

Urban Development Analysis using GIS and Remote Sensing. The Case Study of Makkah City

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ABSTRACT

Makkah Al-Mukarramah has undergone significant urban transformation in recent decades, transitioning from non-urban to urban landscapes driven by fast economic growth. This study aims to analyze the increase in population, urbanization, topography, and land use of Makkah City over the past 20 years, from 2000 to 2020. Makkah holds special significance for the Saudi government due to its religious and regional prominence, resulting in remarkable developmental strides within short timeframes. This has led to a surge in population and spatial expansion towards the city's outskirts, bringing about both quantitative and qualitative changes in the city. The growth rate in Makkah was 2.453% in 2020 and 2% in 2010, indicating a trajectory conducive to future land use/land cover planning. The population has shown remarkable growth, rising from 1,294,000 in 2000 to 1,578,722 in 2010 (22% increase) and further reaching 2,017,793 in 2020 (27.81% increase), nearly doubling over the two-decade span. The city's area expanded to 465 Km² in 2020, compared to 388 Km² in 2010 and 366 Km² in 2000, attributed to a notable increase in the number of districts from 60 in 2010 to 101 in 2020, marking a substantial 68.3% rise. This study used a map scale of 1:300,000 to classify features, such as mountains, urban areas, deserts, and roads. The results indicate a decrease in mountains and deserts, while urban areas and roads have increased, aligning with the population growth observed over the two decades.

Keywords-satellite imagery; Makkah; land use; GIS; remote sensing; urbanization

I. INTRODUCTION

Makkah Al-Mukarramah, serving as the administrative city of Makkah province, is of profound spiritual significance to more than one-fifth of the world population, united in their aspiration to undertake the Hajj journey. Nestled at an elevation of 277 m above sea level, Makkah is situated in a valley within the mountainous corridor of the Saraswat Mountains on the western slopes. The city's urbanization has been intricately shaped by its geographic location, historically constrained by surrounding mountains, with development concentrated around the Haram area. Recent years have witnessed a notable expansion beyond these natural confines, facilitated by improved road networks and modern transportation, driven by escalating population levels [1]. Key infrastructure elements, such as the Jeddah Islamic Port and King Abdul-Aziz International Airport, play pivotal roles in the city's connectivity and accessibility. Notable projects, including the

Al-Harm railway and expansion project, Makkah slum development, improvement of road networks, and completion of the ring roads projects, have significantly altered the city's urban morphology. The analysis in this study is formed using census data from 2000 to 2020, coupled with Landsat data over these years, and applying Geographic Information System (GIS) techniques.

Makkah has also witnessed substantial growth due to an influx of pilgrims of Hajj and Umrah. The growth rate for Makkah city was 2% in 2010, increasing to 2.45% in 2020, with projections indicating a further increase to 3.2% by 2030. This trajectory ensures the continued demand for more land use and land cover planning. The intensive expansion has radiated to the southeast, south, and southwest directions, particularly along the new major road projects, bringing about changes in development patterns, land use typologies, and forms. In particular, the augmentation in multistory structures,

specifically dedicated to accommodating the visitors of Haji and Omera, which surround Haram and Makkah city, has become a defining characteristic. Simultaneously, a series of neighborhood renewal operations have unfolded in areas surrounding Haram, marked by the demolition of older structures and their replacement with newer, higher buildings [1]. This study aims to examine the urban extension of Makkah city over the past two decades, to analyze the impact of the topography on the urbanization process, and to study the land use and land cover changes over the last twenty years.

II. STUDY AREA

The study area, Makkah Al-Mukarramah city, is strategically located in the western part of KSA, approximately 400 Km southwest of Medina, 75 Km east of Taif, and 72 Km west of Jeddah along the Red Sea coast. The Jeddah Islamic Port serves as the closest port, while the King Abdul-Aziz International Airport is the nearest airport [2]. Geographically, the study area encompasses the central part of the western region of Saudi Arabia, with coordinates ranging from 21°15' to 21°37' N and 39°47' to 39°59' E, as shown in Figure 1.

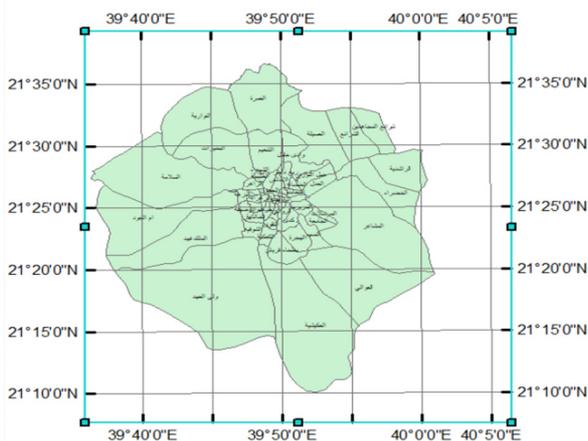


Fig. 1. Makkah Al-Mukarramah city, KSA.

III. MATERIALS AND METHODS

A. Population Analysis

The population data used in this work are sourced from the official population census approved by the General Authority for Statistics and the Makkah Al-Mukarramah city profile provided by the Ministry of Municipality and Rural Affairs. The Makkah Al-Mukarramah city stands as one of the most populous regions in KSA, accommodating over a quarter of the country's population. According to the 2010 census, the region's population was 6,915,006. Among the governorates, Jeddah has the largest share, accounting for 50.3% of the total population, Makkah Al-Mukarramah for 24.2%, and Taif for 14.1%. Notably, the region has one of the highest ratios of Saudi to non-Saudi population, with an estimated 4.55 million Saudi residents [1]. In the specific context of Makkah city, its population has undergone significant growth over the past two decades. In 2000, the population stood at 1,294,000. By 2010, the city's population increased to 1,578,722 and further surged

to 2,017,793 in 2020. Projections for 2030 indicate an expected population of 3,038,873, nearly doubling through the period 2000-2030. Table I provides a comprehensive overview of the absolute evolution of Makkah city's population over the last 20 years, reflecting the substantial demographic changes and growth trends.

TABLE I. POPULATION DATA OF MAKKAH AL-MUKARRAMAH (2000-2020)

Year	Population	Growth rate	Growth
2000	1,294,000	2.48%	28.256
2005	1,325,622	2.95%	38.012
2010	1,578,722	2%	46.139
2015	1,795,849	3.08%	53.702
2020	2,017,793	2.453%	37.218

B. Urban Expansion

The city of Makkah has undergone significant urbanization in recent decades driven by rapid economic growth, transitioning from rural to urban communities. The United States Geological Surveying (USGS) website was employed to analyze this transformation. Deploying the USGS's features and tools, a polygon was delineated around the boundaries of Makkah city for the years 2000, 2010, and 2020. Subsequently, the area and perimeter of the drawn polygons were calculated using ArcGIS. The findings reveal a notable increase in the area of Makkah city, expanding to 465 Km² in 2020 compared to 388 Km² in 2010 and 366 Km² in 2000. This expansion is parallel to a surge in the number of areas within Makkah Al-Mukarramah city, growing from 60 Km² in 2010 to 101 Km² in 2020, representing a substantial expansion rate of approximately 68.3% in the number of areas. Table II offers a detailed summary of the areas and perimeter of Makkah city for the years 2000, 2010, 2020, and 2021. Figure 2 visually illustrates the urban expansion of Makkah over the years 2000, 2010, 2020, and 2021, providing a clear representation of the city's evolving spatial footprint. These data offer valuable insights into the dynamic changes and growth patterns in the urban landscape of Makkah city over the specified years.

TABLE II. AREAS OF MAKKAH CITY BETWEEN 2000-2021

Year	Area	Perimeter	No. of districts	Color
2000	366 Km ²	122 Km	-	Red
2010	388 Km ²	136 Km	60	White
2020	465 Km ²	156 Km	101	Blue
2021	477 Km ²	167 Km	110	Green

C. Topography of Area

The elevation of Makkah city varies from 250 to 350 m above sea level, expanding to the east and encompassing the holy sites. Makkah has a diverse terrain, with hills and mountains scattered along the slopes that serve as urban areas for city residents. Figures 3, 4, and 5 provide a visual representation of the topography of Makkah City over the years 2000, 2010, and 2020, accordingly. The highest elevation in Makkah city was recorded in 2020, reaching 725.6 m. The peak elevation was observed at 662.2 m in 2010, while the highest elevation in 2000 was 524.46 m. It should be noted that 2020 marks the highest elevation, indicating a difference of 63.3 m

from 2010 and a substantial 200 m difference from 2000. This significant increase is attributed to population growth and the expansion of construction facilities during this period. Table III displays a detailed breakdown of elevation data, exhibiting the evolving topographic characteristics of Makkah.

TABLE III. MAXIMUM-MINIMUM ELEVATION OF MAKKAH IN 2000-2020

Year	Minimum elevation (m)	Maximum elevation (m)	Differences	Increase (%)
2000	219.310 m	524.460 m	305.150 m	-
2010	279.140 m	662.100 m	382.960 m	20.31%
2020	210.900 m	725.500 m	514.600 m	25.6%

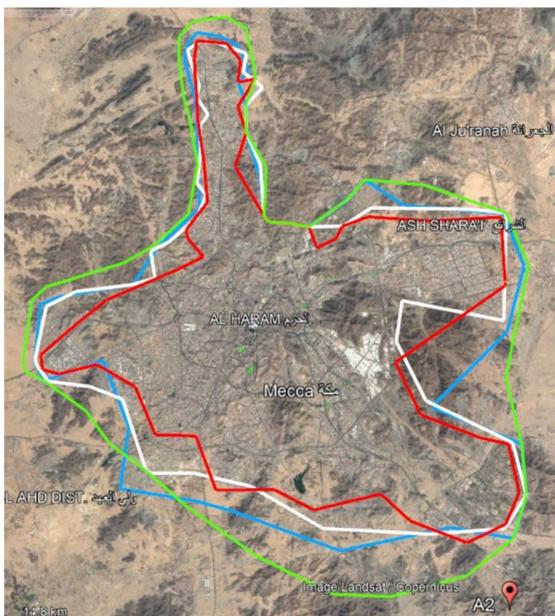


Fig. 2. The urbanization of Makkah over the years 2000, 2010, 2020.

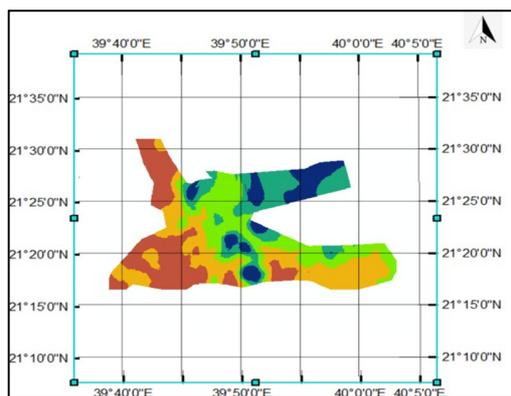


Fig. 3. Digital elevation model (DEM) of Makkah city in the year 2000.

D. Analysis

The methodological approach involved integrating a model using Landsat satellite images and GIS. The tools used for image processing include ERDAS Imagine 2014 and ArcGIS 10.3. The subsequent sections provide a comprehensive overview of the detailed process [3-10].

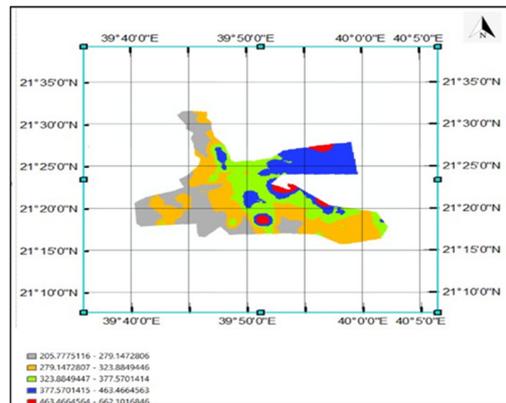


Fig. 4. (DEM) of Makkah city in the year 2010.

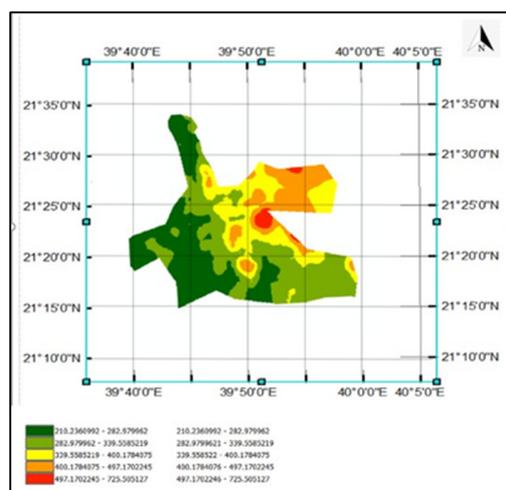


Fig. 5. Digital Elevation Model DEM of Makkah city in the year 2020.

E. Satellite Images

Satellite images were downloaded from the USGS website. The satellite images span various times and were captured by Landsat satellites numbers 5, 7, and 8. Google Earth Pro was also employed to complement the analysis. The resolution of the satellite images is 30 m [11-17]. The sensors applied for satellite images were Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS). Table IV depicts the details of the satellite image data.

TABLE IV. SATELLITE IMAGES DATA

No	Satellite name	Acquisition date	Grid cell size	Ellipsoid	Sensor ID
1	LANDSAT- 5	20/2/2000	30 m	WGS-84	TM
2	LANDSAT- 7	12/12/2010	30 m	WGS-84	ETM+
3	LANDSAT-8	(28-7-2020)	30 m	WGS-84	OLI/TIRS
4	GOOGLE EARTH PRO V9.14	11/7/2021	15 m	WGS-84	-

F. Image Processing

The processing of satellite images is a crucial step in improving their quality and extracting meaningful information.

The ERDAS program is a valuable tool for this purpose, offering a range of techniques to address factors that may affect image quality. The key steps in processing satellite images typically include geometric correction, radiometric correction, atmospheric correction, and image enhancement [18-23]. The quality of Landsat images can be enhanced adopting these techniques within ERDAS, ensuring that they are well-suited for accurate and meaningful analysis of land use/land cover dynamics in Makkah city over the specified periods.

G. Image Classification

Supervised classification was deployed for image grouping, allowing for a targeted and controlled categorization of pixels based on predefined criteria and conditions. The classification process primarily focuses on discerning different Land Use (LU) categories. To ensure precision and relevance, Landsat images are first cropped utilizing the shape file of Makkah, thus confining the analysis to the specific area of interest [24]. The classification attempts to distinguish between the following primary categories:

- Mountains (blue): Representing elevated and hilly terrains.
- Urban Areas (green): Signifying developed and populated regions within the city.
- Desert (red): Encompassing arid and barren landscapes.
- Roads (black): Identifying transportation networks and pathways.

The classification process is conducted on a map scale of 1:300,000, guaranteeing a balanced representation of the features on the map. The chosen color scheme aids in visually differentiating and interpreting the various LU categories. Figures 6, 7, and 8 visually illustrate the results of the classification process, providing a clear and detailed representation of the identified LU categories within Makkah city.

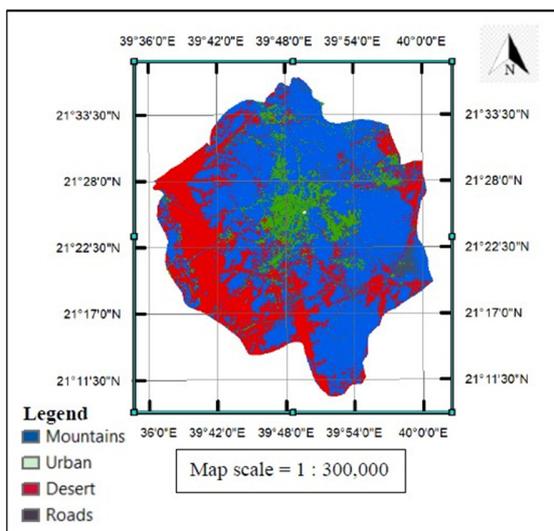


Fig. 6. Land use classification in 2000.

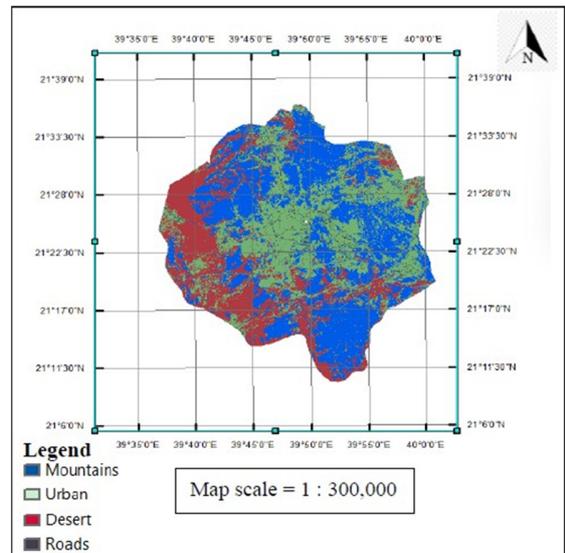


Fig. 7. Land use classification in 2010.

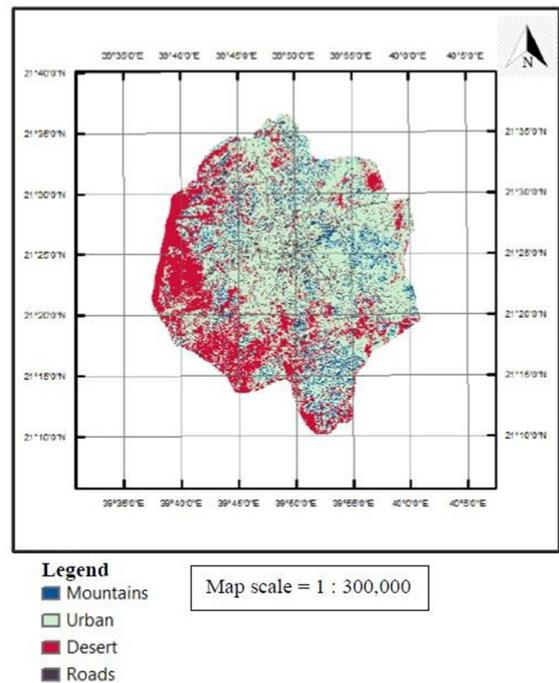


Fig. 8. Land use classification in 2020.

Table V portrays the LU scheme to classify the land in Makkah city that contains small rocks, mountains, residential, commercial services, and transportation communications, including white and yellow sand areas, roads, and networks.

TABLE V. LAND USE (LU) SCHEME IN MAKKAH CITY

Land cover class	Description
Mountains	Mountains, small rocks
Urban	Residential, commercial services, industrial, and transportation communications.
Desert	White and yellow sand and dunes
Roads	Roads and networks

IV. RESULTS AND DISCUSSION

A. Land Use and Land Cover

The LU classification of Makkah Al-Mukarramah city over the years 2000, 2010, and 2020 was carried out using the ERDAS software. The classification resulted in the differentiation of the land into distinct categories based on specific characteristics. As noticed in Figures 6, 7, and 8, the visual representation of the land use classification provides insight into the changes and trends that occurred over these 20 years. As expected, there was a decrease in the extent of mountains and deserts, while the areas classified as urban and roads demonstrated an increase. This observed trend is attributed to the population growth and associated urban development that occurred during the specified time frame. The LU classification map serves as a valuable tool to understand the spatial dynamics and transformations within the city of Makkah, offering a clear visual representation of how different land categories evolved over the study period.

B. Population Growth

The population growth in Makkah city had a rate of 2.45% in 2020 and 2% in 2010. This growth rate is significant as it lays the foundation for future development and planning of land use and land cover in Makkah City. During the observed period, the population exhibited substantial growth. In 2000, the population stood at 1,294,000, and by 2010, it increased to 1,578,722, reflecting an overall increase rate of 22%. Furthermore, in 2020, the population surged to 2,017,793, representing a remarkable growth rate of 27.81%. This indicates that the population almost doubled between 2000 and 2020. Figure 9 visually represents these population trends, highlighting the considerable growth experienced by the city of Makkah over the two decades. The observed growth rate suggests not only a numerical increase in population, but also a strategic and sustainable approach to urban development, laying the groundwork for effective land utilization and cover planning in the future.

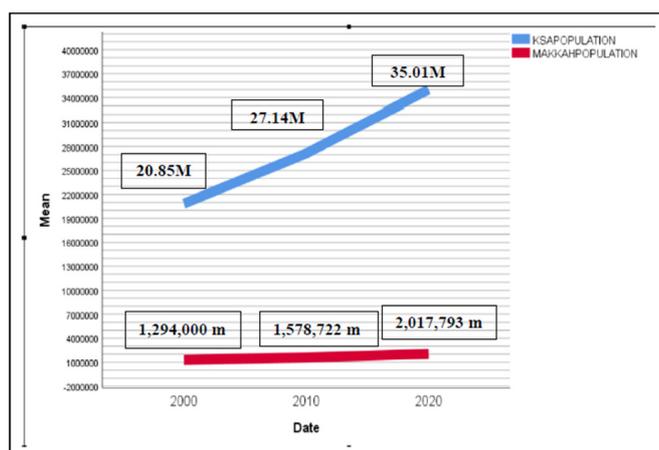


Fig. 9. Multiple lines of KSA (blue) and Makkah population (red).

V. CONCLUSION

This study investigated the expansion dynamics of the city of Makkah Al-Mukarramah, noting the following:

- In 2020, the area of the Makkah city expanded to 465 Km², which constituted a significant increase from the 388 Km² in 2010 and the 366 Km² in 2000. This expansion is attributed to the augmentation in the number of districts within the city of Makkah Al-Mukarramah, increasing from 60 in 2010 to 101 districts in 2020, representing a growth rate of approximately 68.3% in the total number of districts.
- The city of Makkah Al-Mukarramah boasts a varied topography, featuring hills and mountains, which are used as residential areas by the local population. Spanning from west to east, the city's elevation fluctuates between 250 and 350 m above sea level, encompassing its sacred sites. During the past two decades, there has been a discernible shift in the average elevation of the Makkah Al-Mukarramah city.
- In 2000, Makkah Al-Mukarramah's average elevation was 536.33 m, which decreased to 497.33 m by 2010. Subsequently, in 2020, there was a further decrease, with the average level dropping to 438.5 m. This notable decline in average elevation in 2020, compared to both 2010 and 2000, is attributed to the ongoing urban development initiatives. These endeavors entail the removal of mountains and the construction of various facilities, leading to alterations in the city's topography.
- The transformation of Makkah's landscape is a consequence of urbanization and infrastructure development, reflecting the dynamic changes occurring in the city to accommodate the needs of its expanding population and visitors.

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