Studying Land Evolution Patterns and Influencing Factors in Wuhan City over the Past 40 Years Using Remote Sensing

Junting Gan[a]
Nanjing Foreign Language school, Nanjing 210000, China

Keywords: Remote Sensing, Land Use Land Cover, Urban Development, Wuhan, Geographic Information System.

Abstract: Land Use and Land Cover (LULC) refers to the classification of land cover into distinct usage types, which is crucial for urban planning. This study takes the capital of Hubei Province – Wuhan – as an example to analyze the land evolution patterns and influencing factors over the past forty years via remote sensing techniques. The land cover of Wuhan in 1985, 1990, 2005, and 2020 is classified into five categories: farmland, vegetation, water body, built-up area, and bare land in this study. Landsat satellite imagery was processed through supervised classification algorithms in QGIS to create LULC maps of the four years. The results of land classification indicate a continuous increase in built-up areas, which corresponds to rapid urban growth, while farmland and water bodies have seen a slight decline over time. The amount of vegetation declined from 1985 to 2005 before it increased recently in accordance with the central government's efforts to promote sustainable development in the twenty-first century. The paper demonstrates how sociopolitical factors, such as the "reform and opening-up" policies, creation of development zones, and large-scale infrastructure projects, have shaped Wuhan's land evolution patterns. Furthermore, the findings present the twenty-first-century shift in the government’s development priorities from fast industrial expansion to sustainable high-tech sectors. Through analysing these shifts, the study offers insightful information about the influencing factors of urban transformation, emphasizing the significance of strategic planning and policy adaptation to meet changing urban requirements.

1 INTRODUCTION

Human settlement has an expansive nature. People tend to gather and settle in regions with climatic or geographical advantages. As production increases and surplus occurs, non-food-producing populations, which are liberated to specialize in activities other than food production, could be supported. In this context, the technology and production capabilities will significantly improve. Over time, societies have formed and trade prevailed, attracting more people to move into “urban” areas. Consequently, the demand for residential, commercial, and industrial spaces would motivate the settlement, or “urban areas,” to extend to previously unexploited regions, a process that is regarded as “urbanization.” The late twentieth and the twenty-first centuries are a golden time for development. Throughout the last 40 years, developing countries around the globe, such as India and China, have been experiencing rapid growth. Cities have undergone enormous changes in their physical, social, and economic landscapes (Gries and Grundmann, 2018).

Urban development and land evolution are two interdependent concepts. Urbanization leads to profound changes in land use and land cover (often referred to as LULC), often resulting in the conversion of natural landscapes into built environments, which alters the composition and function of the land surface. Meanwhile, changes in LULC, such as the conversion of agricultural land to urban built-up areas, deforestation, and construction of infrastructure, reflect the evolving needs and priorities of urban settlements. These changes can sometimes induce severe environmental and ecological damages (Habibi, 2011), making it essential for scientists to monitor and analyze land evolution patterns to inform policy and decision-making processes.

[a] https://orcid.org/0009-0007-8572-6351

Gan, J.
Studying Land Evolution Patterns and Influencing Factors in Wuhan City over the Past 40 Years Using Remote Sensing.
DOI: 10.5220/0013018200004601

In *Proceedings of the 1st International Conference on Innovations in Applied Mathematics, Physics and Astronomy (IAMPA 2024)*, pages 179-187
ISBN: 978-989-758-722-1

Traditional land-monitoring methods, such as ground surveys, are typically time-consuming and resource-intensive, while providing only localized snapshots of larger areas. Contrary to that, remote sensing offers a synoptic view that can cover extensive regions and produce frequent updates. It is efficient, accurate, and highly customizable. Researchers can conduct their research by inputting the corresponding geographical coordinates and time span to obtain data related to the target study area. This relatively new measure is the process of acquiring information about the Earth's surface without making physical contact with it. It is achieved through the use of satellite or aerial imagery that includes various spectral bands. After being processed by suitable procedures, satellite images would reveal specific characteristics about Earth's surface. Its ability to provide detailed, up-to-date data on LULC makes it an invaluable tool when studying urban development.

When processed using software such as QGIS and ArcGIS Pro, remote sensing data allows for land classification, which involves categorizing pixels in satellite images into distinct land cover types. This classification is achieved through algorithms that identify patterns in the spectral data and then assign land cover types based on these patterns. Researchers can create detailed maps that visualize changes in LULC over time in such a context, thus interpreting the spatial distribution of land cover types and identifying trends in land evolution.

Wuhan is a major city in Central China. Taking Wuhan City as an example, this paper utilizes remote sensing methods, particularly land classification, to investigate the patterns and influencing factors of land evolution over the past 40 years, contributing to the broader understanding of urban land dynamics.

2 BACKGROUND OF WUHAN CITY

Wuhan City, the capital of Hubei Province, is steeped in historical significance and contemporary relevance (Figure 1). Spreading approximately 8494 square kilometers, Wuhan City comprises three distinctive towns: Wuchang, Hankou, and Hanyang. One of the critical factors driving the city's development was its strategic location. Wuhan was located at the intersection of the Beijing-Guangzhou Railway and the Wuhan-Jiujiang Railway, as well as the confluence of the Han River and the Yangtze River. As a major railway and waterway junction, the city has leveraged its logistical advantages to boost regional resource circulation, serving as a critical gateway connecting the eastern coastal regions with the interior provinces of China. The construction of several bridges that span the Yangtze River since the 1950s have also solidified Wuhan's role as a transportation nexus in Central China.

Figure 1: Wuhan's Location in China. (File:Wuhan-location-MAP-in-Hubei-Province-in-China.jpg - Wikimedia Commons, 2022).

Over the past 40 years, Wuhan has experienced dramatic change. It has evolved from a small, regional industrial hub into a thriving metropolis with a robust economy. The city's rapid growth can be traced back to the adoption of China's reform and opening-up policies in the early 1980s. The set of reforms, first proposed in 1978 by Deng Xiaoping, leader of the Communist Party of China (CPC) at that time, marked an era of rapid industrialization and modernization across the nation. In the beginning, Wuhan was dominated by heavy industries, particularly steel-making and automotive manufacturing. Wuhan's population grew steadily in this period as people began to relocate to urban areas in search of relatively high-paid jobs. The 1991 establishment of the Wuhan Economic and Technological Development Zone (WEDZ) was a great leap forward in the development of the city. The Development Zone sparked the growth of traditional and high-tech industries, including electronics and information technologies. It also attracted foreign investments. The 1990s also witnessed a massive investment in public transit, new highways, and bridges over rivers. The increased spending in infrastructure were approved by the government to accommodate the city's growing population and increased civic engagement. In the 2000s, Wuhan's economy saw substantial modernization and adaptation. There existed a growing emphasis on developing high-value industries such as biotechnology. Meanwhile, Wuhan was included in the Rise of Central China Plan, a strategic project first proposed in 2004 to foster development in Central China. The Plan also emphasized on environmental issues, and transformed Wuhan to a sustainable track (Wang et al, 2022). The city has successfully shifted to high-tech industries and services in the twenty-first century, establishing the Optics Valley of China (OVC) as a symbol. Situated in Wuhan's East Lake High-Tech Development Zone, the OVC has become a leading center for innovation and technology that houses numerous research institutions, universities, and high-tech enterprises.

Throughout these decades, Wuhan's structural transformation from a regional center to a metropolis has induced change in the city's landscape, altering LULC situation. Total area of wetland, for instance, have been declining since the 1980s due to economic development (Xu et al., 2010). Such an evolution makes Wuhan City an ideal case study for examining the change patterns and the influencing factors.

3 METHODS

This research is based on Landsat satellite imagery. To study land evolution patterns in Wuhan City over the past 40 years, 4 unique years are chosen: 1985, 1990, 2005, and 2020, each representing key periods in the city's development trajectory. 1985 marks an early stage in Wuhan's urban development when the reform-and-opening-up policy just came into effect. By 1990, Wuhan had begun experiencing more significant urban growth reflecting economic reforms' early impacts. The year 2005 captures the continued expansion and urbanization during a period of rapid economic development in China, especially a witness to the transition from heavy industries to high-tech industries. Most recent data from 2020 allows for the assessment of the current state of urban growth and comparison with previous decades, which are invaluable for interpreting the long-term trends in LULC.

3.1 Data Acquisition and Preprocessing

The research utilized Landsat 5 images for the years 1985, 1990, and 2005, and Landsat 8 images for year 2020. Related data were downloaded from Geospatial Data Cloud official website. The selected imagery included seven spectral bands for Landsat 5 and eight bands for Landsat 8, which provided the necessary spectral resolution for accurate land cover classification. Three satellite images are required to cover the study area. The next step is to stitch the three images together and create a seamless composite image that could cover the entire Wuhan City (Figure 2a). After using the "Mosaic To New Raster" feature from the ArcGIS tool box, the image that fully covers Wuhan City is obtained, as shown in figure. To make the data more concise, the specific region corresponding to Wuhan City is extracted after creating the mosaic. The Wuhan City administrative boundary shapefile was used to guide the cropping process, serving as input data when using the "Clip" tool from ArcGIS Analysis Toolbox. The cropping operation was then performed automatically to extract the digital elevation model (DEM) of Wuhan City from the larger composite image. This step ensured that the analysis was confined precisely to the geographical boundaries of the city, so as to produce a focused and relevant dataset for subsequent land cover classification and analysis (Figure 2b).

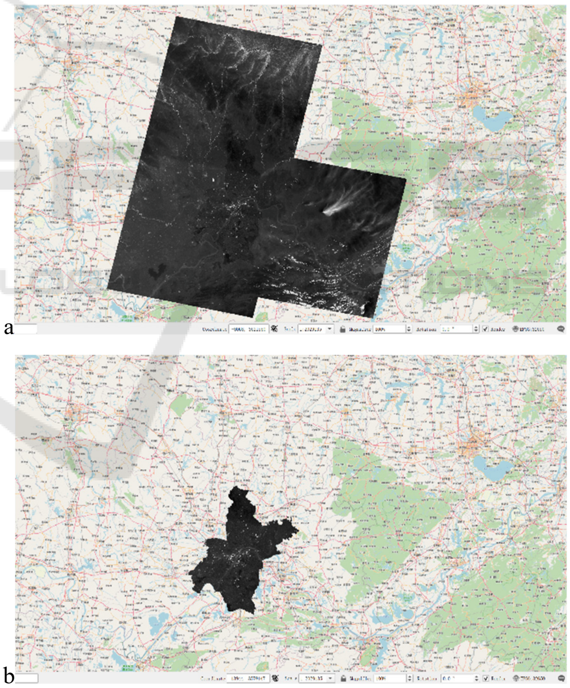

Figure 2: (a) Mosaicking 3 images to fully cover Wuhan; (b) Cropping out Wuhan City (Picture credit: Original).

After obtaining the cropped data of 4 years, a supervised classification is conducted in QGIS version 3.36.2. In the supervised classification process, regions of interest (ROIs) were selected manually to serve as training input for the classification algorithm. Such a process was accomplished through the Semi-Automatic

Classification plugin (SCP) in QGIS, a feature that classifies land cover types based on user-input training data.

3.2 Land classification

This study classifies land cover into five distinct categories: farmland, vegetation, water body, built-up area, and bare land. Since the processing procedure for each category is consistent, this part uses the creation of ROIs for water bodies as an example for detailed interpretation. Using the drawing tools provided by the SCP plugin, polygons could be created around representative samples of water bodies. In Figure 3, for example, the orange polygon has been drawn to encompass areas identified as water bodies.

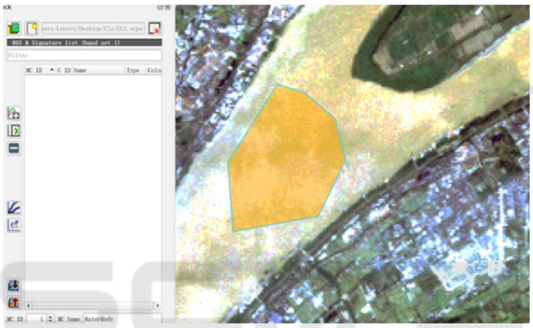

Figure 3: Example of Water Body ROI City (Picture credit: Original).

The selected ROIs are then added to the SCP plugin's ROI list. Each ROI is assigned a unique ID and labeled with the category name, in this case, "Water Body." The ROIs are then saved as part of the SCP training layer.

It is noted that precision in delineating ROIs is critical in the classification process. Comparing the selected ROIs with true-color satellite maps (Figure 4a) or maps generated from other band compositions can ensure the effectiveness of input ROI. In this case, the Normalized Difference Water Index (NDWI), which highlights water bodies using green and near-infrared bands (Figure 4b), can help distinguish lakes and rivers from other land cover types. The precise boundaries of water bodies can be confirmed by further overlaying the NDWI map with true-color composite.

After all these ROIs have been manually created and checked, the next step was running the classification algorithm. The “Maximum Likelihood Classification” algorithm is applied in the calculation. At last, small adjustments were made, including smoothing, filtering, and even reclassifying to ensure accuracy and clarity of the classification. Repeat this process four times, and the land classification map for the years 1985, 1990, 2005, and 2020 are created (Figure 5).

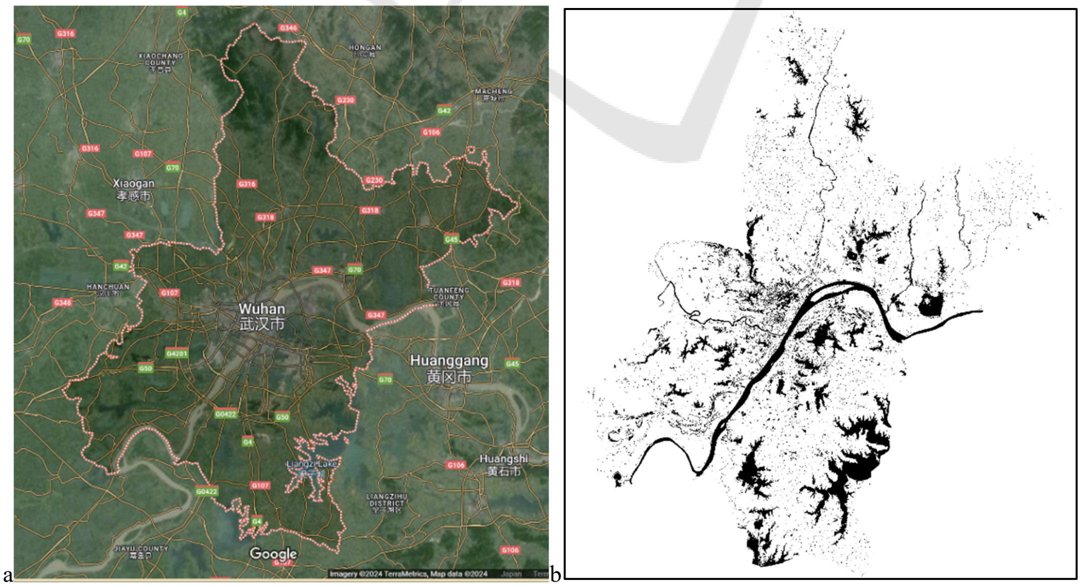

Figure 4: (a) Wuhan City true color satellite map from Google Map; (b) NDWI map of Wuhan City (1985) City (Picture credit: Original).

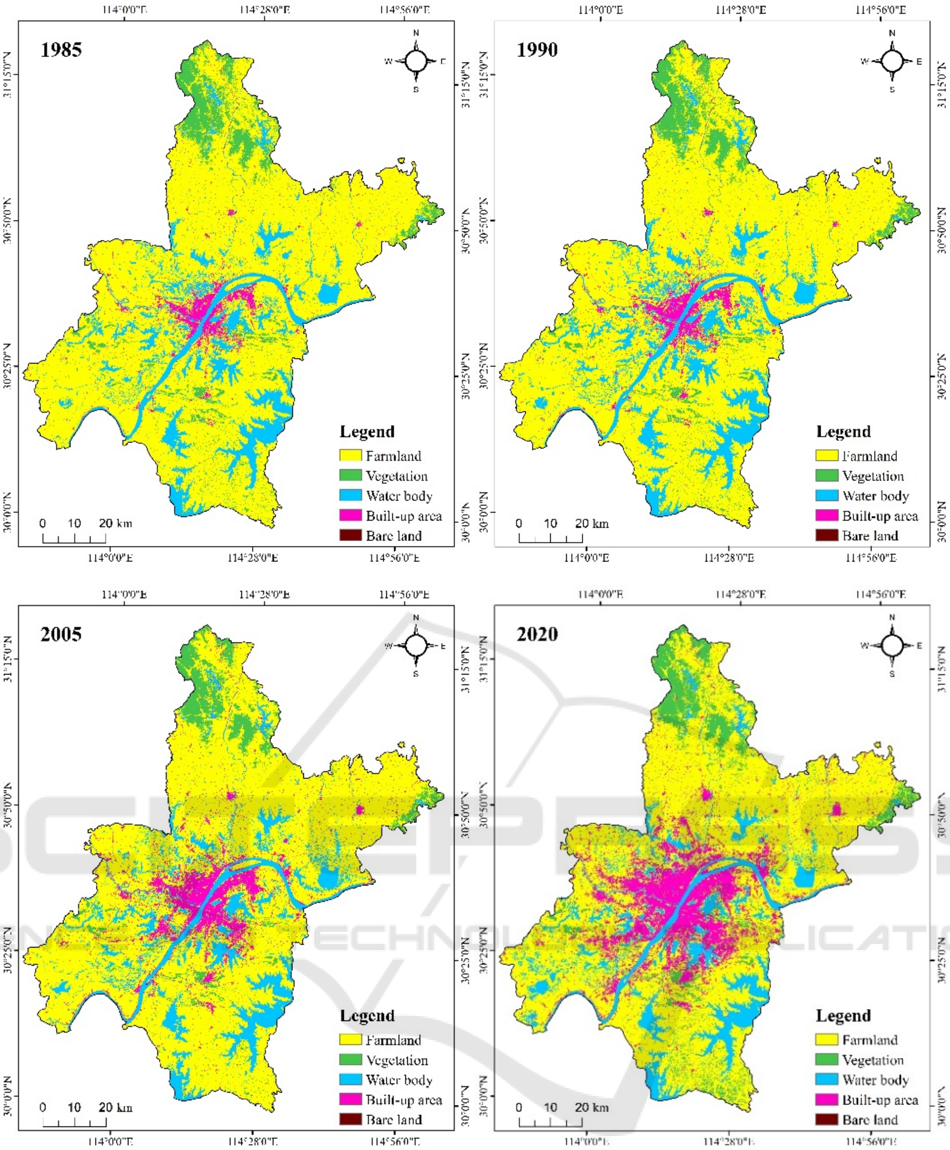

Figure 5: Land Use and Land Cover Map of Wuhan City (Picture credit: Original).

4 RESULTS

Through the LULC maps for Wuhan City for the years 1985, 1990, 2005, and 2020 presented above, we can observe the following results.

4.1 Land Use Distribution Across Years

In 1985, the LULC in Wuhan City were primarily dominated by farmland, which covered an area of 6472.990 km² (75.4834% of the total land). Vegetation areas comprised 597.549 km² (6.9682%). Water bodies, including rivers and lakes, occupied 1214.230 km² (14.1595%). Built-up areas, which include urban and developed regions, covered 289.022 km² (3.3704%). Bare land was minimal, with an area of 1.594 km² (0.0186%).

By 1990, farmland remained the predominant land use, covering 6346.680 km² (74.0104%) of the total area. Vegetation areas slightly increased to 601.958 km² (7.0196%). Water bodies expanded to 1298.890 km² (15.1467%). The built-up area also saw an increase in area, reaching 326.217 km² or 3.8021% of the land. Bare land remained minimal, covering 1.639 km² (0.0191%) of the total land.

In 2005, farmland covered 6181.440 km² (72.0836%). Vegetation areas decreased to 515.572 km² (6.0122%) and water bodies slightly decreased to 1233.530 (14.3846%). The built-up area saw a notable increase, covering 644.092 km² (7.5109%). Bare land was still almost negligible, with an area of 0.745 km² (0.0087%).

By 2020, farmland had further reduced to 5542.850 km² (64.6366%) of the total land. Vegetation areas covered 652.525 km² (7.6093%) of the land. Water bodies occupied 1186.140 km², representing (13.8319%). The built-up area significantly increased to 1193.500 km², constituting 13.9177% of the land. Bare land remained very minimal, with an area of 0.391 km², accounting for 0.0046% of the total land.

4.2 Changes in Land Use Over Time

Changes in land use distribution over time is studied to better interpret the acquired data. A line chart indicating the proportion of different land use types in each of the 4 years shows the trends and shifts in the area of various land use categories over the 35 years (Figure 6a). Figure 6b illustrates the percentage change in each land use category over three distinct periods: 1985-1990, 1990-2005, and 2005-2020. This bar chart provides a clearer contrast of how different land use types have evolved over time.

Across the 35-year period, farmland continuously declined approximately 1.95% from 1985 to 1990, 2.60% from 1990 to 2005, and 10.33% from 2005 to 2020. At the same time, vegetation areas experienced fluctuations, initially increasing by 0.74% from 1985 to 1990, then decreasing by 14.35% from 1990 to 2005, and finally increasing significantly by 26.56% from 2005 to 2020. Water bodies, similarly, showed minor variations over the periods. It increased by 6.97% from 1985 to 1990, then decreased by 5.03% from 1990 to 2005, followed by a 3.84% decline from 2005 to 2020. Built-up areas saw a significant and continuous increase throughout the study period. After experiencing a 12.87% increase from 1985 to 1990, built-up areas nearly doubled from 1990 to 2005, increasing by 97.44%. It then increased by 85.30% from 2005 to 2020. Bare land, on the other hand, decreased substantially by 54.53% from 1990 to 2005 after a slight increase in the late 1980s. It also saw a dramatic decrease of 47.58% from 2005 to 2020.

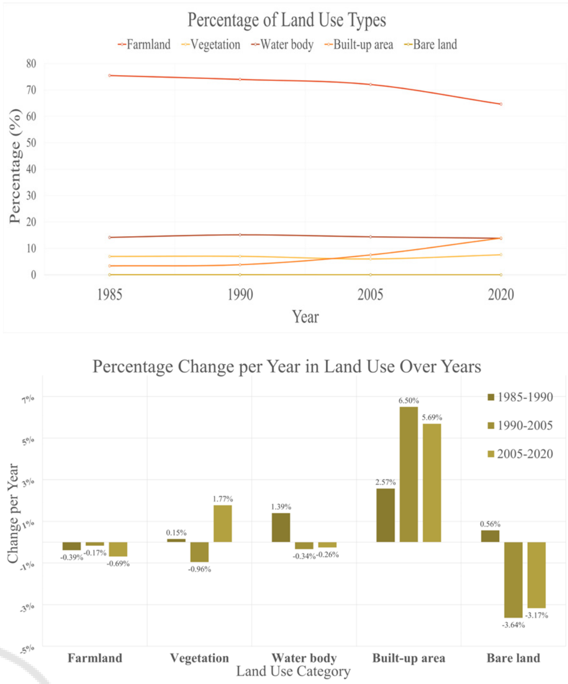

Figure 6: (a) Percentage of Land Use Types; (b) Percentage Change in LULC Types Over Years City (Picture credit: Original).

5 DISCUSSION

The most striking change in Wuhan's LULC distribution over the 40 years is the significant increase in built-up areas, which presents the city's economic development and policy-driven urban planning.

5.1 The stage of 1985-1990

The 1980s was the initial stage of China's rapid development. Leader of the Communist Party of China at that time, Deng Xiaoping, initiated a set of reforms referred to as "Reform and Opening Up" in 1978, aiming to boost economic development and promote liberalism in China. Decentralizing economic decision-making and promoting transition to market-oriented economy, Deng's vision was to modernize China's economy and integrate it into the global market. However, when the reform had just started, poverty was rampant, and economy still haven't recovered from the aftermath of the Cultural Evolution. It was not until the middle or late 1980s that reform policies began to take effect. The decentralization policies indeed spurred industrial development. The machine-building industry, which had traditionally relied on state support, had to adapt to market conditions and compete for resources and markets, thus improving its own strength. Similarly, the textile industry received preferential treatment and investment to boost production and profitability (Solinger, 1986). The city, with its strong industrial base in machine-building and textiles, generally leveraged these reforms to attract investment and boost economy. In 1987, the city began receiving direct investment from Hong Kong enterprisers. Despite the initial amount being relatively small (100 million USD), it laid the foundation for future cooperation between the two regions (Liu & Tu, 1998). These socio-economic developments, induced by political reforms earlier this decade, began to sprout between 1985 and 1990, which laid the groundwork for the city's rapid development in the subsequent decades.

According to the data gathered by the study, total area of built-up regions increased by 12.87% from 1985 to 1990, representing the largest change among all land use types. Meanwhile, farmland area saw a slight decrease (Figure 6b). The conversion of farmland and other land types into built-up areas was driven by the need to accommodate the growing industrial and commercial activities. This increased urbanization, arguably, reflects the effects if Reform-and-Opening-Up policies, where the economy began to recover and trade started to flourish.

5.2 The stage of 1990-2005

The period from 1990 to 2005 witnessed substantial changes in LULC distribution in Wuhan City. The total built-up area nearly doubled within these fifteen years. It is inferred that both the establishment of relative policies and the growth of international trade resulted in the increase of built-up area.

A pivotal development during this time was the establishment of the Wuhan Economic and Technological Development Zone (WEDZ) in the early 1990s. It was an open area located southwest of downtown Wuhan, along the banks of the Yangtze River. Created to attract investment and promote industrial growth, the WEDZ provided a concentrated area for industrial activities when urban land's limited industry-carrying capacity forced heavy industries to leave urban areas. Since Development Zones like WEDZ attracted major industries, the demand for construction land increased. Moreover, less developed areas distant from the core zones, such as those beyond the immediate periphery of WEDZ, offered comparative advantages due to lower land costs. These regions attracted newly-emerged industries who seek cost efficiencies (Gao et al., 2020), which, arguably, further promoted expansion of built-up land, especially in southwestern regions of the city, where the expansion is clearly noticeable when comparing the 1990 and 2005 land cover classification maps (Figures 5, 6). Another significant event is the opening of Wuhan Tianhe Airport in 1995. By that time, the WEDZ was a thirty-minute drive from the city center and Wuhan's two railway stations, a forty-minute drive from Tianhe Airport, and situated along the Yangtze River. Such a convenient transportation further enhanced its attractiveness to investors and facilitated engagement in trade activities.

The continued increase in trade and foreign investment is certainly another contributing factor to changes in land use. Since Hong Kong's direct investment in Wuhan began in 1987, it has remained the largest source of foreign direct investment in the city (Hong Kong has been a part of China since 1997). By 1993, the number of new investment agreements signed with Hong Kong enterprises surged from 5 to 656, the investment value rising to $733 million USD from $1.24 million USD in 1987 (Liu & Tu, 1998). In the late 1990s and early 200s, Sino-foreign joint venture projects such as the completion of the No.2 Yangtze River Bridge and the expansion of Wuhan Tianhe International Airport were completed, further enhancing the city's infrastructure. The increased investment and development projects contributed to the rapid expansion of urban areas as new residential, commercial, and industrial zones were developed to support these activities. The significant increase in built-up areas and decrease in farmland and vegetation area between 1990 and 2005 was mostly due to construction of Development Zones, improved transportation, and large foreign investment, all of which fueled the rise of the industrial sector.

5.3 The stage of 2005-2020

From 2005 to 2020, urban development in Wuhan City continued to expand. This period saw an increase in built-up areas by 85.3%, probably driven by the Rise of Central China Plan. Meanwhile, due to a transition in development priorities, vegetation area was experiencing growth after declining for decades (Figure 5, 6b).

First proposed in 2004 by Premier Wen Jiabao, the Rise of Central China Plan came into effect in 2006, aiming to develop central China into a leading center for advanced engineering. The plan focused on key areas of new urbanization, modern agriculture, ecological sustainability, and support to the nation's opening-up drive (Clear Roadmap Laid Out for Rise of Central China, 2017). The strategy proved to be a success, promoting economic growth and alleviating socioeconomic disparities in the Central China-Wuhan Urban Agglomeration (WUA) (He et al., 2017). In 2011, with the proposal of "Greater Wuhan" as a national central city, Wuhan committed to spending over 420 billion yuan on infrastructure improvements over the next five years, striving to compete economically with Guangzhou City, the capital of Guangdong Province. Five ring highways, six new bridges, and five new underwater tunnels were built in the fifteen years (Wang et al., 2022). The continuing increase in infrastructure spending resonated with this study's result data, which showed that built-up areas continued to expand from 2005 to 2020.

From 2005 to 2020, a significant shift towards sustainability happened. During the previous phases of development, China experienced rapid economic growth, and sustainability was not a priority. At the end of the 20th century and into the 21st century, there has been a growing awareness of the importance of environmental-friendly development. In 1994, China adopted the Agenda 21, marking the start of a forward-looking set of objectives that support long-term sustainability of the society (Li et al., 2007). In these fifteen years, private businesses and high-tech enterprises have significantly increased in prominence, whereas state-owned industries and traditional sectors have gradually lost ground. Symbolic turning points included reorganizing state-owned industries, shutting down polluting firms, and eliminating outdated production lines in heavy industries (Wang et al., 2022). Key ecological islands, such as Tianxingzhou and Baishazhou have been preserved in their natural state to support ecological conservation and recovery efforts. This strategy aligns with the national initiative to sustain the Yangtze River basin's ecology and meets the requirements for enhancing the Wuhan ecosystem's resilience (Wang et al., 2022). These strategies resonate with this study's result that vegetation area experienced a 26.6% increase from 2005 to 2020.

6 CONCLUSION

This paper employs remote sensing techniques to address the changing land use tendencies in Wuhan City and associated contributing factors. Land cover of Wuhan is classified into five categories: farmland, vegetation, water body, built-up area, and bare land. LULC maps are then produced for the years 1985, 1990, 2005, and 2020, each representing significant periods in the city's development.

Based on the data acquired, the patterns of land type changes over the past 35 years were calculated. The land use dynamics in Wuhan Municipality have changed remarkably from 1985 to 2020. Over these four decades, there has been a significant increase in built-up areas, indicative of rapid urbanization and economic growth. Concurrently, the continuous decline in farmland and the initial decline followed by a recent increase in vegetation areas reflect the government's shifting priorities: first towards urban development and more recently towards sustainability and ecological conservation. Since most land conversion has been directed towards urban development rather than leaving land undeveloped, bare land has remained minimal throughout the period.

A combination of socio-political factors has driven the evolution. The "reform and opening-up" policies initiated in the late 1970s laid the foundation for the city's industrial and trade growth. The establishment of Development Zones, particularly the Wuhan Economic and Technological Development Zone, along with the construction and enhancement of Wuhan Tianhe International Airport in the 1990s, significantly boosted industrial activities and attracted foreign investment. These developments catalyzed rapid urban expansion, making the period from 1990 to 2005 the fastest in terms of the growth of built-up areas. The Rise of Central China plan, implemented in 2006, further accelerated urban growth and infrastructure construction. The twenty-first century also witnessed a shift towards a more sustainable path. Wuhan has gradually shifted from traditional heavy industries to emerging high-tech industries, and have adopted eco-friendly strategies.

This study of Wuhan City's land evolution over the past 40 years reveals a combined impact of economic policies, infrastructural development, and strategic planning on urban landscapes. By providing detailed and easily accessible time-series data, remote sensing proved to be an effective method when studying and interpreting geographical patterns.

REFERENCES

File:Wuhan-location-MAP-in-Hubei-Province-in-China.jpg - Wikimedia Commons. (2022, August 7). https://commons.wikimedia.org/wiki/File:Wuhan-location-MAP-in-Hubei-Province-in-China.jpg

Gao, X., Zhang, A., & Sun, Z. (2020b). How regional economic integration influence on urban land use efficiency？A case study of Wuhan metropolitan area, China. *Land Use Policy, 90*, 104329. https://doi.org/10.1016/j.landusepol.2019.104329

Gries, T., & Grundmann, R. (2015b). Fertility and Modernization: The Role of Urbanization in Developing Countries. *Journal of International Development, 30*(3), 493–506. https://doi.org/10.1002/jid.3104

Habibi, S., & Asadi, N. (2011). Causes, Results and Methods of Controlling Urban Sprawl. *Procedia Engineering, 21*, 133–141. https://doi.org/10.1016/j.proeng.2011.11.1996

He, J., Li, C., Yu, Y., Liu, Y., & Huang, J. (2017). Measuring urban spatial interaction in Wuhan Urban Agglomeration, Central China: A spatially explicit approach. *Sustainable Cities and Society*, *32*, 569–583. https://doi.org/10.1016/j.scs.2017.04.014

Li, F., Liu, X. S., Hu, D., & Wang, R. S. (2007). Evaluation method and its application for urban sustainable development. *Acta Ecologica Sinica, 27*(11), 4793-4802.

Liu, M., & Tu, J. (1998). The position and role of wuhan city in the regional economic macro-strategies of china. *Chinese Geographical Science, 8*, 106–116.

Solinger, D. J. (1986). China's new economic policies and the local industrial political process: The case of Wuhan. *Comparative Politics, 18*(4), 379–399. Ph.D. Programs in Political Science, City University of New York. http://www.jstor.org/stable/421690

State Council of the People's Republic of China. (2017, April 5). *Clear roadmap laid out for rise of Central China*. English.gov.cn. https://english.www.gov.cn/policies/policy_watch/2017/04/05/content_281475617525468.htm

Wang, L., Li, Z., & Zhang, Z. (2022b). City profile: Wuhan 2004–2020. *Cities, 123*, 103585. https://doi.org/10.1016/j.cities.2022.103585

Xu, N. K., Kong, N. C., Liu, N. G., Wu, N. C., Deng, N. H., Zhang, N. Y., & Zhuang, N. Q. (2010b). Changes of urban wetlands in Wuhan, China, from 1987 to 2005. *Progress in Physical Geography, 34*(2), 207–220. https://doi.org/10.1177/0309133309360626