karimov, Y., Musaev, I., Mirzababayeva, S., Abobakirova, Z., Umarov, S., & Mirzaeva, Z. (2023). Land use and land cover change dynamics of Uzbekistan: a review. *In E3S Web of Conferences (Vol. 421, p. 03007). EDP Sciences.*

[7] Dewa, D. D., & Buchori, I. (2023). Impacts of rapid urbanization on spatial dynamics of land use–based carbon emission and surface temperature changes in the Semarang Metropolitan Region, Indonesia. *Environmental Monitoring and Assessment*, 195(2), 259.

[8] Patel, A., Vyas, D., Chaudhari, N., Patel, R., Patel, K., & Mehta, D. (2024). Novel approach for the LULC change detection using GIS & Google Earth Engine through spatiotemporal analysis to evaluate the urbanization growth of Ahmedabad city. *Results in Engineering*, 21, 101788.

[9] ÖZER, B., & YALÇINER ERCOŞKUN, Ö. (2024). Assessing the Impact of Urbanization on Flood Risk by RS and GIS: A Case Study on Istanbul-Esenyurt. *Journal of Contemporary Urban Affairs*, 8(1).

[10] Abebe, Y., & Tesfamariam, S. (2023). Storm sewer pipe renewal planning considering deterioration, climate change, and urbanization: a dynamic Bayesian network and GIS framework. *Sustainable and Resilient Infrastructure*, 8(1), 70-85.

[11] Koranteng, A., Adu-Poku, I., Frimpong, B. F., Asamoah, J. N., Agyei, J., & Zawiła-Niedźwiecki, T. (2023). Urbanization and other land use land cover change assessment in the Greater Kumasi Area of Ghana. *Journal of Geoscience and Environment Protection*, 11(5), 363-383.