

Article

The Impact of Light Rail Transit on Urban Development in Dubai, UAE

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Abstract: Over the last two decades, the United Arab Emirates (UAE) has experienced significant urban growth, prompting the Dubai Roads and Transport Authority (RTA) to advocate for sustainable transport solutions. This led to the implementation of the Light Rail Transit (LRT) to address urban mobility, environmental sustainability, and energy efficiency. Dubai has strategically prioritized infrastructure and transportation network expansion to support its rapid development. This paper aims to examine the critical role of the LRT system, particularly the metro and tramway, in steering Dubai towards sustainability. Metro and tramway systems offer crucial high-capacity public transport, enhance connectivity, stimulate economic growth, and contribute to a sustainable environment. The study assesses the transformative impact of the Dubai Metro on urban development, focusing on key stations like Jabal Ali, Al-Barsha First, and Business Bay. Using qualitative research methods, including GIS, spatial maps, interviews, case studies, and land use investigations, the research analyzes population density, connectivity, accessibility, and urban land use patterns around these stations. Results indicate a positive impact of the Dubai Metro on both commercial and residential land use, improved connectivity, and enhanced accessibility, reinforcing its role in cultivating a sustainable urban environment.

Keywords: sustainable transportation; light rail transit; urban development; Dubai Metro



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1. Introduction

Due to the substantial urban growth that the United Arab Emirates (UAE) has seen over the past 20 years, the Dubai Roads and Transport Authority (RTA) has been pushing for sustainable transportation options. Road transport pollution, the number of traffic accidents, and travel times have all grown due to this growth [1,2]. To solve these problems, the RTA developed the Light Rail Transit (LRT) system, concentrating on energy efficiency, environmental sustainability, and urban mobility [3]. To counteract the adverse effects of road-based transportation, Dubai has prioritized growing its transportation and infrastructure network, which helps to facilitate the city's rapid development. This study explores how the LRT system helps Dubai overcome these obstacles and achieve higher sustainability.

Transportation infrastructure plays a pivotal role in shaping the physical, social, and economic characteristics of a city. A robust transport system is essential for fostering economic activities, influencing land use, growth trends, and accessibility. The problems associated with road transport, such as high pollution levels, frequent accidents, and long commuting times, underscore the need for an efficient and sustainable alternative. Sustainable transportation solutions, designed to meet diverse requirements, contribute to improved air quality, energy savings, and reduced environmental impacts [2]. They also establish vital connections between individuals, businesses, and services, promoting economic development and increasing population density.

In response to the growing transportation needs and the challenges posed by conventional road transport, Dubai has systematically promoted sustainable public transportation. The RTA's Integrated Public Transport Plan, which includes the Dubai Metro and other modes of transport, aims to address these issues by providing an efficient alternative to road transport. The city's Transit Oriented Development Plan, exemplified by ambitious projects like the Dubai Metro, seeks to enhance and upgrade the transportation system. Established in 2009, the Dubai Metro is committed to mitigating urban development challenges and expanding the city's urban footprint [3].

Recognizing the limitations of vehicle-centric practices, Dubai has proactively restricted vehicular movements while developing an integrated transit system with a central focus on the Dubai Metro. The Metro is a pivotal node in the transportation network, contributing to sustainable transport and positively influencing the local economy [4–6]. Numerous studies have explored the impact of light rail systems on property values and regional economies, highlighting both overall effects and localized differences [4–6]. Other studies investigated the environmental impact of light rail systems in the form of noise, vibrations, and air pollution [7,8]. One of the primary advantages of the LRT system is the capacity to reduce air pollution. By shifting a significant number of passengers from private vehicles to public transit, the LRT system contributes to lower emissions of pollutants such as nitrogen oxides (NO_x), particulate matter, and carbon dioxide (CO₂) [9,10]. This shift helps improve urban air quality and supports public health by decreasing the incidence of respiratory and cardiovascular diseases related to air pollution [11]. However, it is also crucial to consider the potential negative impacts of LRT systems. Noise pollution is a significant concern, as trains and associated infrastructure can increase noise levels in surrounding areas [7,8,12]. This noise pollution can impact local communities' quality of life and pose health risks, such as stress and hearing impairment [13].

This paper addresses the research problem by examining how the Dubai Metro, an LRT system, has influenced urban development in Dubai, UAE, particularly regarding connectivity and accessibility. It utilizes spatial and temporal indicators, remote sensing techniques, and Geographic Information System (GIS) technology, focusing on three key Metro stations: Jebel Ali, Al-Barsha, and Business Bay. The aim is to evaluate how the introduction of the Metro has impacted urban development, specifically through improvements in connectivity and accessibility. The study compares satellite imagery from Landsat 8-OLI and data from external sources, such as OSM and Google Earth Pro, for 2008 and 2020, using ArcMap10.8 for analysis [14].

2. Literature Review

Transportation infrastructure in a city plays a crucial role in shaping its physical, social, and economic characteristics. A robust infrastructural foundation is essential for thriving economic activities, as transport significantly influences land use, growth trends, and accessibility. Sustainable transportation that meets diverse requirements contributes to improved air quality, energy savings, and reduced environmental impacts [15]. It establishes vital links between individuals, businesses, and services, promoting economic development and increasing population density.

Dubai has embarked on a systematic endeavor to promote sustainable public transportation in response to growing transportation needs and the importance of sustainability. The RTA adopted a comprehensive strategy that combines multiple modes of transportation as part of the Integrated Public Transport Plan. The city's Transit Oriented Development Plan, which is marked by ambitious projects like the Dubai Metro, enhances and upgrades the transportation system. Established in 2009, the Dubai Metro is a testament to the city's commitment to coping with urban development challenges and expanding its urban footprint [16].

Recognizing the limitations of vehicle-centric practices, Dubai has taken proactive measures to restrict vehicular movements while developing an integrated transit system with a pivotal focus on the Dubai Metro [17]. The Dubai Metro serves as a node in the

transportation network, paving the way for sustainable transport and positively influencing the local economy. Numerous studies have explored the impact of light railways on property values, revealing overall effects and localized differences among properties near Metro stations [18–20].

2.1. Light Rail Transit (LRT) as a Sustainable Transport Mode

Modes of transportation play a crucial role in determining how individuals navigate between destinations. They constitute essential infrastructure and communication assets categorized into individual, public, or air transportation. Public transportation, characterized by the shared use of a single trip, stands out as an eco-friendly and cost-effective method of travel, encompassing buses, metros, and trams [21].

LRT emerges as a significant facet of public transportation systems, blending characteristics of trolleys and subways. Distinguished by its rolling stock resembling conventional trams, LRT operates at higher capacities and speeds, often on exclusive rights-of-way. The term “light” denotes its lower passenger capacity than commuter trains, making it suitable for smaller metropolitan cities and as a feeder for larger metros and commuter railways [22]. LRT is noted for being six times safer than car travel and capable of operating in adverse conditions like snow, rain, or ice. This resilience reduces reliance on private vehicles. While its long-term benefits are evident, LRT’s success hinges on sustained commuter engagement and its integration with other public transport modes. As a sustainable transportation mode, LRT offers safe, reliable, and secure access while addressing social, environmental, and economic factors [23].

Recent studies have highlighted the significant impact of LRT systems on urban development, sustainability, and economic growth. Cervero (2011) demonstrated that properties near transit stations in Seoul, South Korea, experienced increased property values and enhanced economic activities [24]. Brown (2023) found that integrating LRT systems with other public transport modes enhances overall urban mobility and sustainability [25]. These studies provide a global context but often overlook the unique challenges faced by rapidly developing cities in the Middle East, such as Dubai. Our study fills this gap by comprehensively analyzing the Dubai Metro’s impact on urban development, focusing on key stations like Jabal Ali, Al-Barsha First, and Business Bay.

Theoretical frameworks such as Transit-Oriented Development (TOD) emphasize the importance of integrating land use and transportation planning to create sustainable urban environments. TOD principles advocate for high-density, mixed-use developments within walking distance of transit stations, promoting reduced reliance on private vehicles, enhanced public transport usage, and improved environmental outcomes [26]. Sustainability theories, such as Banister’s sustainable transport pyramid shown in Figure 1, further support evaluating Metro systems’ environmental and social impacts. These frameworks guide our research design, methodology, and analysis, providing a robust foundation for understanding the complex dynamics between transportation infrastructure and urban development [27].

Given the unprecedented urban growth in Dubai, the study’s findings are crucial for informing future urban planning and transportation policies. As a pioneering LRT system in the region, the Dubai Metro serves as a model for sustainable urban development. This study highlights the Metro’s role in enhancing connectivity and reducing traffic congestion and underscores its contributions to economic growth and environmental sustainability. Policymakers and urban planners can leverage these insights to design and implement more effective and sustainable transportation systems in other rapidly growing cities. The research focuses on the transformative impact of the Dubai Metro on urban development by examining key stations like Jabal Ali, Al-Barsha First, and Business Bay. Utilizing qualitative research methods, including GIS spatial maps, interviews, case studies, and land use investigations, this research offers a nuanced understanding of how LRT systems can drive sustainable urban growth in a rapidly developing context. By adopting a mixed-method approach, the study integrates insights from both quantitative and qualitative data

sources, providing a comprehensive understanding of the complex dynamics affected by introducing the Dubai Metro.

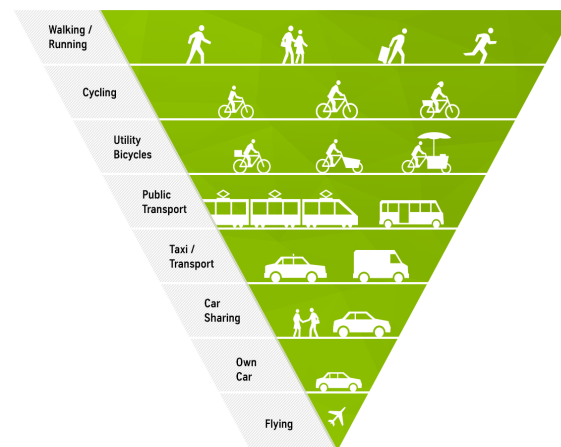


Figure 1. The pyramid structure demonstrates the varying levels of sustainability linked to different modes of transport [27].

2.2. Morphological Pattern of Dubai

As cities evolve through urban development, Dubai's transformation aligns with the Multiple Nuclei Model, featuring a central business district (CBD) and smaller centers bordering valued residential areas for convenient travel. The city's expansive growth, driven by vehicle transportation, began in Deira and Bur Dubai, evolving into five distinct CBDs today [28,29].

- Deira/Bur Dubai: As historic CBDs, these areas remain vital to Dubai's cultural heritage and remain bustling urban centers.
- Downtown/Business Bay: This secondary CBD is a significant economic and financial hub, encompassing both Downtown and Business Bay areas.
- Dubai Marina/JBR: Known for hospitality and leisure, this CBD is a magnet for international tourists, featuring prominent areas such as Dubai Marina and Jumeirah Beach Residence (JBR).
- EXPO 2020 Center: A burgeoning economic center offering affordable housing, it focuses on exhibitions, tourism, and the logistics sector.
- Dubai Silicon Oasis Center: Devoted to science, technology, and education, this center promotes creativity, accelerates digital economy growth, and facilitates talent development.

The city's diverse morphological pattern, characterized by these distinct CBDs, showcases its unique qualities and economic vitality. Continuous expansion and strategic planning reflect Dubai's vision of a dynamic, forward-thinking urban landscape.

2.3. Growth and Transportation Challenges in Dubai

Dubai, which has experienced exponential growth since 2000, witnessed a surge in transportation needs. The RTA was established in November 2005 to oversee transportation services and infrastructure within Dubai and neighboring emirates. Despite substantial investments in infrastructure and roads, the rapid increase in vehicles, coupled with persistent road traffic, has led to significant congestion issues in the most congested cities in the Middle East [30].

2.3.1. Dubai Bus

The most widely used road transportation mode in Dubai is the RTA's bus system. With over 190 routes, 1518 buses, and 1600 bus stops, the system carries approximately 30 million people weekly. Linking 82% of Dubai's urban areas, it comprises local, intercity, and express routes and caters to approximately 369,248 passengers daily [31].

2.3.2. Dubai Taxi

Taxis are essential to Dubai's transportation network, catering to both local inhabitants and international residents, tourists, and guests. In 2016, there were 104 million taxi rides, and the fleet is expected to reach 12,765 in 2020. Dubai's taxi service, overseen by the RTA, provides diverse services, such as women's taxis, and strives to increase the Taxi Availability Index from 3.71 to 4.09 taxis per 1000 individuals in the coming years [32].

2.3.3. Water-Transit System

Acknowledging the importance of water transportation, the RTA offers three local marine transit options: Abras (small boats), water buses, and water taxis. Abras are particularly popular for short trips like the Deira to Bur Dubai crossing. This water transportation network is crucial in easing movement across Dubai Creek, with routes including Deira Old Souk to Al Ghubaiba and Dubai Old Souk Marine Station to Al-Sabkha [33].

2.4. Percentage Share of Transportation Modes

Based on recent data, the distribution of public transportation usage in Dubai is as follows: Dubai Metro 36%, buses 30%, taxis 22%, and tramway 12%. These percentages indicate the popularity and reliance on different transportation modes within a typical unit of time, such as daily or monthly usage statistics [34].

To provide a clearer understanding, we compare these transportation modes based on three criteria: price, time, and availability [15,16]:

- Price
 - Dubai Metro: The cost of a single journey on the Metro varies depending on the number of zones traveled, ranging from AED 3 to AED 7.50. Monthly passes are available, offering cost-effective options for regular commuters.
 - Buses: Bus fares are generally lower than Metro fares, with single journeys costing between AED 3 and AED 5. Monthly passes can also be used across both Metro and bus services.
 - Taxis: Taxis are more expensive, with fares starting at AED 12 and increasing based on distance and time of day. This makes taxis less affordable for daily commuting.
 - Tramway: The tram fare is integrated with the Metro system, making it cost-effective for short trips within certain areas. Its pricing is similar to Metro fares.
- Time
 - Dubai Metro: The Metro offers fast and reliable service with frequent trains during peak hours, reducing travel time significantly compared to road-based transport.
 - Buses: Buses cover a wide network but are subject to road traffic, making travel time less predictable and generally longer than the Metro.
 - Taxis: Taxis provide door-to-door service, which can be quicker than buses but still subject to traffic delays. They are often the fastest option for direct routes not served by the Metro.
 - Tramway: The tramway is efficient for short distances within certain areas like Dubai Marina and Jumeirah Beach Residence but has limited coverage compared to the Metro and buses.
- Availability and Development Opportunities
 - Dubai Metro: The Metro has extensive coverage with plans for further expansion, including new lines and stations, enhancing its availability and development opportunities.
 - Buses: Buses have the most extensive network, reaching areas not covered by the Metro or tramway. The fleet and routes are regularly updated to meet growing demand.

- Taxis: Taxis are widely available 24/7, providing flexibility for users. However, their development is limited compared to public transit due to higher costs and environmental considerations.
- Tramway: The tramway is limited in geographic scope but serves high-density areas well. Expansion opportunities exist but are less extensive than those of the Metro.

2.5. Dubai Metro: Navigating Urban Growth and Connectivity

In response to economic growth, increased air travel, property development, and tourism, the Dubai Municipality needed a rail system. To alleviate traffic congestion on Sheikh Zayed Road, which connects Dubai Creek to Jebel Ali, and to support Dubai's rapid urban expansion, the government initiated the construction of the "Dubai Metro", a light rail system. The Dubai Metro, the world's longest automated driverless system, was implemented in two phases:

Phase 1: The first Metro Line (Red Line) was launched in stages between 2009 and 2011, comprising 29 stations and serving 32,000 passengers per hour [35]. The entire metro system spans 74.6 km, with 13 km underground. Plans include seven monorails to complement the Dubai Metro, connecting areas such as Dubai Land, Palm Jumeirah, and other districts adjacent to the main track. The Red Line's coverage area encompasses both modern and historic service hubs, recently developed mixed-use properties, four prominent shopping centers, and two bustling stations at Dubai International Airport. The Green Line, with 18 stations, primarily serves the old CBD area along both sides of Dubai Creek, accommodating over 329,365 daily commuters [36]. By September 2017, the passenger count had reached 1 billion, reflecting the city's population and business growth.

Phase 2: The RTA expanded the existing lines and introduced a new line, Route 2020, extending the Dubai Metro Red Line from Nakheel Harbor and Tower Station to the Expo 2020 site. This extension serves approximately 270,000 residents in areas including the Gardens, Discovery Gardens, Al Furjan, and Jumeirah Golf Estates, as shown in Figure 2. The extension adds seven more metro stations, reducing travel time to 16 min from Dubai Marina Station to Expo Station [37].

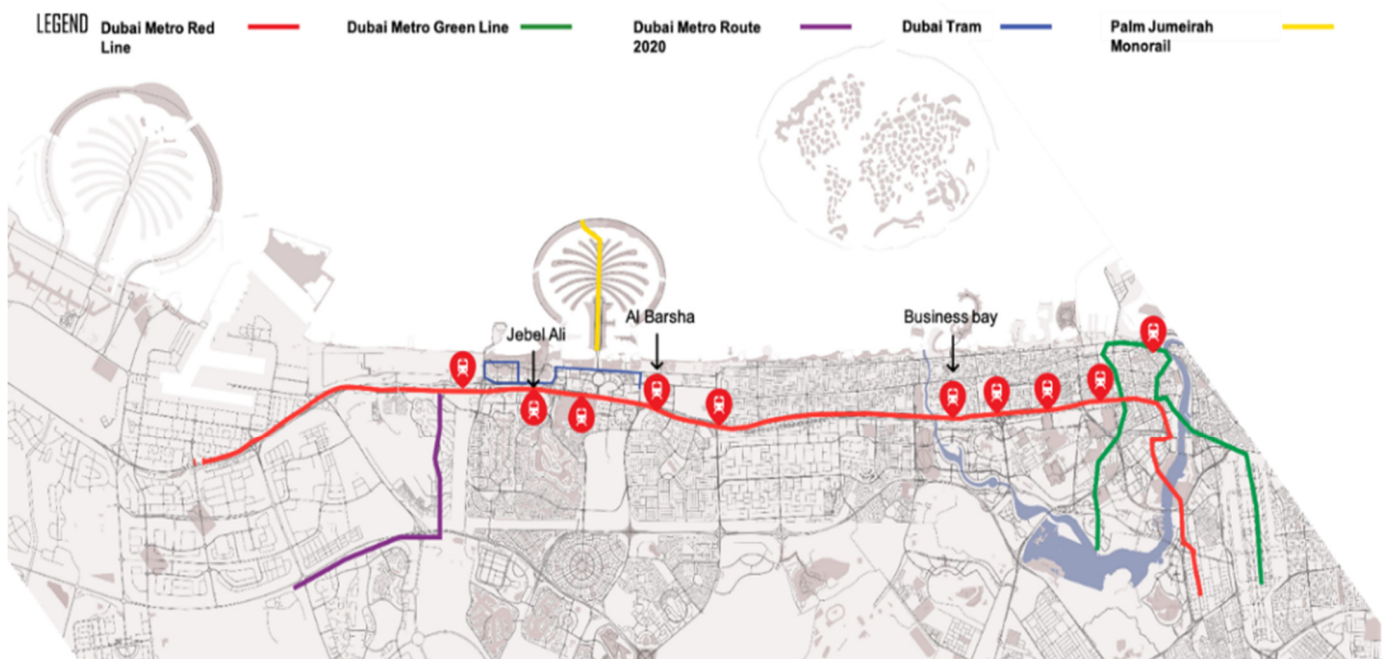


Figure 2. Metro network in Dubai, adapted from the Roads and Transport Authority [38].

Dubai Metro, a groundbreaking rail transit system, has played a pivotal role in transforming Dubai's transportation landscape. As a response to the city's burgeoning needs

driven by economic growth, population expansion, and increased urbanization, the Dubai Government strategically invested in developing a sustainable and advanced LRT system. This system, renowned for its cutting-edge technology, has not only addressed traffic congestion but has also become a symbol of Dubai's commitment to sustainability, as shown in Table 1.

Table 1. Sustainability aspects and implementation in Dubai Metro.

Sustainability Aspect	Implementation in Dubai Metro
LRT technology	Utilizes LRT for flexibility, allowing sharper bends and steeper slopes.
Advanced features	World's largest online protocol camera infrastructure, integrated operation control system, and cutting-edge maintenance systems.
Urban guided transportation	Includes urban guided transportation options, which operate on a separate right of way from road, train, passenger, and pedestrian movements.
Construction impact on sustainability	Plays a crucial role in improving sustainability, focusing on energy conservation, and minimizing environmental impact.
Travel time and self-regulation	Reduces travel time significantly and ensures a high level of safety through an intelligent, automated system.
Transit capacity and service quality	Drives a considerable increase in public transportation usage, enhancing reliability, punctuality, and overall service quality.
Traffic congestion and economic stimulation	Effectively reduces traffic congestion, stimulates the economy, and fosters job opportunities and tourism growth.
Energy consumption and surveillance	Implements energy-saving measures such as regenerative braking power, district cooling technology, and efficient energy control systems.

3. Research Methodology

Choosing the research methodology for this study involved careful consideration of the research objectives, the researchers' epistemological stance, and adherence to professional standards [39]. A clearly defined methodology steers the research process, linking philosophical principles to specific procedures through the research design [40]. This methodology includes the overarching research strategy and the particular data collection and analysis methods. By adopting a mixed-method approach, the research seeks to integrate insights from both quantitative and qualitative data sources, providing a comprehensive understanding of the complex dynamics affected by the introduction of the Dubai Metro, as shown in Figure 3.

3.1. Quantitative Data Collection

- GIS mapping: Utilizes spatial data and metro station records to analyze the distribution of development around Metro stations.
- Questionnaires: Conducts face-to-face surveys to gather passengers' perceptions and demographic data.
- Population statistics: Draws on statistical reports and GIS maps to provide insights into population subsets and historical changes.
- Document analysis: Examines public transportation data and accident statistics to assess the overall status of the transportation system.
- Population density analysis: Incorporates additional data about how the metro line increased population density around it, particularly near metro stations. It includes two maps, one depicting the area before the metro construction and one after, to visualize the changes in population density.

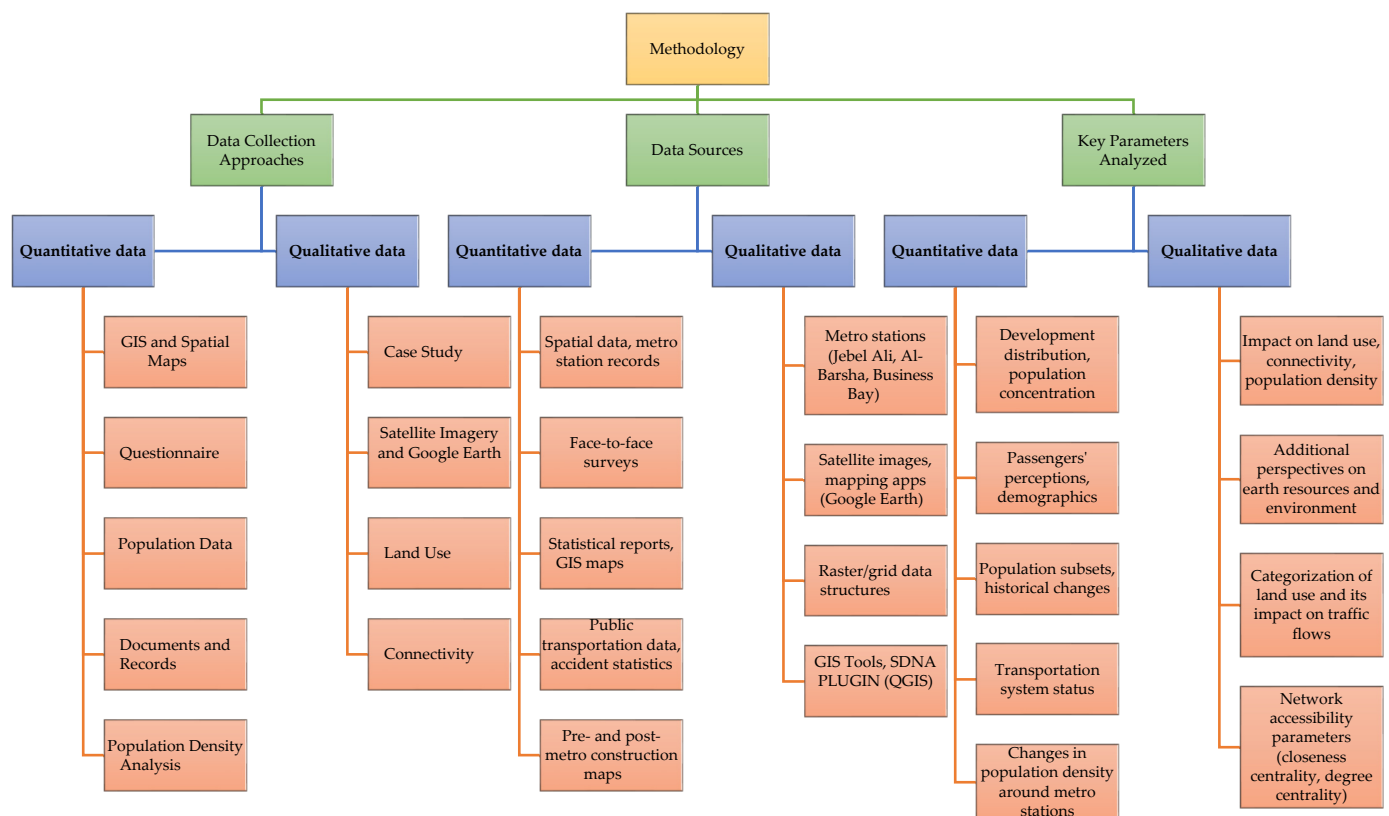


Figure 3. Summary of research methodology and data collection.

3.2. Qualitative Data Collection

- Case studies: Selected Metro stations (Jebel Ali, Al-Barsha, Business Bay) are investigated to understand the impact on land use, connectivity, and population density.
- Satellite Imagery and Google Earth: Satellite images and mapping apps are used to provide additional perspectives on Earth resources and the environment.
- Land Use Analysis: Raster/grid data structures are applied to categorize land use and its impact on traffic flows.
- Connectivity Assessments: GIS tools and the SDNA plugin, version 4.1 (QGIS 3) are employed to measure network accessibility parameters (closeness centrality, degree centrality).

3.3. Study Areas

Three districts were purposefully chosen based on the following criteria:

1. **Jebel Ali:** A significant port and free zone area connected to the city center by the Dubai Metro's Red Line. It includes two stations: Energy and Ibn Battuta Metro stations. The newly expanded Metro route, Route 2020, connects Jebel Ali station on the Red Line to the EXPO 2020 Line, covering transit stops such as Jebel Ali, Gardens, Discovery Gardens, and Al Furjan.
2. **Al-Barsha:** Acknowledged as a recent residential expansion in the city, Al-Barsha's advantageous position is bordered by Al Sufouh to the north, Emirates Hills to the west, Al Quoz to the east, and Dubai Sports City to the south. This region is pivotal in connectivity assessment and is connected to major real estate projects such as Provident Estate, the Mall of the Emirates, and the Dubai Autodrome, offering insights into economic effects via land value assessment.
3. **Business Bay:** Emerging as a prominent residential and professional hub, Business Bay is often called the new CBD. Covering an area of 5900 km², it integrates offices, residential structures, and an extensive road and canal network. Positioned as the

future business capital and freehold city, Business Bay aims to offer world-class amenities and a high-speed lifestyle. Functioning as a CBD, it is strategically connected to the Dubai Metro's Red Line through stations like Burj Khalifa and Dubai Mall, fostering accessibility and engagement.

4. Results

The connection between public transportation and human activities is growing in importance, becoming a key consideration for residents. This shift is driven by an increased personal focus on efficient time management. Accessibility is crucial in a location's attractiveness, influencing society, individuals, and potential commercial, hospitality, and recreational investors [32]. Lower accessibility is linked to decreased population density, economic activities, recreational opportunities, industrial operations, and other essential engagements, thereby limiting contributions to the local economy.

4.1. The Impact of the Dubai Metro

The LRT significantly impacts urban areas by improving accessibility, fostering new economic opportunities, and attracting investors to develop businesses. Introducing Metro stations, public bus stops, and urban railway lines precipitates transformative shifts in adjacent land utilization. Conversely, the absence of a Metro network in an area can negatively affect the environment, leading to higher car usage, increased traffic congestion, greater energy consumption, and elevated air pollution. Hence, the presence of a Metro system is crucial, as it positively influences land use and population density around the stations.

To assess the Dubai Metro's effects on land utilization changes, the initial phase includes gathering imaging data of Dubai to extract multi-temporal spatial land use details. Leveraging satellite imagery from Landsat 8-OLI and external resources such as OSM database and Google Earth Pro 7.1.8, alterations between 2008 and 2023 are identified, utilizing ArcMap 10.8 as the principal analytical software.

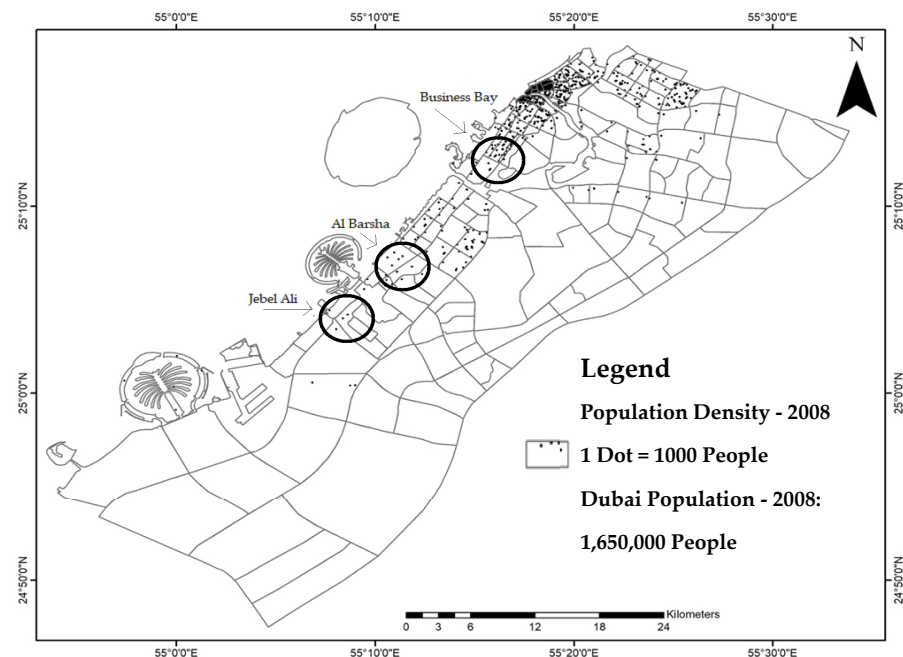
4.1.1. Population Distribution Pattern

Dubai has experienced substantial urban growth, leading to significant population development and urbanization. Urbanization is characterized by the population concentration in larger urban areas and an increase in population density within those areas. From 2008 to 2023, Dubai's population grew from 1,650,000 to 3,600,000, largely due to urban transportation advancements and other developments. The Dubai Metro has significantly contributed to this population growth, primarily through urbanization driven by transport infrastructure development. Improved accessibility has increased the area's value, attracting more residents. This infrastructure expansion, including new metro lines, has led to a rapid increase in the number of inhabitants, especially around metro stations, enriching the area with social and economic facilities.

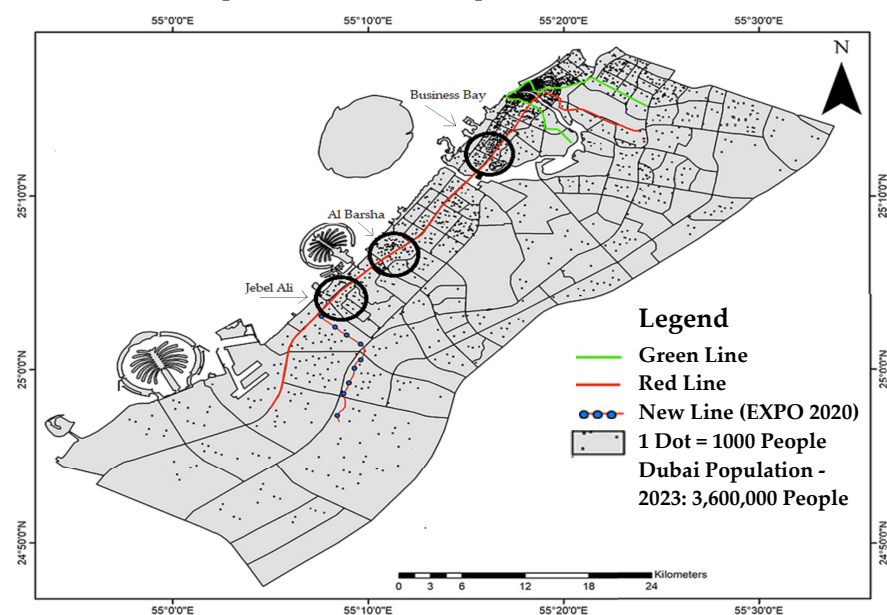
Figure 4a,b illustrate the change in population density before and after the construction of the Dubai Metro. In 2008, most of the population was concentrated in coastal areas such as Deira and Bur Dubai, with low population density in the central regions. By 2020, as an effect of the Dubai Metro's infrastructure development and other urban developments, the high population density extended to areas bordering the Dubai Creek and along the metro lines. The new metro lines facilitated the creation of new residential centers, providing fast and reliable transportation and making these areas more attractive for living. Thus, the relationship between the development of new metro lines and the increase in population density is confirmed, highlighting the Dubai Metro's significant impact on urban and economic growth.

The updated land use data for 2023 has been integrated into the population distribution maps of Dubai to illustrate the changes around the selected case studies: Jebel Ali, Al-Barsha, and Business Bay. These updates show a significant increase and development in the population density around these three stations, as depicted in Figure 4. The maps

are intended to demonstrate both the broader urban impact of the metro line and the specific changes around the selected stations. The introduction and expansion of the metro system have not only enhanced land use and connectivity but also significantly influenced population density and urban development. The maps shown in Figure 4 visually represent these changes, providing a comprehensive overview of how the metro has reshaped these areas.



(a) Population distribution pattern of Dubai in 2008



(b) Population distribution pattern of Dubai in 2023

Figure 4. Changes in the population density pattern of Dubai, visualizing the changes around the study areas between 2008 and 2023. Source: The authors, based on the database produced by ArcMap 10.8.

4.1.2. Land Use

Land use change is influenced by various factors, with population growth and accessibility playing pivotal roles. The increasing population drives the need for additional housing, services, and recreational spaces, prompting changes in land use. The dynamic relationship between land use and transportation becomes evident, especially around transport nodes like Metro stations. The emergence of such nodes positively impacts the land value, making these areas desirable for residence due to their essential connections with the city center and other significant locations. This symbiotic relationship enhances economic potential and benefits both residents and economic agents.

Jebel Ali

Jebel Ali District in Dubai underwent substantial land use changes between 2008 and 2023. Before the Dubai Metro's construction in 2008, the area was dominated by industrial and residential spaces but lacked essential amenities. The introduction of the Metro by 2020 transformed the district, increasing residential, green, commercial, and industrial areas. This expansion enhanced connectivity, attracting residents and economic operators and significantly elevating the area's value. The most updated Metro's influence on land use in 2023 is evident, as illustrated in Table 2. As shown in Table 2, the residential land use pattern has expanded by 8 times, growing from 37 hectares in 2008 to 301 hectares in 2023. Likewise, commercial areas experienced a notable surge of about 6 times, increasing from 74 hectares in 2008 to 531 hectares in 2023. Industrial zones expanded by 35%, and the primary road infrastructure grew from 192 to 601 km. However, green spaces decreased by about 60%, mainly due to residential, industrial, and commercial development, while lakes remained unchanged. Figure 5 shows the most updated land use map in 2023 for the Jebel Ali Area, illustrating the changes to the overall land distribution caused by the metro station line.

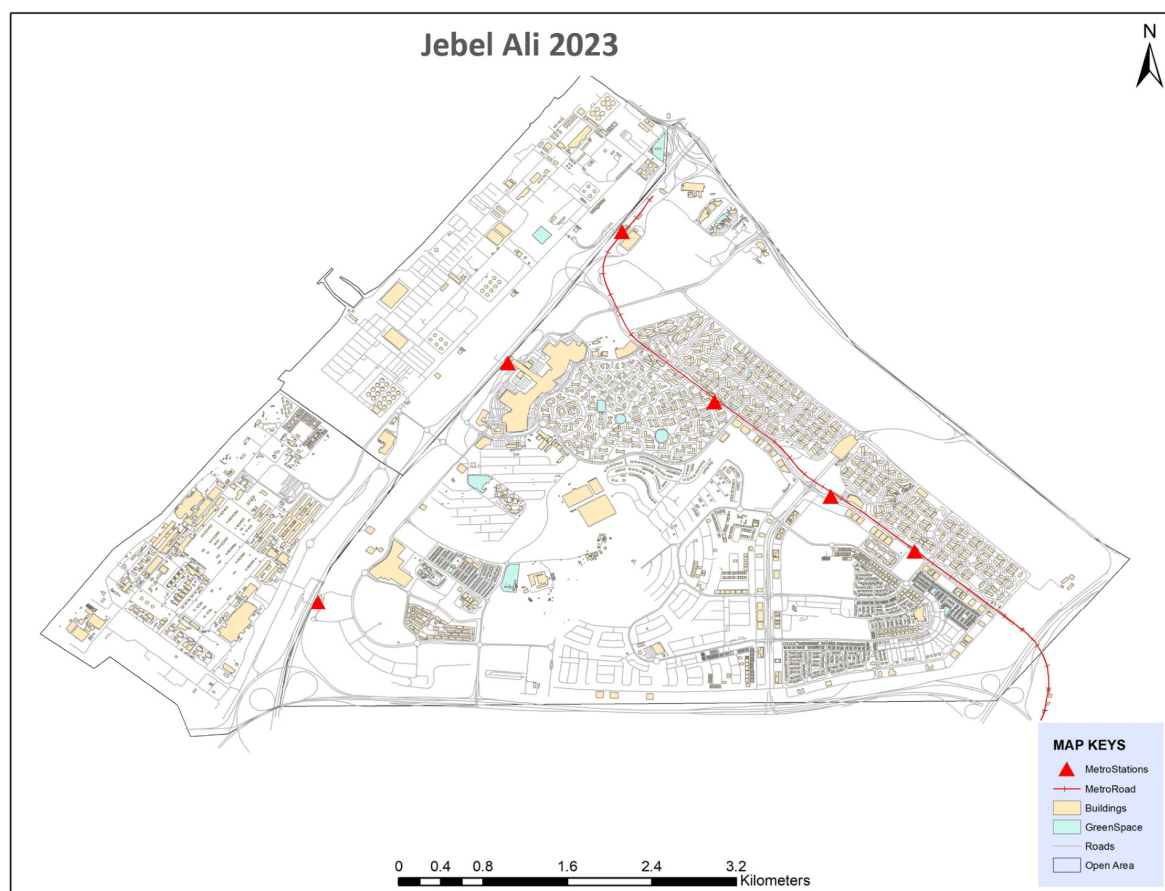


Figure 5. Land use map for the Jebel Ali area in 2023.

Table 2. Change in land use at Jebel Ali.

Land Use (ha)	2008	2020	2023
Residential	37	273	301
Commercial	74	474	531
Industrial	252	299	341
Green space	28	13	11
Lakes	8	8	7
Main Streets (km)	192	543	601

Al-Barsha

The Al-Barsha District underwent significant changes between 2008, 2020, and 2023 following the introduction of the Dubai Metro, as outlined in Table 3. This district experienced a notable 150% rise in residential land use from 2008 to 2023, leading to increased demand for commercial premises. Commercial and green areas expanded by around 8 and 5 times, respectively, mirroring the residential growth. Additionally, street plots increased by 70%, emphasizing the impact of improved connectivity, accommodating the growing population, and enhancing accessibility. Notably, industrial land use emerged after the construction of the Dubai Metro. The focus on sustainability is evident in the increase in green spaces by more than 5 times between 2008 and 2023, aligning with Dubai's clean energy goals. The presence of lakes remained unchanged, showcasing a balanced approach to urban development. The changes highlight the positive correlation between Al-Barsha residential growth, commercial development, and improved transportation infrastructure. Figure 6 shows the most updated land use map for 2023 for Al-Barsha District, illustrating the overall land use distribution changes.

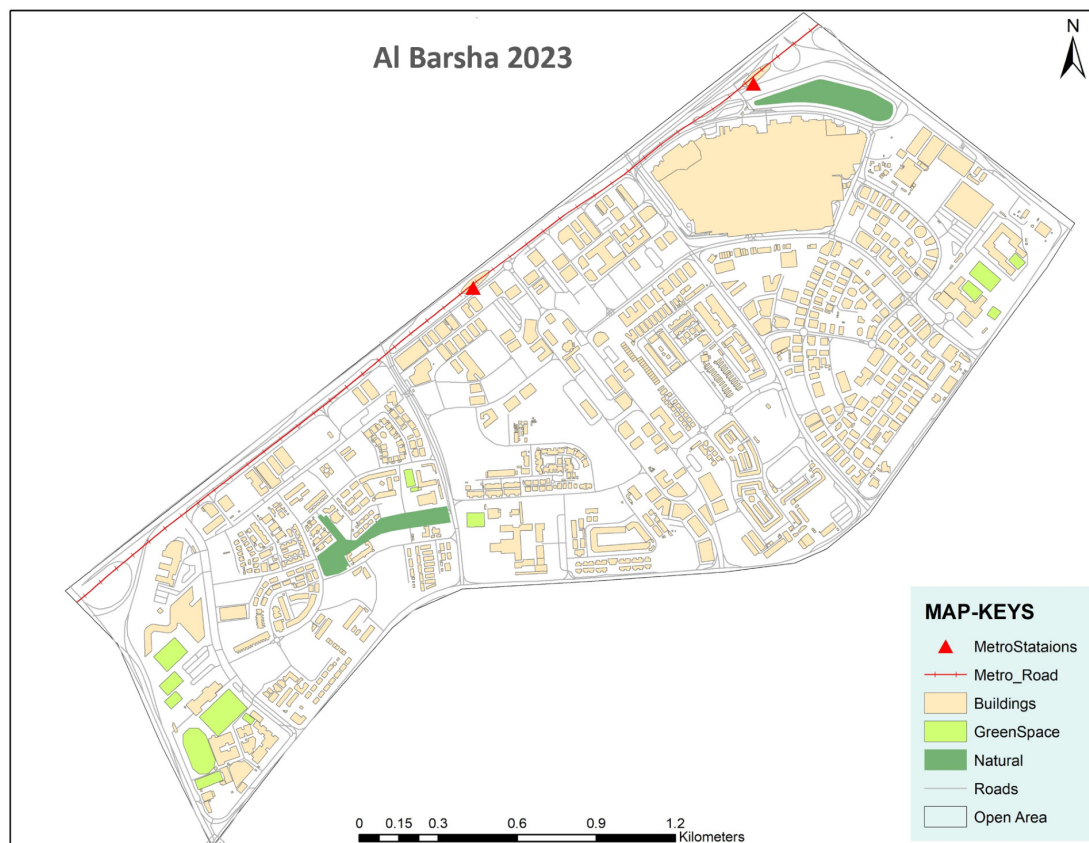
**Figure 6.** Land use map for the Al-Barsha District in 2023.

Table 3. Change in land use at Al-Barsha.

Land Use (ha)	2008	2020	2023
Residential	10	22	25
Commercial	34	296	310
Industrial	-	15	17
Green Spaces	2	10	10
Lakes	4	4	4
Roads (km)	62	101	105

Business Bay

The residential development in Business Bay District, positioned as Dubai's emerging CBD, has witnessed notable shifts in land use from 2008 to 2023, as outlined in Table 4. Initially less developed, the area underwent substantial urbanization and experienced rapid growth influenced by the Metro. Unlike Jebel Ali and Al-Barsha, Business Bay does not feature industrial land use but emphasizes residential, commercial, and green spaces, including water features. Residential and commercial areas flourished along the water arm, especially on the left bank. The Metro's presence further catalyzed development, fostering increased commercial land use by nearly 7 times from 2008 to 2023. Wetlands expanded, with waterways and lakes growing by more than 2 times, while green spaces decreased by nearly 50%. The district's road network expanded by nearly 2 times, contributing to its evolving urban form. These changes showcase Business Bay's journey from an underdeveloped area to a thriving commercial and residential hub. Figure 7 shows the most updated land use map in 2023 for the Business Bay Area, illustrating the changes to the overall land distribution caused by the metro line and other infrastructure developments.

**Figure 7.** Land use map for the Business Bay area in 2023.

Table 4. Change in land use at Business Bay.

Land Use (ha)	2008	2020	2023
Residential	0	6	6
Commercial	1	5	7
Green spaces	41	11	21
Lakes	6	10	13
Waterways	48	121	103
Roads (km)	54	n/a	135

4.1.3. Connectivity

Connectivity in transportation refers to the efficiency of travel, considering factors like time, cost, alternatives, comfort, and safety. A well-connected network helps disperse traffic and reduce congestion. The study uses measures like the quantile method and GIS software (ArcGIS 10.6) to interpret connectivity, emphasizing a 1 km radius around Metro stations. This distance corresponds with user preferences for walking to stations, facilitating efficient land use planning. Metrics include proximity to highways and the number of Metro stations within the coverage area.

Jebel Ali

As shown in Figure 8, Jebel Ali District demonstrates varying connectivity levels through green, yellow, and red lines. Green represents low connectivity, mainly residential, while Yellow indicates moderate connectivity with a mix of residential and commercial spaces. The Red Zone signifies the highest connectivity, linked to Jebel Ali Metro Station, fostering sustainable economic, social, and environmental development. Jebel Ali stands out with the best connectivity, featuring multiple zones of high connectivity in Figure 8.

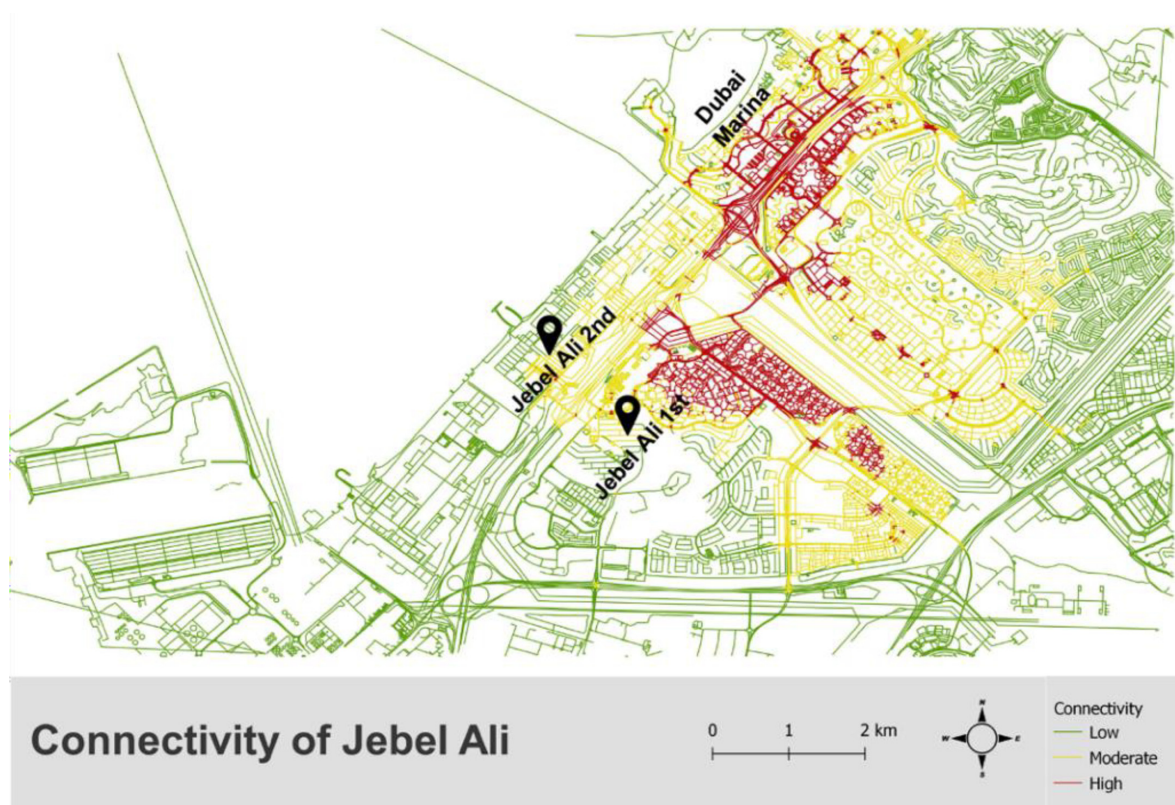


Figure 8. Connectivity of Jebel Ali District in 2020. Source: compiled by the authors, based on the database produced by ArcMap 10.8.

Al-Barsha

Al-Barsha Metro Station and its surroundings showcase commendable connectivity, ranking third after Jebel Ali and Business Bay. Unlike Jebel Ali, Al-Barsha lacks areas with moderate connectivity, primarily featuring low connectivity zones. The area has undergone significant population and infrastructure expansion, surpassing 1000% in the past 12 years, with an annual growth rate exceeding 94%. The advantageous location relative to Dubai's center contributes to efficient transportation, with bus lines and the Metro connecting Al-Barsha by an average trip time of 53.7 and 44.6 min, respectively. The area's lack of significant residential zones and prominent shopping and industrial centers mitigates pressure on transportation infrastructure. However, potential future residential development may necessitate rapid infrastructure expansion to ensure sustainability. Figure 9 shows the connectivity map of Al-Barsha District in 2020.

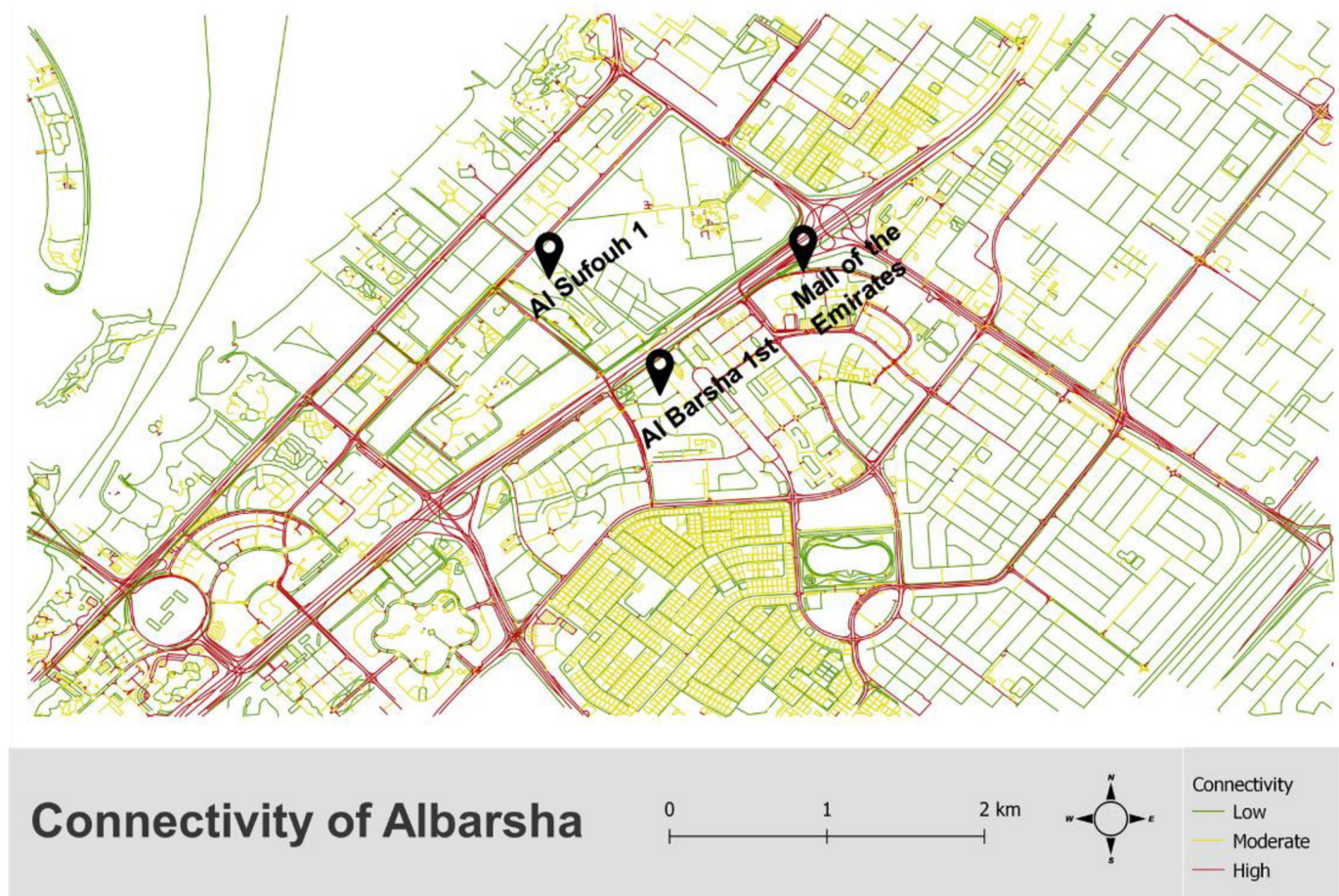


Figure 9. Connectivity of Al-Barsha District in 2020. Source: compiled by the authors, based on the database produced by ArcMap 10.8.

Business Bay

The connectivity layout near Business Bay Metro stations and its surroundings mirrors that of Jebel Ali, showcasing dense, well-connected zones focused on the district core and residential sectors. Over the past 12 years, the population in Business Bay has surged by 600%, yet it remains a well-established and highly developed area. Figure 10 highlights the area's advanced development, indicating potential strain on transportation infrastructure due to new residential developments.

Business Bay's proximity to Dubai's center ensures it is well-connected. Bus travel averages 62 min, whereas the Metro significantly reduces the journey to approximately

37 min, enhancing connectivity. Bus stops are usually an 8 min stroll away, while the Metro station is a 25 min walk.

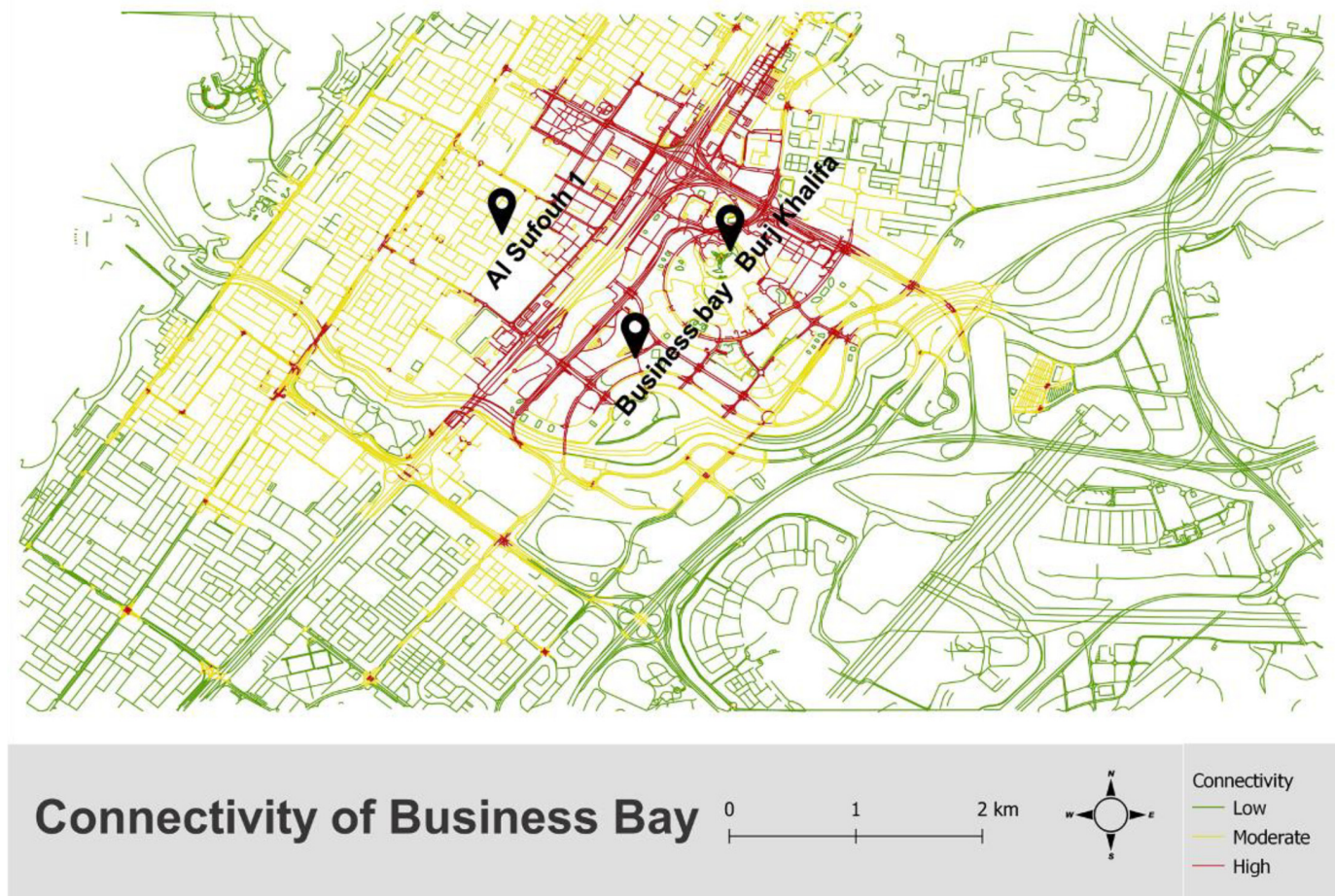


Figure 10. Connectivity of Business Bay District in 2020. Source: compiled by the authors, based on the database produced by ArcMap 10.8.

The 2020 connectivity map of Business Bay shows high-connectivity zones concentrated around the Burj Khalifa, reflecting the significant infrastructure demand from residents and tourists. Moderate connectivity is noted in Al Sufouth 1 and nearby areas, while the coastal region, a key tourist and economic hub, displays a higher distribution of average connectivity zones. Despite some low-connectivity areas, the dominance of moderate and high-connectivity zones mitigates the impact on the local population. For a detailed view, see Figure 10, depicting the 2020 connectivity map of the Business Bay District.

5. Discussion

This research highlights persistent connections between the Dubai Metro and urban growth, significantly influencing land use metrics. Accessibility and population expansion positively correlate with changes in land utilization, particularly in residential zones, illustrating ongoing enhancements. The period after the Metro's introduction (2008–2020) witnessed significant urban expansion driven by industrialization and improved infrastructure. Jebel Ali, hosting Dubai's largest seaport, experienced substantial growth around Metro stations, particularly Jebel Ali station. Al-Barsha transformed into an economic hub, while Business Bay saw increased clustering near Metro stations.

The analysis utilizes GIS techniques with a 500 m buffer zone around Metro stations, uncovering highly significant transformations in areas adjacent to Metro stations, as detailed in Table 5. The measured expansion underscores the Metro's pivotal role in shaping urban development.

Table 5. Calculating the growth of three districts within a 500 m radius of the metro station. Source: compiled by the authors, based on the database produced by ArcMap 10.8.

Districts in Square Meters	Jebel Ali (2008)	Jebel Ali (2020)	Al-Barsha (2008)	Al-Barsha (2020)	Business Bay (2008)	Business Bay (2020)
Buildings within 500 m radius	81.5	290,394	215,359	346,614	28,986	79,342
Comments	Extremely significant change		Marginal change		Significant change	

The Dubai Metro's influence on urban growth is clear, especially near Jebel Ali Metro stations, where the built environment expanded markedly to about 290,394 m². This growth is attributed to excellent connectivity, pedestrian-friendly infrastructure, and access to public transit. The strategic positioning of metro stations facilitated the development of the Jebel Ali district, supporting significant events like Expo 2020 and international conferences.

In Al-Barsha, the presence of two metro stations, including one connected to the Mall of the Emirates, transformed the district into a bustling commercial hub. The provision of metro stations led to the emergence of hotels and increased commercial activities. Similarly, Business Bay experienced substantial growth, becoming an employment hub with a significant increase of over 50,000 m² in buildings. The LRT was crucial in relocating inhabitants and industries from the old central city to the new economic development zone in Business Bay.

The results correspond with established theories indicating the substantial impact of urban metro systems on land development. The Dubai Metro, with its convenient accessibility and attractive travel options, played a crucial role in the city's urban expansion and enhancement. The study emphasizes the vital role of transportation investments in generating development, especially in areas lacking transport infrastructure. Referring to Table 6, a comparison with previous studies underscores the consistent impact of public transportation, particularly metro systems, on urban growth in various geographic areas. The Dubai Metro investment is critical to the city's transit-oriented development (TOD).

Table 6. Comparing the results of previous studies with the conclusions of this study.

Author Name (Year)	Research Location	Research Methodology	Research Findings	Outcome of this Study
Raguz (2010) [41]	Manila, Philippines	Geographic information System (GIS)	The Manila LRT led to a population decline as the city grew, and as new CBDs developed, citizens actively sought out less crowded areas with sufficient open spaces, leading them to relocate out of the city center.	Contrary to expectations, Dubai's population initially concentrated mostly in the old region. However, after the Metro's construction was completed, many chose to live a greater distance from the city center.
Xia et al. (2017) [14]	Beijing, China	Geographic information System (GIS)	Three metro stations saw different land use changes. Commercial land transformed into a multi-functional center after the LRT. In comparison, residential and industrial areas at the other two stations experienced fewer changes.	This study aligns with the research findings, as it indicates that the land changes depended on the number of stations present in the area and the predominant land type in the district.

Providing public infrastructure and financial incentives to promote development near transportation stations is vital, as exemplified prominently in Dubai. This kind of approach has played an essential part in stimulating population expansion and facilitating the process of commercialization. Al-Barsha district exemplifies this strategy, showcasing increased green space, TOD, commercial ventures, and industrial development. The surge in economic activities in Al-Barsha is directly attributed to the well-developed transport facilities, highlighting the interconnected relationship between robust transportation infrastructure and thriving urban development.

6. Conclusions

This study centers on three Dubai Metro stations to evaluate the influence of LRT on the city's urban development, employing GIS and remote sensing techniques. Examining changes from 2008, 2020, and 2023 associated with the Dubai Red Line Metro, the study reveals a notable 15% increase in the built-up area and population density along Metro lines, shaping Dubai's evolving landscape.

The equitable impact of LRT, notably the Dubai Metro, has become evident over the past 12 years, witnessing an approximate 15% increase in population density around the Metro stations. The clustering of linear settlements near these stations highlights the substantial demand for residential and commercial space along the Metro routes. This highlights the transformative impact that new Metro lines have on heightened population density by bringing more people together, particularly in areas experiencing residential and economic development.

The landscape shift from predominantly industrial and residential in 2008 to advanced road networks, expanded residential areas, and a multifunctional center by 2023 highlights the Metro System's significant impact and emphasizes the population-dependent nature of land-use change.

The study revealed increased road connectivity around the Metro's surroundings due to substantial development, aligning with the RTA's considerations for carrying capacity and built-up areas. This approach contributes to Dubai's sustainability by ensuring precise and controlled development, creating a complex and livable urban environment.

By affecting population density, building density, land-use modifications, and road utility enhancement, the Metro facilitates the completion of complex urban infrastructure. The Metro initiative significantly improves accessibility and mobility, enhancing the city's livability for residents and visitors.

Dubai's economic standing, technological advancements, and the Metro's influence contribute to its development. Population growth near the Dubai Metro improves interdistrict and intertown transportation and connectivity. The research underscores the Dubai Metro's significant influence on population density, corresponding with individuals' inclination to live close to the Metro due to its convenient transportation options.

The study recommends economic impact assessments, buffer assessments, and community perspectives to open avenues for future investigations. These measures aim to upgrade the Red Line, enhancing public and environmental friendliness in Dubai. Future transport-related studies should delve into micro-urban scale analyses, pedestrian flows, and additional measures to understand and incorporate the social impact of urban density along the Metro line into spatial planning regulations.

7. Recommendations

The Dubai Metro is crucial to the city's public transport network and exemplifies Dubai's dedication to global connectivity and environmental sustainability, demonstrating commitment, innovation, and cutting-edge capabilities. The city of Dubai is shaped by a comprehensive transformation journey towards sustainable urban development for a prosperous metropolis. Dubai continually strives to optimize its transit systems and align them with urban development goals. This exploratory study examines the urban development of Dubai in the wake of the Dubai Metro, with a particular focus on the necessity of integrated planning to guarantee transit systems that are dependable, adaptable, and sustainable. The following recommendations are proposed for the Dubai government and RTA departments to consider, addressing key aspects such as environmental sustainability, infrastructure development, and strategic planning for future growth.

- **Environmental Monitoring and Management Strategy:** Conduct thorough research on the environmental ramifications of major initiatives like the Dubai Metro, focusing on emissions. Furthermore, environmental impact assessments (EIA) must be conducted before project commencement. Formulate and implement an environmental

management strategy (EMS) to oversee and alleviate environmental effects throughout Metro operations.

- Extended Metro Operating Hours: Anticipate population growth and alleviate traffic congestion by extending Metro operating hours, reducing reliance on individual vehicles and mitigating environmental burdens.
- Private Sector Contributions: Encourage private developers to contribute to infrastructure costs in areas experiencing population clusters around Metro lines, leveraging increased land values to fund future Metro services.
- Coordinated Infrastructure Development: Align public infrastructure enhancements with new projects in districts characterized by high population density, pedestrian-friendly environments, diverse land use, and upgrades to public spaces. To create a new central area that attracts a larger residential population, transform the metro stations into neighborhood-friendly ones and promote seamless connectivity.
- Tactical Metro Line Placement: Strategize future Metro line routes at highway junctions or along vital arterial routes, ensuring ample capacity and secure access in alignment with prospective urban growth.

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