The Impact of Light Rail Transit (LRT) On Urban Land Use: A Case Study of the Greater Manchester Metrolink

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CENGIZ YENIKALAYCI

SCHOOL OF ENVIRONMENT, EDUCATION AND DEVELOPMENT

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LIST OF ABBREVIATIONS

TOD	Transit-Oriented Development
UK	United Kingdom
CBD	Central Business District
BART	Bay Area Rapid Transit
LRT	Light Rail Transit
BRT	Bus Rapid Transit
HRT	Heavy Rail Transit
GIS	Geographic Information Systems
LUPTAI	The Land Use and Public Transport Accessibility Index
GMCA	Greater Manchester Combined Authority
TfGM	Transport for Greater Manchester
2CC	Second City Crossing
Ha	Hectare

ABSTRACT

This research aimed to analyse the impact of the Greater Manchester Metrolink light rail transit (LRT) investment on urban land use and the impacts of line extensions on the urban land-use change between 1990 and 2018. In line with this aim, two objectives were determined. The first objective was to understand the impacts of Metrolink LRT on urban land use and land cover, focusing on residential, commercial and industrial, urban green areas, and other land uses. In this context, the impact of both the Metrolink LRT line and the stations on the change in land use has been examined. The second objective was to understand the impact of accessibility to Metrolink LRT stations on changes in urban land use.

This study used land-use and transportation infrastructure data. Metrolink LRT before (1990), during (2000 and 2012) and after construction (2018) land cover data, as well as phase 3 pre-construction (2006) and post-construction (2018) land use data were used. Land use data and transportation infrastructure data on Metrolink LRT lines and stations were overlapped in the Geographical Information Systems (GIS) and used in spatial analysis for the first objective. In addition, it was used to generate data at different levels of accessibility to stations for statistical (regression) analysis for the second objective.

In spatial analysis, linear and circular buffer tool was used in GIS, which helps to analyse and visualize the spatial data by giving fast and objective results to compare land uses in different years, considering the period before and after the Metrolink LRT investment. Linear regression analysis, which helps to examine the effects of different variables on changes in land use, was used to understand the impact of accessibility to Metrolink LRT stations on changes in land use.

This study concluded that the land cover changed along the Metrolink LRT lines before (1990), during (2000-2012) and after construction (2018). Similar changes were observed in the land uses around the stations determined within the phase 3-line extension between 2006-2018. The increase in industrial and commercial areas in the buffer zone has led to the destruction of environmental elements. In contrast, the Metrolink LRT did not cause a significant change in residential areas. While the largest changes in land cover were observed during Metrolink's pre-construction and construction period, these changes decreased significantly in the post-construction period. The change in land use is most evident in the medium accessible area, while the least change is in the weak accessible area. In addition, transit-oriented development (TOD) has been adopted in Greater Manchester since the Metrolink LRT encourages mixed land uses around the line and station. However, it is insufficient as the residential areas have not increased significantly and should be supported by the necessary TOD policies.

Keywords: Urban transportation, land-use change, transit-oriented development (TOD), light rail transit (LRT), Greater Manchester.

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DECLARATION

No portion of the work referred to in the dissertation has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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1. INTRODUCTION

1.1 Background of the Study

In our time, because of rapid urbanisation, the population in cities is increasing rapidly. It is expected that the urban population, which is almost half, will reach 68% by 2050 (United Nations [UN], 2018). In this way, urban areas expand rapidly, and therefore, transportation needs increase more than at any other time. Together with infrastructure systems, transportation types and its users (Ozbay, 2018), urban transportation is a fundamental requirement (Alaylı, 2007) that people need to consider in their decisions of life, business, education and entertainment, and it has impacts on the lifestyles of people (Coyle *et al*., 1994).

Urban areas are generally places where social, cultural and economic activities are carried out. These activities in urban areas are provided by regular and irregular passenger and freight movements. All passenger and freight movements in different parts of the cities should be supported by urban transportation. On the other hand, the reflection of human activities carried out in urban areas and related to socio-economic characteristics on the space is defined as urban land-use (Eboli *et al*., 2012; Rodrigue *et al*., 2013). The relationship between urban transportation and land use has been frequently studied in the literature, and various definitions have been made. Wegener (2004, p. 129) called this relationship as the "*land-use transport feedback cycle*". Similarly, Shaw and Xin (2003) defined the interaction between urban transportation and land use as a dynamic process affected by changes in time and space. In this context, changes in urban land use affect travel demand and lead to changes in the use of urban transportation; in the same way, changes in the urban transportation system affect accessibility and change land-use patterns.

In order to examine the impact of urban transportation on urban land use, models and theories proposed in the past should be examined and integrated into current studies (Rodrigue *et al*., 2013). The early models by Western thinkers are Regional Land Use Model and Industrial Location Model, followed by the Concentric Zone, Sector and Multiple Nuclei Land Use Models. The high accessibility of city centres, low transportation costs, increasing demand, and changing land-use patterns are critical takeaways from the early models. Transit-oriented development (TOD) is another spatial organisation model to examine the urban transportation-land use nexus. The most common definition of TOD is to reach mixed land uses such as commercial, residential and industrial facilities without using a vehicle, by public transport or on foot (Renne, 2009; Houston *et al*., 2015; Wood *et al*., 2016). As it is a frequently used tool to solve transportation problems in cities (Horner, 2021), instead of the early models, this study adopts the TOD model to explain the land-use change caused by transport infrastructures.

There are different variables affecting the built environment, such as density, diversity, accessibility, proximity, and urban design. They are considered crucial in the two-way relationship between urban transportation and land use to explain changes in urban land. In urban land-use and land-cover change studies, accessibility is handled with different dimensions. Pirie (1979) drew attention to the individual dimension of accessibility. On the other hand, by drawing attention to the social and economic dimensions of accessibility, Niemeier (1997) stated that only infrastructure-based accessibility analysis would be easy but insufficient. Apart from these approaches, Handy and Niemeier (1997) examined the locational accessibility dimension of transportation systems and stated that locational accessibility could be used to analyse land use and produce alternative transportation policies. Therefore, this study focuses on Handy and Niemeier’s (1997) locational accessibility approach and defines accessibility by proximity, a linear or network-based measurement of land use distances from urban transport infrastructure (Pacheco-Raguz, 2010).

The changes in urban land use might have a linear form or a cluster of nuclei consisting of one or more focal points, which are analysed separately in the literature (Baerwald, 1982). However, making station and line analyses of light rail transit (LRT) investments separately is seen as a gap in the literature. As a result, the surroundings of the station (cluster) and transportation route (corridor) should be analysed while examining the impact of public transportation investments on urban land use. Different results have been obtained in the literature for the impacts of LRT on land uses. Handy (2005) stated that urban land-use change caused by LRT is generally seen in high-density areas, and smart growth strategies can be used to explain this. From another perspective, Shen (2013) concluded that urban development mostly takes place around the new rail system line and station, and these are observed very close to the central business district (CBD). In addition, the increasing interest in LRT and land use contributed to the development of TOD, and many cities adopted this model and supported it with appropriate urban policies (Higgins *et al*., 2014).

1.2 Research Aim and Objectives

This research aims to analyse the impact of the Greater Manchester Metrolink light rail transit (LRT) investment on urban land use and the effects of line extensions on the urban land-use change between 1990 and 2018. In line with this aim of the dissertation, two objectives and four research questions outlined below were pursued.

1. To understand the impacts of light rail transit investments (Metrolink LRT) on urban land use and land cover, focusing on residential, commercial and industrial, urban green areas, and other land uses.
    - Has the Metrolink LRT investment in Greater Manchester resulted in changes in urban land cover and land use?
    - How has urban land cover changed along with the Metrolink LRT line between 1990 (before the Metrolink investment) and 2018 (after the Metrolink investment)?
    - How has urban land use changed around the Metrolink LRT stations built with phase 3 (3a and 3b) line extensions between 2006 and 2018?
2. To understand the impact of accessibility to light rail transit stations (Metrolink LRT) on changes in urban land use.
    - How has accessibility to the Metrolink LRT stations built with phase 3 (3a and 3b) line extensions between 2006 and 2018 impacted changes in urban land use?

1.3 Dissertation Structure

This part of the introduction provides information about the dissertation structure, which consists of 6 chapters. After the general introduction in Chapter 1, Chapter 2 examines the two-way relationship between urban transportation and land use from different perspectives with national and international literature. By determining the gap in the literature, information is given about the conceptual framework and the aim and objectives of the study together with the data and sources, data analysis, validity and reliability, limitations and ethical issues in Chapter 3. In addition, this chapter details the study's case study and provides information on the Metrolink LRT in Greater Manchester. Chapter 4 includes the results of spatial and statistical analyses, and Chapter 5 analyses and discusses the results with the existing literature. Chapter 6, the last part of the study, is the conclusion of the dissertation and ends with policy implications and recommendations for future studies. A summary of the stages followed in the study is given in Figure 1.1.

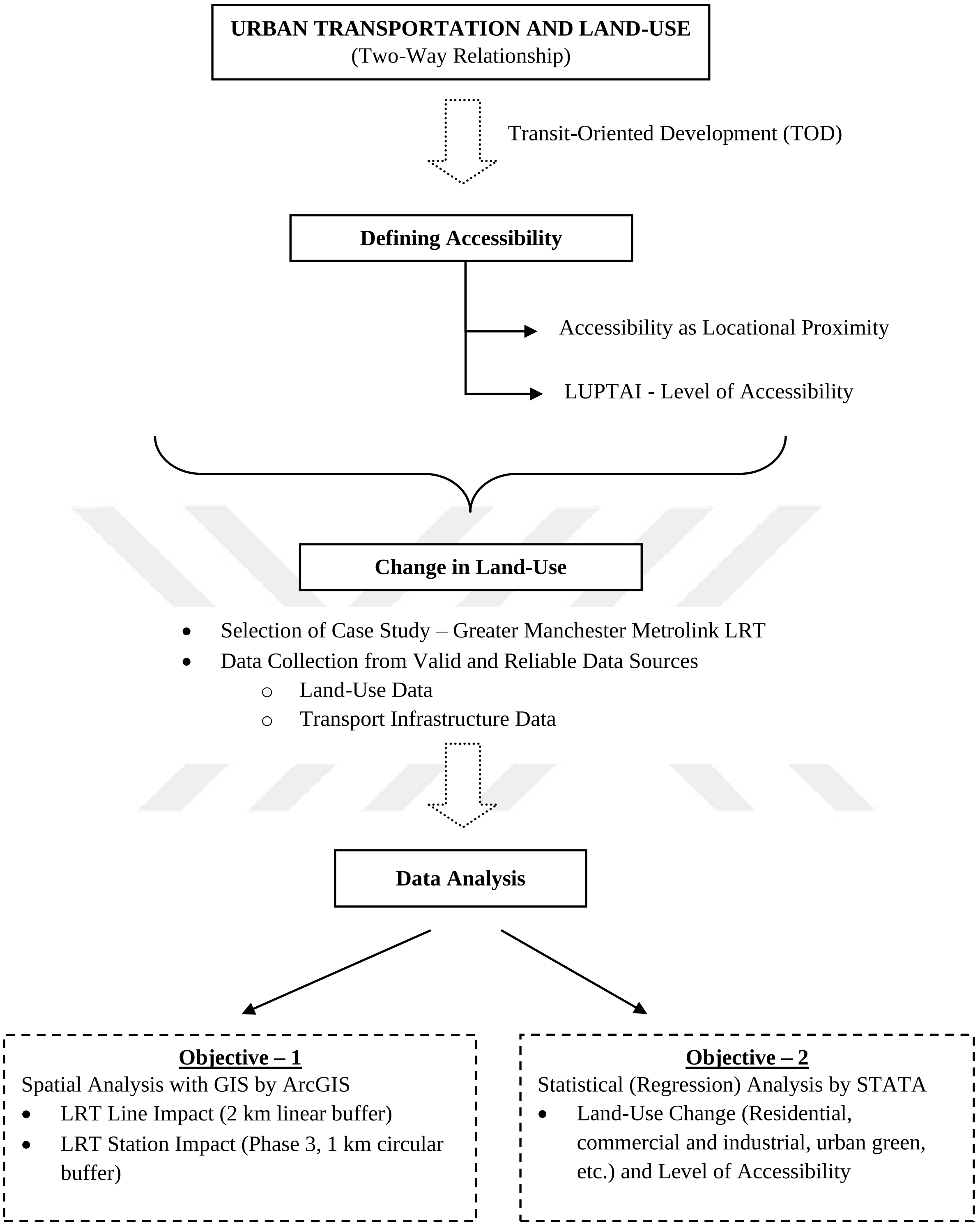


Figure 1.1 Structure of the study, a summary of the steps to be followed

2. LITERATURE REVIEW

2.1 Introduction

In this, the two-way relationship between urban transportation and land use is examined from different perspectives with the national and international literature, and other concepts that are effective in this relationship are traced. In the first part of this chapter, the changing dynamics of today's cities and their impacts on urban transportation have been discussed. Then, the spatial organization models of urban land use-transport nexus, especially the transit-oriented development (TOD), and the built environment variables have been examined. In the last part of the literature review, the changes in urban land use caused by light rail transit (LRT) investments have been discussed by presenting case study findings from different city contexts.

2.2 The Two-Way Relationship Between Urban Transportation and Land Use

As a result of rapid urbanization in our time, the population in urban areas is increasing rapidly. Therefore, the urban population, which is currently close to half, is expected to reach 68% by 2050 (UN, 2018). In this way, urban areas expand rapidly, and therefore, transportation needs increase more than at any other time. Urban transportation that is a whole with infrastructure systems, transportation types, and users (Ozbay, 2018) is considered one of the fundamental requirements for people to continue their lives as it meets transportation needs, which increases with the population (Alaylı, 2007).

Transportation has various effects on individuals and cities. It helps to protect the well-being of individuals with its contributions to citizens in economic and social fields (Zhao, 2010). Furthermore, since transportation is an important factor that people need to consider in their life decisions, business, education, and entertainment, it impacts people's lifestyles (Coyle *et al.*, 1994). However, uncontrolled urban expansion in metropolitan areas is causing changes in urban transport patterns, especially with increased trip distance and motorisation (Kenworthy, 1995; Gakenheimer, 1999). For this reason, it can be stated that there is a close relationship between urban areas and transportation networks.

Urban areas are generally places where social, cultural and economic activities are carried out. These activities in urban areas are provided by regular and irregular passenger and freight movements. Regular activities are done regularly and continuously, such as education, work and shopping, and are made to become routine by individuals. Irregular activities are generally based on passenger mobility that does not require continuity, such as sports, entertainment and health services. Besides passenger mobility, the mobility that occurs in urban areas and covers the distribution of the load resulting from production activities is freight mobility. Transportation is used effectively from production to distribution of the load (Rodrigue *et al.*, 2013). Therefore, adequate urban transportation facilities should support all passenger and freight movements in different parts of the cities.

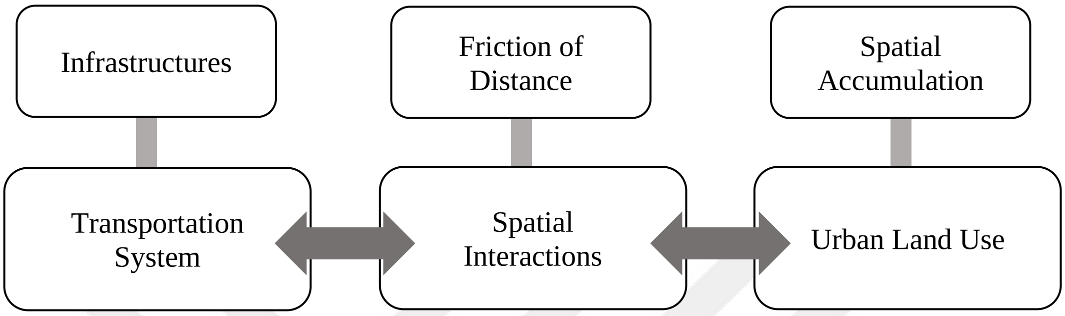


Figure 2.1 The relationship between the transportation system and land use through spatial interactions *(Source: Based on Rodrigue, 2020)*

Reflection of human activities carried out in urban areas and related to socio-economic characteristics on the space is defined as land-use (Eboli *et al.*, 2012; Rodrigue *et al.*, 2013). A transport system is the increased accessibility of transport infrastructures and modes to support the urban mobility of freight and passengers (Rodrigue *et al.*, 2013). As shown in Figure 2.1, the relationship between urban transportation systems and land use has been frequently examined in the literature and emphasised that they highly affect each other. Hence, Shaw and Xin (2003) defined the interaction between urban land use and transportation as a dynamic process affected by changes in time and space. In this context, changes in urban land use affect travel demand and lead to changes in the use of urban transportation. Similarly, changes in the urban transportation system affect accessibility and change land-use patterns in urban areas. In addition, land-use decisions are affected by constructing a new line or improving the existing transportation system, changing the land selection demand, and these factors continue to affect each other mutually (Iacono *et al.*, 2008). Hence, decisions are taken regarding transportation, and land use planning supports common goals (Litman, 2021) and that there is a cyclical relationship between them (Kelly, 1994).

2.3 Spatial Organisation Models of the Land Use-Transport Nexus

In order to examine the impact of urban transport on urban land use, models and theories proposed in the past should be examined, and they must be integrated into current studies (Rodrigue *et al.*, 2013). Therefore, spatial organisation models that Western thinkers propose to examine the land use-transport nexus are frequently addressed in the literature. Early models are Regional Land Use and Industrial Location, followed by the Concentric Zone, Sector and Multiple Nuclei.

2.3.1 Early urban land use models

The first model put forward was von Thünen's (1842) Regional Land Use Model. This model analysed the market, the manufactured products, and the distance from the market holistically. It has been determined that agricultural products are affected by economic rents, production cost, market price and transportation cost from the production stage to the sales stage (Parr, 2015). In addition, the proximity of agricultural lands to the marketplace increases land prices and reduces transportation costs, which means that more should be paid for a better location. Another early model was Industrial Location Model (Weber, 1929). This model aimed to reach the raw materials needed by the industry and reduce the transportation costs of the products produced to the point of sale. The location with the lowest transportation costs was defined as the ideal location. Thus, proximity to transportation systems, changing accessibility, and transportation costs determine land-use decisions in the early models.

The concentric zone model examined the relationship between the proximity of different social classes to the central business district (CBD) and their socio-economic status. In this regard, it has focused on transportation, accessibility, and land-use change, especially in individuals' housing preferences. It has been concluded that transportation costs may decrease with new transportation investments or improvements, and hence, cities sprawl as people prefer places far from the city centre (Rodrigue *et al.*, 2013).

Unlike the previous land-use models, Sector and Multiple Nuclei Land Use Models focused on the impact of urban transport corridors (Hoyt, 1939) and multiple nuclei (Harris and Ullman, 1945) on land use, used in the preparation of the research questions of this study. As a result of increasing motorisation in cities, urban expansion is increasing, and many sub-centres, also known as nuclei, are formed in cities. In addition, with the bid rent theory (Alonso, 1964), it was determined that the rent values are high, and the lands here are limited in the city centres.

As the demand decreases from the city centre to the city periphery, the rents decrease, and there are suitable lands. This situation can be explained as the high accessibility of the city centres, low transportation costs, increase in demand and the change in land use accordingly.

2.3.2 Transit-oriented development (TOD) model

The transit-oriented development (TOD) model, which considers urban transportation, land use and accessibility as a whole, is a tool to solve cities' transportation problems (Horner, 2021). Therefore, instead of the early models created to examine the impact of urban transportation on land use, this study adopts the TOD model and uses it to explain the land-use change caused by transport infrastructure. The most common definition of TOD is to reach mixed land uses such as commercial, residential and industrial facilities without using a vehicle, by public transport or on foot (Renne, 2009; Houston *et al*., 2015; Wood *et al*., 2016). In this context, it is expected to reach public transport stops/stations in 5-10 minutes or 400-800 meters (Ma *et al*., 2018). In this sense, it aims to locate the settlements to maximise accessibility to public transportation stops/stations.

The TOD approach is essential in ensuring the continuity of mobility in cities in a sustainable way. Sohoni *et al*. (2017), who defined sustainability as the coordination between land use and urban transportation, has defined the TOD as an essential tool that is highly accessible by public transport, encourages mixed-use, and ensures sustainability by reducing vehicle dependence. Similarly, Berawi *et al*. (2020) stated that public transport access to land uses with high passenger demand will contribute to sustainability. In this respect, with the adoption of the TOD model in urban planning, there will be a noticeable decrease in the use of vehicles; thus, the traffic problem in the cities will be solved, and the urban sprawl will be brought under control (Feudo, 2014; Griffiths and Curtis, 2017; Taki *et al*., 2017). Similarly, urban design policies are needed to integrate the TOD approach into cities and maximise its benefits. As a matter of fact, by ensuring that urban transportation modes and land use work in harmony, attractive public spaces can be created, and the benefits provided can be utilised in the best way (Jacobson and Forsyth, 2008).

2.4 Factors Affecting Land Use Change

Urban planners have made various studies to make the relationship between urban transportation and land use more evident. In this context, various factors that affect urban land use and accelerate their changes have been identified. Some of the factors used in the literature frequently are the change in accessibility, existence and usability of lands, suitable social and physical environment for urban development, government plans and policies supporting urban development (incentive to TOD, financing, planning and zoning, urban densification, limiting vehicle use, etc.) (Cervero, 1984; Higgins *et al*., 2014). In addition, different built environment variables such as density, diversity, proximity and urban design can also explain changes in land use. However, Acheampong and Silva (2015) concluded in their study that there is no consensus on all these variables in urban form and transportation. In this context, since accessibility is defined as the distance to LRT investments (line and station) in this study, it would be appropriate to examine proximity and accessibility to understand better the relationship between urban transportation and change in land use.

2.4.1 How does accessibility affect urban land use?

Transportation, being used to meet basic needs such as education, health, commuting, as well as social needs such as travel and entertainment for individuals, is necessary for the storage, distribution and transportation of the products produced by the companies between different locations. Accessibility is included in the transportation policies prepared in this context (Engelberg *et al*., 2021). There are various studies and definitions in the literature to examine the role of accessibility on land use and urban transportation. Accessibility is defined as having the necessary transportation infrastructure and land uses for individuals or groups to reach their destination for their daily activities (Geurs and van Wee, 2004). In addition, Hansen (1959) defined accessibility as the potential for an increased opportunity because of the interaction. Similarly, Dalvi and Martin (1976) stated that the potential created by the benefit of location in reaching a place is accessibility. Therefore, accessibility has the potential to examine the relationship between land use and urban transportation.

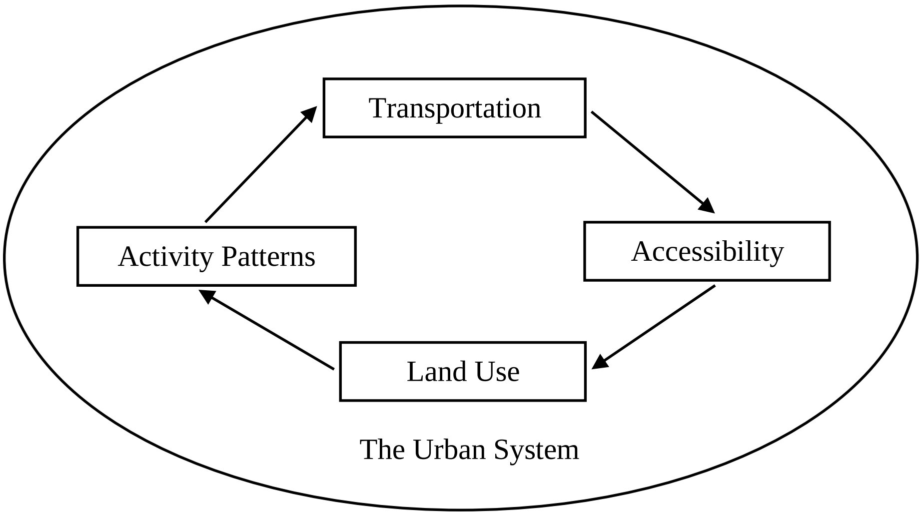


Figure 2.2 The cyclical relationship between transportation and land use through accessibility and activity pattern change *(Source: Giuliano, 2004, p. 239)*

Giuliano (2004) determined that transportation and land use affect each other through changing activity patterns and accessibility. This cyclical relationship between transportation and land use is seen in Figure 2.2. As a new railway investment or improvement of existing railway lines in the transportation network will increase accessibility to existing land uses, changes will occur in urban functions such as residential, industrial and commercial uses around the station and railway line. As a result, the change in land use will influence people’s lifestyles (Trinidad, 2017). It is, therefore, appropriate to define transportation, land use, accessibility and human activities as a cyclical relationship.

In urban land-use and land-cover change studies, accessibility is examined with different dimensions. Pirie (1979) drew attention to the individual dimension of accessibility, emphasising that urban functions should be within reach of people and that individuals should be considered as the focal point in their planning. On the other hand, by drawing attention to the social and economic dimensions of accessibility, Niemeier (1997) stated that only infrastructure-based accessibility analysis would be easy but insufficient. In this context, it has been stated that the actual financial value can be determined by not ignoring the social and economic dimensions in land use and transportation policies and by making a cost-benefit analysis. Apart from these approaches to accessibility, Handy and Niemeier (1997) examined the locational accessibility dimension of land use and transportation and stated that locational accessibility could be used to measure the performance of land use and urban transportation policies and to produce alternative policies. This study takes the locational accessibility approach of Handy and Niemeier (1997), and therefore, accessibility is defined by proximity.

2.4.2 Proximity as a variable affecting accessibility

Proximity is the variable in the built environment primarily used as the distance to the transport infrastructure. Linear or network-based distances of urban land uses to transportation infrastructures affect urban land-use decisions. In studies examining the effect of proximity, the risk of pollution for land uses increases as the distance to transportation infrastructure decreases, and land uses such as commercial and residential increase the demand for transportation and cause high density (Pacheco-Raguz, 2010). Similarly, Hess and Almeida (2007) examined the proximity of land uses to transportation infrastructure and the change in property values in their study and found that residential areas, which are very close to public transportation, lost some value due to the negative impact of noise and crowds. However, there was a significant increase in the value of properties within walking distance of the station areas.

Changes occurring in land use and land cover because of proximity to transport investments can have conflicting results (Kasraian *et al.*, 2016). Wu and Yeh (1997) examined the railway investment in Guangzhou, China and the change in land use on and around the railway line and concluded that increasing proximity to the transportation infrastructure accelerated the development and expansion in the city. On the contrary, Cervero and Landis (1997) examined the land-use change in and around Bay Area Rapid Transit (BART), a railway project in California, and they determined that the proximity to BART did not cause any change in land use and that land-use change should be encouraged with policies and plans.

2.5 Rail Transit Investments and Urban Land Use Change

The uncontrolled expansion of cities and land use plans that encourage the use of vehicles cause many environmental, social and economic problems in society. The most important proof of this is the traffic density that arises due to increasing vehicle use in many cities, especially in megacities (Downs, 2004). Various plans and policies are being prepared to reduce vehicle dependency. In this context, since the beginning of the 20th century, Western countries' use of public transit systems and increasing accessibility to these systems have been actively used to combat traffic problems (Abdullah *et al.*, 2020).

While examining the impact of urban transportation infrastructure on urban land use, public transportation accessibility is considered, and different effects such as urban land-use change, urban development density and changes in property values are examined. In this context, in bus rapid transit (BRT) studies; change in property prices and its broad economic impact for the region (Cervero and Kang, 2011; Bocarejo *et al*., 2013; Nelson *et al.*, 2013), change in land use (Perk and Catalá, 2009), in rail system investments and metro works; impact on land use, and property values (Dewees, 1976; Calvo *et al*., 2013; Guerra, 2014) were examined. Baerwald (1982) stated that these changes might have a linear form or a cluster of nuclei consisting of one or more focal points. He also stated that corridor development that allows growth along a two-way axis like rail or highway could be seen. Therefore, the station (cluster) and transportation route (corridor) surroundings should be analysed while examining the impact of public transportation investments on urban land use.

Previous sections have examined that urban transportation investments increase accessibility for the region and cause changes in land use. These changes become more apparent in the medium and long term, increase the region's attractiveness with the effect of accessibility and play an accelerating role in the development of cities. In this way, transportation attracts new residential, industrial and commercial investments to the region where it is applied (Ozbay, 2018). Railway investments contribute to the increase in accessibility and accelerate population movements by reducing transportation costs and are seen as an essential investment in shaping land uses with the increase in urban density (Hurst and West, 2014).

Rail transit systems are generally examined under two categories. These are heavy rail transit (HRT) and light rail transit (LRT) systems. HRT systems, also named rapid transit, transport crowded passenger groups with their own right-of-way, elevated or ground-level subway (Pushkarev *et al*., 1982). HRT systems are generally used to meet the intercity transportation needs of passengers. Another rail transportation system is LRT. As it works at a lower speed and capacity than HRT, LRT moves in its own road corridor with a single or a series of wagons. Trams and super trams are the best-known examples of this system powered by electricity and often uses the streets in common with other vehicles (Cervero, 1984).

Impacts of rail transit systems on urban space increase the land values in and around the region where they are applied because of accessibility, create new land use clusters and contribute to the region's revival (Cervero, 1984). In this context, not only HRT but also LRT causes a change in land use to a large extent. It has been determined that LRT, which can effectively respond to urban transportation needs, reduces transportation costs in areas close to stations, reduces vehicle dependence, and thus reduces emissions harmful to the environment. However, the desire of individuals to live in places with high accessibility increases the demand around the station. It causes changes in land use along the transportation corridor, especially around the station (Hurst and West, 2014).

2.5.1 Light rail transit (LRT)

Many studies have been realised to examine the impact of LRT on cities. In their study, Gardner *et al*. (1994) stated that the economic development provided in the cities with the LRT investments carrying the human density in the city leads to urban development, which can be clearly seen in undeveloped or developing cities. Changes in the urban area lead to different impacts in different parts of the city. For example, Handy (2005) stated that the land-use change caused by LRT is generally seen in high-density areas, and smart growth strategies can explain this. From another perspective, in his study, which examines the effect of the newly implemented urban rail system investment on land use, Shen (2013) stated that urban development mostly takes place around the new rail system line and station, and these are observed very close to the CBD. In addition, it was seen that the increasing interest in LRT and land use contributed to the development of TOD, and many cities adopted this concept and supported it with appropriate urban policies (Higgins *et al*., 2014).

The impact of LRT on urban land use is often associated with station areas. In this context, it is stated that due to the change in the station environment after the investment, mixed uses have increased, trade and wholesale activities are observed, and residential areas increases as going from the station area to the city periphery (Lee and Sener, 2017). Besides, impacts of LRT investment on land use vary as per the location. When BART in California is examined, it is seen that there are different impacts at different locations along the line (Paez, 2006). In their studies conducted in Minneapolis, Goetz *et al*. (2010) examined the impact of the Hiawatha LRT line on the station and the designated buffer zone and found that there were no extensive changes in land use, except for small-scale changes, one year after the completion of the line. Similarly, in Hurst and West (2014) analysis of corridor and station on the Metro Blue Line LRT, while a small-scale increase was observed in industrial and single-family housing during the construction phase, it was determined that this change decreased after construction and during operation.

Land-use change of the LRT line in Houston between 2005 and 2014 was examined (Lee and Sener, 2017), and it was found that there was an increase in commercial activities in area 4-10 years after the line was opened. However, it was concluded that the construction of new LRT lines only led to increased high-density residential and mixed land uses around the station, even though no visible changes were seen in urban land use. Some studies in the literature in the last 20 years in this regard have been examined and given in Table 2.1.

Table 2.1 Studies conducted in the last 20 years to examine the impact of LRT on urban land use

Author (Year)	**Case study**	**Aim**	**Methodology**	**Data**	**Results**
Ma *et al*. (2018) *	Changchun City	Examining the impact of different transport routes and land use development	Spatial (ArcGIS) and statistical (one-way ANOVA-SPSS) analyses	Raw spatial data, land use maps and aerial photographs	Stronger spatial correlation with residential than commercial; negative correlation with industrial uses
Hurst and West (2014)	the METRO Blue Line, Minneapolis	Examining the impact of the new LRT on urban land use	Before/After (Difference-in-difference method) and spatial (ArcGIS) analysis	Land use at the parcel level and aerial photographs	Minor land-use change during operation; no land-use changes with proximity during construction or operation
Pacheco-Raguz (2010)	Manila, Philippines	Investigation of the impact of LRT on land use with accessibility and distance variables	Before/After, spatial (ArcGIS) and statistical (correlations and regressions) analyses	Land use map and transportation network data (accessibility and proximity)	A consistent relationship between LRT1 and urban land use, accessibility and distance influences land use
Lee and Sener (2017)	The city of Houston, Texas	Investigation of land use development around LRT stations	Analysis and control corridors within buffer analysis	Land use at the parcel level	The land-use change caused by the new LRT is modest and not different than control corridors; minor changes in residential uses
Abdullah *et al*. (2020)	Kelana Jaya LRT, Malaysia	Evaluation of the relationship between land uses (station area) and ridership	Land use calculation with LUPTAI and observation around stations (100-200-300-500 meters)	Land use, built-up area and ridership data	No strong correlation between accessibility and ridership
Saputra and Nabila (2020)	Palembang, Indonesia	Estimation of land-use changes around the LRT corridor	Explorative approach: cellular automata model, a 500-meter radius around line	Land use data and land use maps	Change in land use pattern; more commercial land use around the corridor in 2025

(*Focused on the LRT impact, *Source: The researcher compiled from different documents prepared for the impact of LRT on urban land use)*

2.6 Conclusion

In this part of the study, the two-way relationship between urban transportation and land use has been examined using the existing literature. In this context, the increasing importance of urban transportation in today’s cities has been affecting the daily decisions of individuals and land use. The relationship between land use and urban transportation, called the *“land-use* *transport feedback cycle"* (Wegener, 2004, p. 129), was aimed to be examined by developing various models in history. Among these models, the TOD model, which is still used today and provides sustainable mobility in cities, has been adopted as a basis in this study. In addition, in this section, where accessibility has been defined as proximity to transportation investments, it is concluded that transportation infrastructures in cities affect transportation demand and people's location selection, therefore, built environment. In the last part of the section, within the scope of the TOD approach, the effects of public transportation investments such as LRT in cities to changes in the built environment around the station and line over time have been examined with various examples.

In the literature, making station and line analyses of rail system investments separately (LRT in this study) is seen as a deficiency. Rail system investments have both linear and cluster effects on the urban land, which should be examined together (Baerwald, 1982). Therefore, this gap identified in the literature is used in the next part of the study to provide detailed analyses within the conceptual framework.

3. RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

In the research design and methodology chapter of the study, the gap identified in the literature is detailed with the conceptual framework, and information is given about the methods used to fill this gap. In this context, the aim and objectives of the study, together with the study's case study, Metrolink light rail transit (LRT) in Greater Manchester, are detailed. In addition, the data and sources, data analysis, validity and reliability, limitations and ethical issues are discussed.

3.2 Conceptual Framework

In this study, the model by Rodrigue (2020) showing the relationship between urban transport systems and land use through spatial interactions (Figure 2.1) and the cyclical interrelationship model by Giuliano (2004), including accessibility and activity patterns in cities (Figure 2.2), were combined and used as a conceptual framework. New transportation infrastructure to be applied to cities, LRT investment in this study, cause changes in urban land use by affecting human activities. Likewise, changes in land use affect demand for transportation and drive the implementation of new transport infrastructures. In this process, a cyclical interaction occurs with the change of accessibility, which changes with the proximity to a new LRT line and stations.

As defined by Baerwald (1982), changes in urban land use will be observed along the line (corridor development) and around the stations (clusters with nuclei developments) of LRT investments. Therefore, the change in urban land use and land cover, both along the LRT line and around the stations, have been analysed as a gap in the literature defined in the previous chapter. Land-use change with urban land development will affect human activities and encourage new LRT line and station investments, encouraging the pedestrian-friendly transit-oriented development (TOD) concept implemented in cities (Ma *et al.*, 2018). The new interaction between transportation and land use is given as a conceptual framework in Figure 3.1.

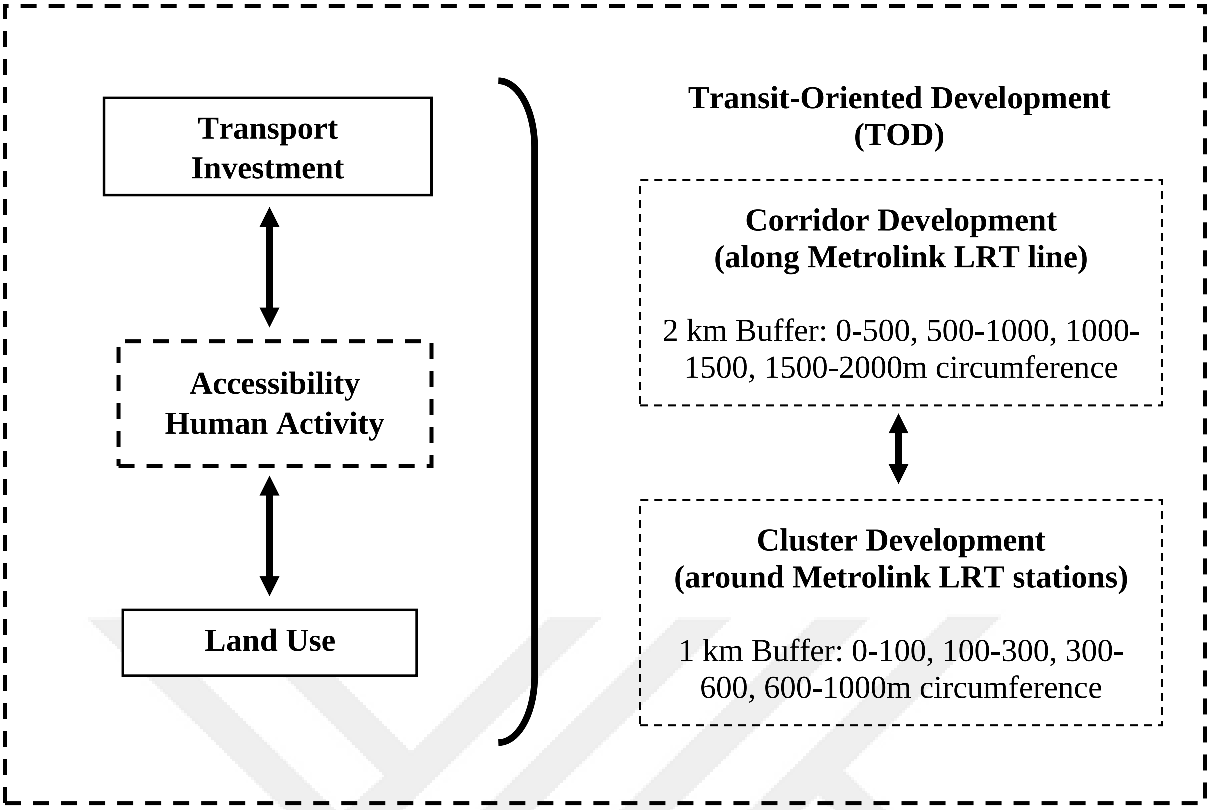


Figure 3.1 Conceptual framework *(Source: Based on Baerwald, 1982; Giuliano, 2004; Rodrigue, 2020)*

3.3 Research Aim and Objectives

This research aims to analyse the impact of the Greater Manchester Metrolink light rail transit (LRT) investment on urban land use and the effects of line extensions on the urban land-use change between 1990 and 2018. In line with this aim of the dissertation, two objectives and four research questions were addressed as follows:

1. To understand the impacts of the Metrolink LRT on urban land use and land cover, focusing on residential, commercial and industrial, urban green areas, and other land uses.
    - Has the Metrolink LRT investment in Greater Manchester resulted in changes in urban land cover and land use?
    - How has urban land cover changed along with the Metrolink LRT line between 1990 (before the Metrolink investment) and 2018 (after the Metrolink investment)?
    - How has urban land use changed around the Metrolink LRT stations built with phase 3 (3a and 3b) line extensions between 2006 and 2018?
2. To understand the impact of accessibility to the Metrolink LRT on changes in urban land use.

- How has accessibility to the Metrolink LRT stations built with phase 3 (3a and 3b) line extensions between 2006 and 2018 impacted changes in urban land use?

3.4 Case Study: Greater Manchester Metrolink LRT

The case study is used as an explanatory tool to analyse complex space-based problems (Zainal, 2007). It also helps analyse the problems in-depth and examine the data related to complex issues (Bryman, 2016). Therefore, this study is appropriate to use a case study approach as the LRT investment in a single city is analysed for a certain period. The reason for choosing Greater Manchester as a case study was the increasing importance of Manchester, which started with the industrial revolution and its strategic importance due to its location in the centre of England. In addition, it has recently made many successful initiatives, especially public transportation investments, to ensure the districts' economic development.

3.4.1 Background of Greater Manchester

Consisting of 10 different local authorities as Bolton, Oldham, Manchester, Stockport, Rochdale, Salford, Tameside, Trafford, Bury and Wigan (Greater Manchester Combined Authority [GMCA], 2020), Greater Manchester is a city-region governed by the Greater Manchester Combined Authority (GMCA). As shown in Figure 3.2, located in the northwest of England, Greater Manchester is approximately 300 km from the capital London and covers 1287 km^2 (Knowles, 1996). It is also the second-most populous urban area in the United Kingdom (UK), with a population of around 2.8 million (World Population Review, 2018).

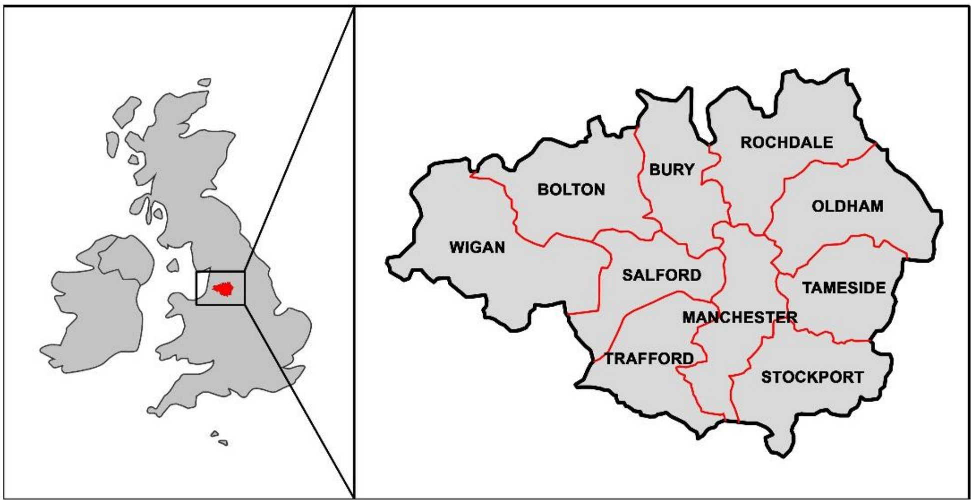


Figure 3.2 Location of Greater Manchester (on the left) and its local authorities (on the right)

Greater Manchester is strategically important to regional transport as it is located at the centre of England's north-south and east-west axes. During the industrial revolution, Manchester has become a hub in the region by effectively responding to the increasing need for transportation of cotton, food, as well as raw materials and coal needed for industry, with its canals and railway infrastructure connecting the cities (Maw, 2013). In this way, its strategic importance for England increased even more. Later, despite the abandonment of dependence on industry to create a post-industrial society after World War II, railway infrastructure remaining from the industrial revolution period continued to be used in cities (Lever, 1991). Thus, rail systems have great importance and contribution to Greater Manchester's urban transportation.

3.4.2 Metrolink LRT

Metrolink, a tram system in Greater Manchester, is considered an LRT. It provides service along a 62-mile line with 99 stations, and therefore, it is characterised as the most extensive LRT system in the UK regarding its line length and the number of stations (Manchester Evening News [MEN], 2020). Metrolink LRT, owned by Transport for Greater Manchester (TfGM), is contractually operated with a joint structure created between Keolis and Amey (Keolis, 2019; TfGM, 2021). In this context, the companies with which the contracts are made regularly publish punctuality and reliability reports for the line. As a result of extensive investments and modernisation works, it is accepted as the pioneer of modern LRTs working on the street in the UK (MEN, 2020).

Metrolink LRT has been built in several phases since 1990 to increase public transportation access, prevent traffic congestion, and support new economic developments in Greater Manchester (Knowles, 1996). It has experienced significant developments with phase 1, phase 2, phase 3 (3a and 3b), phase 2CC and the current Trafford Park line extensions. Metrolink, where all lines converge in the city centre, serves Manchester Airport, Altrincham, Ashton under Lyne, Bury, East Didsbury, Eccles and Media City, Oldham and Rochdale, Trafford Park regions with its eight lines (Railway Technology, 2018). As seen in Table 3.1, the gradual development of Metrolink is also of great importance in meeting the increasing transportation needs, as well as the objectives of the 2040-targeted city's transportation strategy action plan prepared by TfGM on behalf of GMCA (TfGM, 2017). In this perspective, Metrolink LRT, as an essential investment in reaching the city's transportation strategies and reaching its future visions, is known as the most successful LRT line outside of London. For this reason, the government support for the use of LRT in urban transportation continues (Knowles, 2007).

Table 3.1 Metrolink LRT development phases

Phases	Line Extension	Length (km)	Stations (added)	Cost	Construction Started	Opening Date
Phase 1	Bury to Altrincham	31.5	26	£145m	1990	1992
Phase 2	Salford Quays and Eccles	6.5	12	£160m	1997	2001
Phase 3	Oldham to Rochdale East Manchester and Ashton-under-Lyne South Manchester and Manchester Airport Previous phase extensions	56	54	£593m	2009	2011-2014
Phase 2CC	From Lower Mosley Street to Victoria Station	1.3	1	£1.5bn	2014	2017
Trafford Park Extension	Cornbrook to the Trafford Centre	5.5	6	£350m	2016	2020

(Source: Knowles, 1996; Senior, 2009; TfGM, 2016; Railway Technology, 2018)

3.4.3 Metrolink LRT development phases

Metrolink LRT had expanded in several phases, from 1990, when the first construction work began, to 2020, when the last phase was put into operation. The new lines and stations of Metrolink LRT added in different phases are given in Figure 3.3.

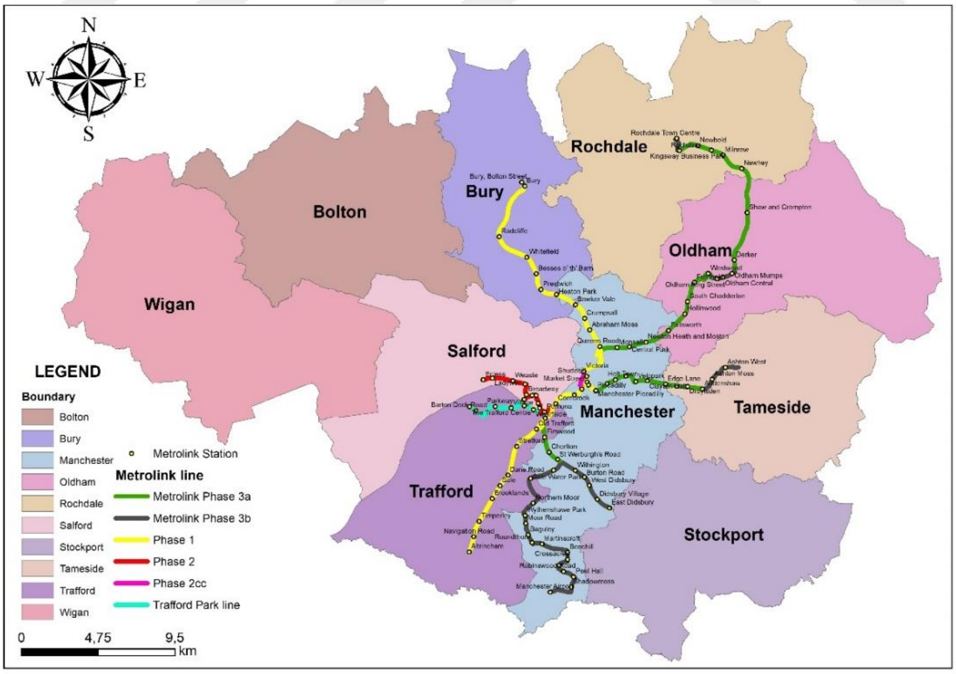


Figure 3.3 Metrolink LRT's lines and stations added at different development phases as part of line extensions *(Source: Elaborated by the researcher using ArcGIS software based on Metrolink LRT Route/Line data via https://www.openstreetmap.org/; Metrolink LRT Stations data via https://tfgm.com/public-transport/tram/geographical/network-mape)*

3.4.3.1 Metrolink phase 1

Greater Manchester public transport network, which was actively used during the industrial period, could not meet today's needs because it was worn out. In order to develop the frayed public transport network in a more integrated, modern and contemporary way, Metrolink LRT was proposed in 1982, and the government approved its construction in 1988. In this situation, it was aimed to convert the existing heavy rail transit (HRT) to LRT for the line to be built between Bury, Manchester city centre and Altrincham in phase 1 (Knowles, 1996; Senior, 2009).

Construction works that began in 1990 connected Victoria station in the city centre to the north with the Bury line and Piccadilly station from the south with the Altrincham line. The construction of phase 1 ended in 1992. In addition, to provide more accessibility, Victoria and Piccadilly stations in the city centre were also connected by LRT. There are 15 stations from Bury to Manchester city centre and 14 stations from Manchester city centre to Altrincham. With a total length of 31.5 km, the new line investment cost £145 million and started to be used as a modern street tram (Railway Technology, 2018).

3.4.3.2 Metrolink phase 2

After completing phase 1 of Metrolink, the focus was on phase 2 to further extend the lines. Metrolink's phase 2-line extension was carried out in the quay area because of the urban regeneration activities. The Salford Quays, where ships were abandoned since the late 1980s, has been reintroduced to the city with mixed land use approaches and land uses such as residences and offices revitalised the city's economy. With the arrival of a new Metrolink LRT line to the region within the scope of urban renewal activities, the TOD has been adopted, and it is aimed that public transportation and land use could work in harmony (Knowles *et al.*, 2020).

Construction works were started for the new 6.5-kilometre line in 1997, the Manchester city centre-Salford Quays line was put into service in 1999. The Salford Quays-Eccles line was put into service in 2000 to benefit more from the urban renewal works carried out in the Salford Quays area (Senior, 2009). Thus, 11 stations were built from Cornbrook station to Eccles (Rail, 2017). The cost of constructing the line extension to Eccles was determined as £160 million (Railway Technology, 2018). Indeed, line extensions carried out within phases 1 and 2 are shown in Figure 3.4.

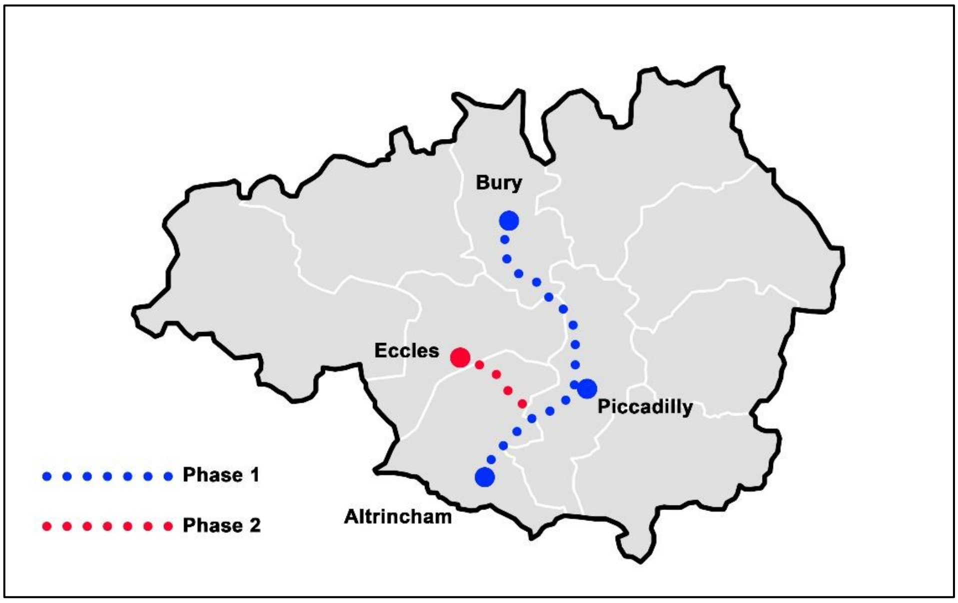


Figure 3.4 Metrolink phase 1 and phase 2-line extensions

3.4.3.3 Metrolink phase 3 (3a and 3b)

As part of the study's second objective (research question 4), which aims to understand the impact of accessibility to the Metrolink LRT on changes in urban land use, land uses around phase 3 stations were determined, and their variation with distance from the station was analysed. Phase 3 has been chosen as it is Metrolink's most comprehensive line extension with more budget and time frame than other phases, and it has been highly influential in its growth with the construction of a new 56 km line and 54 new stations. It is planned to add four new lines to Metrolink with phases separated as 3a and 3b, which are the Oldham and Rochdale Line, the East Manchester Line, the South Manchester Line, and the Airport Line lines. Thus, it has been stated that the safety and flexibility of the urban LRT system will be increased because of the extensive line extensions taking place in Metrolink (Laing O'Rourke, 2017).

As part of phase 3a, new lines have been proposed from the city centre to Oldham and Oldham to Rochdale. In this case, it was envisaged in the works started in 2009 that the 23-km Oldham line will be converted from HRT to LRT, and the 2.7-km unused Cheshire line will be renewed, with a budget of £593 million. In addition, the 6.4-km line in the east of Manchester provided a second city pass with access to Chorlton and MediaCityUK together with the Tameside extension. With the completion of phase 3a in 2013 by TfGM, the total length of the Metrolink line reached 69 kilometres (TfGM, 2016; Railway Technology, 2018).

As part of phase 3b, it was decided to build a new line for Manchester Airport and East Didsbury with the remaining extensions from phase 3a. It is planned to extend the line to Oldham, Rochdale and Ashton-under-Lyne centres by starting construction work in 2009. It became operational after the end of the line extension within the scope of phase 3b in 2014 (TfGM, 2016; Laing O'Rourke, 2017; Railway Technology, 2018). Line extensions carried out within the scope of phases 3a and 3b are shown in Figure 3.5.

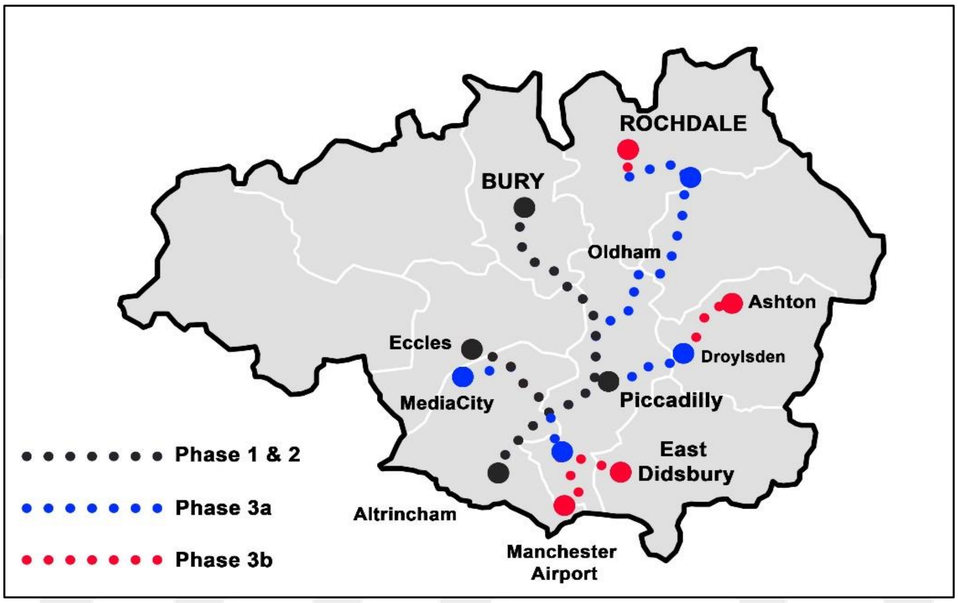


Figure 3.5 Metrolink phase 3 (3a and 3b) line extension

3.4.3.4 Metrolink phase 2CC and Trafford Park extension

The gradual investments in the Metrolink LRT and the extension of the lines caused increased passenger and vehicle density in the city centre. For this reason, it was thought that a new line should be built to the centre to reduce the LRT and passenger density in the city centre (BBC News, 2011). This new line, also known as the second city crossing (2CC), has been designated as the phase 2CC and built by TfGM. In order to reduce the increasing density of St. Peter's Square and Piccadilly Garden in Manchester city centre, phase 2CC envisaged the construction of a new LRT line to Victoria station in the north of the city centre. The LRT extension, completed and put into operation in 2017, is 1.3 kilometres long with one new station (Railway Technology, 2018).

The latest and current development at Metrolink is the construction of a new line to Trafford centre. In 2013, it was decided to build the Metrolink Trafford Park Line. Construction for the new Trafford line, with a project cost of £350 million, started in 2016, and the construction of a new 5.5-kilometre line and six stations was completed in 2020. Thus, accessibility has been increased with the new extensions by providing access to Trafford Centre from the Pomona station (European Investment Bank, 2018; Railway Technology, 2018). Metrolink 2CC and Trafford Centre line extensions are shown in Figure 3.6.

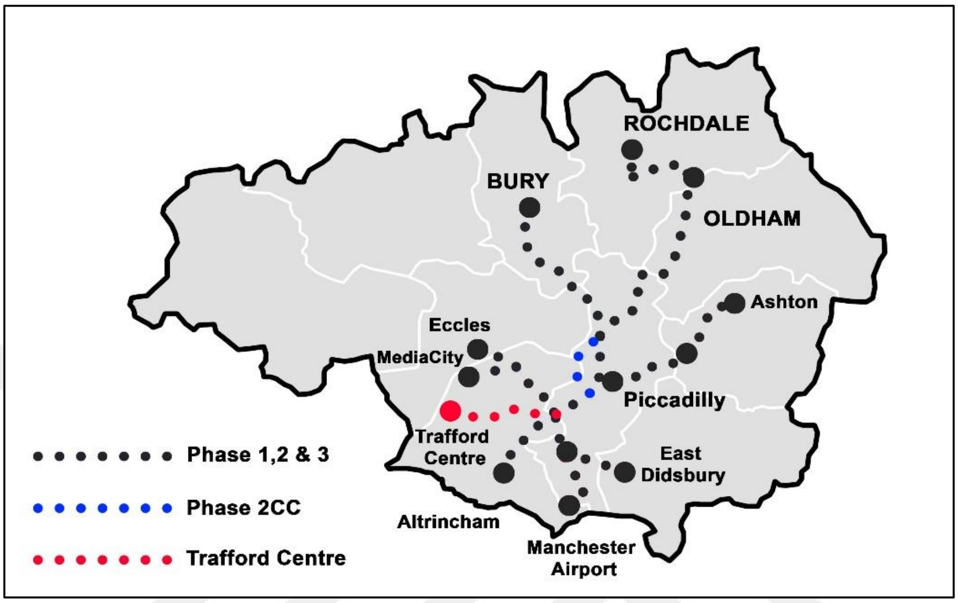


Figure 3.6 Metrolink 2CC and Trafford Centre line extensions

3.5 Data and Source

This study uses desk research with data collection methods from existing sources instead of fieldwork due to time, budget, and pandemic period limitations. Spatial data obtained from secondary data sources were used and classified as land use and transportation infrastructure data. The details of the data and sources used in the study are given in Table 3.2.

Table 3.2 The details of the data and sources used in the study

	Year	Data Type	Data Source	Website	Format
Land Use Data	1990	Aerial Photographs & Satellite Images	EDINA Environment Digimap Service	https://digimap.edina.ac.uk	TIFF Geospatial Data (Scale 1:10000)
		Land Cover			Vector/ GeoPackage
	2000	Land Cover	Copernicus/CORINE (CLC)	https://land.copernicus.eu/	Vector/ Shapefile
	2012				
	2018				
	2006	Land Use	Copernicus/Urban Atlas	https://land.copernicus.eu/	Vector/ Shapefile
	2018				
Transport Infrastructure Data	2021	Metrolink LRT Route/Line	The OpenStreetMap (OSM)	https://www.openstreetmap.org/	Vector/ Shapefile
	2020	Metrolink LRT Stations	TfGM	http://data.gov.uk/dataset/metrolink-and-rail-stations	CSV file
	2021	Metrolink LRT Geographical Map	TfGM and Ordnance Survey Data (2010)	https://tfgm.com/public-transport/tram/geographical/network-map	PNG file

(Source: The researcher elaborated on the collected data and sources)

3.5.1 Land use data

Within the scope of the first objective of the study, reliable sourced spatial data were used to measure the impact of Metrolink LRT on urban land use before (1990), during (2000 and 2012) and after construction periods (2018). Since there are no detailed land use data of previous years (1990-2000), land cover data for all the lines of Metrolink (n=8) were used to examine the change that LRT investment will create in the urban area. While the land cover data for 2000, 2012 and 2018 were obtained from Copernicus, the data for 1990 were obtained from Digimap. However, as it was obtained from a different data source, legend-based problems such as not specifying industrial and commercial areas were observed in 1990. As a result, land cover data were overlapped and regulated in the GIS environment using aerial photographs and satellite images of the period.

Within the scope of the study's second objective, spatial data of the Metrolink phase 3 pre-construction (2006) and post-construction (2018) were obtained. Since detailed spatial data on the land use around the stations constructed with phase 3 (n=52, f=236) are needed, Copernicus-Urban Atlas land use data were used in the station analysis. Thus, the effect of different accessibility to the LRT station on the changes in land uses can be examined.

In addition, land use and land cover datasets were handled and then reclassified. The 37 potential land use/cover categories were grouped into six: settlement, commercial and industrial, forest, water body, urban green, and others. The reclassified land use/cover categories are given in Table A.1 in the appendix.

3.5.2 Transport infrastructure data

Up-to-date transport infrastructure data were obtained on the lines and stations of Metrolink LRT in Greater Manchester and used with this study. In this context, a vector format (shapefile) and open source OSM data of Metrolink lines were used. For the location of Metrolink LRT stations (CSV file) constructed in different phases and still in operation, Metrolink LRT Geographic Map was used to check the station data provided by TfGM. Land use and transport infrastructure data were overlapped in the GIS and used in spatial analysis for the study's first objective and in the production of accessibility data for statistical (regression) analysis for the second objective.

3.5.3 Validity of data, limitations, risk and ethical consideration

It is of utmost importance to use reliable and proven data to obtain accurate and precise findings within the scope of the study. Therefore, the data used in this study were obtained only from reliable and valid sources. In addition, it has been preferred to provide the data from the same sources while examining different periods to prevent incompatibility of the data.

There are limitations of the study since the most recent land use and land cover data used in the study belong to 2018. This is because Copernicus spatial data sources have not provided more up-to-date data. The use of more up-to-date data in the study could have led to observing the different impacts of Metrolink LRT on urban areas. In addition, in the spatial data obtained, industrial and commercial areas were shown as a single field and examining these areas separately could provide information about the different impacts of LRT investments on industry and trade. In addition, the change in land use, the distance to the LRT line and stations and the accessibility variables were used in the spatial and statistical analyses. Using variables such as built-up density and population in the analyses to diversify the variables could have made the results obtained at the end of the study more comprehensive.

Since this dissertation only uses secondary data analysis with desk research, no risk assessment is required. Also, an ethics decision tool approved by the University of Manchester was applied before the study, and it was concluded that ethics approval was not required.

3.6 Analysis Approach

3.6.1 Spatial analysis with GIS

In recent years, the production, analysis and use of geographical and spatial data have become widespread and such data has begun to play a crucial role in many disciplines (Lloyd, 2010; Campo, 2012). In addition to determining the locations of water bodies, electricity and natural gas lines by marking, the spatial data used to determine the locations of the objects can also be used to measure the impact of investments, making daily life much easier. GIS is very useful in creating and modifying the raster and vector spatial data, analysing it using various tools and creating maps by visualising it in the final stage (Lloyd, 2010). For this reason, while examining the impact of the Metrolink LRT investment on urban land use and land cover, the Geographic Information Systems (GIS) assisted spatial analysis method was chosen since GIS helps analysis and visualisation by giving fast and objective results to compare land uses in different years.

3.6.1.1 Before/After analysis

Impact analysis before and after the investment was applied for the Metrolink lines and stations within the scope of the spatial analysis. The reason for choosing this analysis method is that the impact of the applied LRT investments on land uses in the urban area becomes more evident in the long run (Hurst and West, 2014). In this context, before the LRT investment is implemented, the urban land uses could be examined, and what changes have occurred after the investment could be determined. It is stated that pre-investment analyses are studied more in academic fields, especially in large-scale urban investments such as transportation infrastructure, while changes that occur after the investment are less examined (Nicolaisen and Driscoll, 2016). In this respect, detailed impact analysis before, during and especially after the construction are essential to examine the changes in the urban land.

The analysis after the LRT investment made it possible to measure the medium and long-term impacts by covering a broader period. Thus, 1990 was chosen for the pre-investment period of the Metrolink LRT; the during-construction short-term impact analysis focused on 2000 and long-term impact analysis focused on 2012 when most of the phases were completed and put into service. The post-investment period focused on 2018 in the long-term impact analysis due to the time passed through most phases. Similarly, the year 2006, before the phase 3-line extension was put into operation, and 2018, six years after the opening, were examined.

The following equation was applied to calculate the change (%) in land use size (ha) in spatial analysis.

$$Land\ use\ change\ (\%) = \left\{\frac{(land\ size\ (ha)\ of\ last\ year) - (land\ size\ (ha)\ of\ first\ year)}{(land\ size\ (ha)\ of\ first\ year)}\right\} \times 100 \tag{3.1}$$

If the result is positive, the size (ha) of land uses has increased compared to the previous year.

If the result is negative, the size (ha) of land uses has decreased compared to the previous year.

3.6.1.2 Buffer analysis (linear and circular)

The spatial data were analysed through a buffer analysis using GIS. The reason for using buffer analysis within GIS is that it plays a fundamental role in examining spatial features and determining their relationships with different variables. Indeed, using the buffer analysis tool within GIS greatly supports urban transportation and land use studies (Ma *et al.*, 2018). In addition, different types of data sets can be analysed with the GIS, and thus, provides a stable environment for research (Horner, 2004).

Within the scope of the first objective of the dissertation, to examine the change, a buffer zone of 2km (2000 meters) was determined around the Metrolink LRT line (with all phases), and land cover within the buffer zone was compared for 1990, 2000, 2012 and 2018. The purpose of keeping the buffer zone more expansive is to capture more changes. The 2km-buffer zone consists of 4 different zones as 0-500, 500-1000, 1000-1500 and 1500-2000 meters according to its level of accessibility. While determining these distances, as discussed in the previous chapter, the TOD approach and the maximum distance people can walk while reaching public transportation were considered (Ma *et al.*, 2018). The buffer zone used for the first objective is given in Figure 3.7.

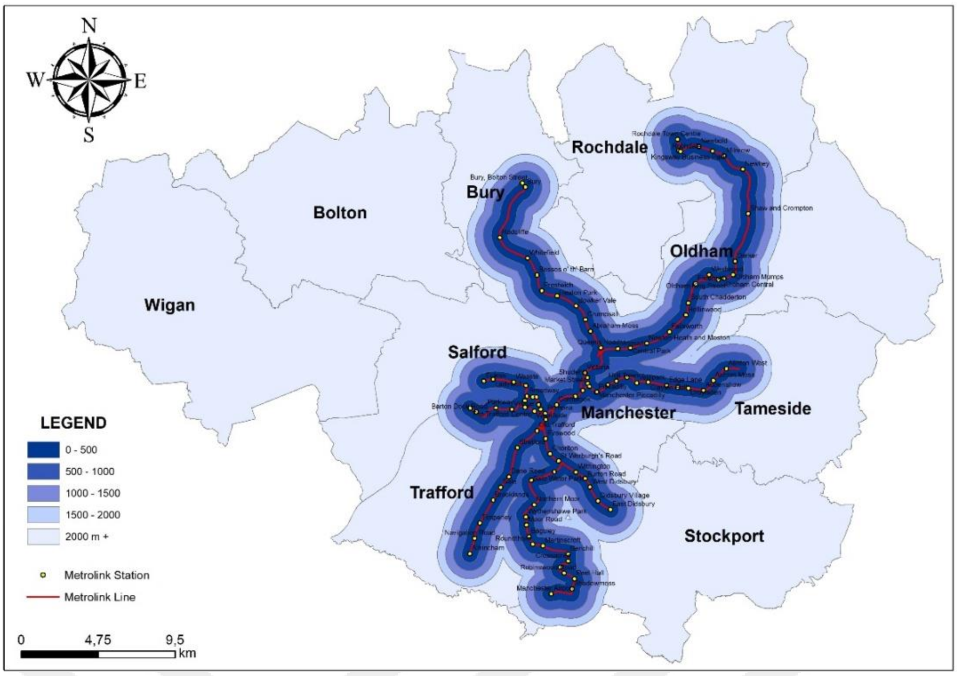


Figure 3.7 Buffer zone along the Metrolink LRT line

The third research question of this dissertation focuses on urban land-use change around the Metrolink LRT stations built with phase 3 (3a and 3b) line extensions between 2006 and 2018. Therefore, stations within the phase 3-line extension were marked within GIS, and circular buffer zones were established. The Land Use and Public Transport Accessibility Index (LUPTAI) is used to classify the one-kilometre buffer zone around the stations. The ability of individuals to easily reach destinations frequently used in daily lives, such as housing, health, trade, education and business centres in cities, is measured by LUPTAI (Bertolaccini *et al.*, 2018). In this context, integrating urban land use and transportation infrastructure is essential for accessibility and plays a vital role in the index. LUPTAI proposes classifying urban areas by accessibility in four different categories: high, medium, low, and weak (Pitot *et al.*, 2006). Accordingly, the higher the accessibility to transportation investments, the faster and easier it is to reach common uses in cities (Handy and Clifton, 2001). In this study, buffer zones were classified as 0-100 m (high), 100-300 m (medium), 300-600 m (low) and 600-1000 m (weak) and coloured according to their level of accessibility. The classification of the buffer zone according to LUPTAI is given in Figure 3.8.

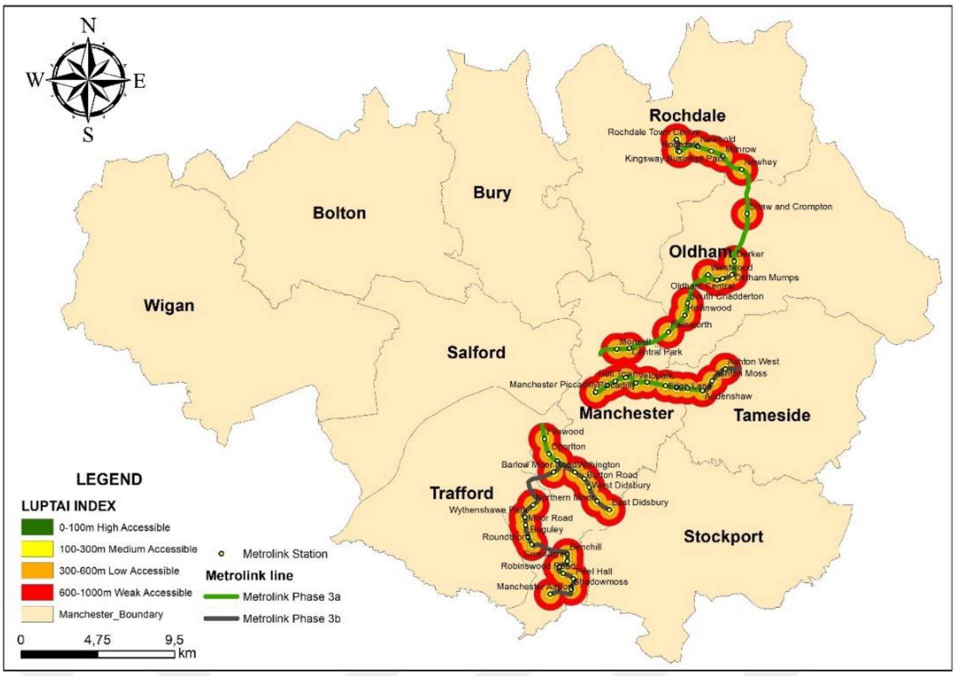


Figure 3.8 Classification of the buffer zone around the Metrolink LRT stations according to LUPTAI

3.6.2 Statistical (regression) analysis

Regression analysis, a statistical method, simply measures the relationship between data sets of different variables and produces reliable results (Chatterjee and Hadi, 2013). It is frequently used in multifactor data analysis, defines the causal effects of different variables on each other as statistical significance (Sykes, 1993). In this context, regression analysis, which is frequently used in urban planning literature, is mainly used with GIS, a spatial analysis tool. After modelling the changes in urban land uses and land cover over the years with GIS, it is highly effective in examining the roles of different variables on the change. For example, the effects of variables such as density and population (Achmad *et al*., 2015), socio-economic factors (Huang *et al.*, 2008) and slope, altitude, distance (Hyandye *et al*., 2015) on the urban land use and land cover change can be explained by regression analysis. For this reason, regression analysis is highly appropriate in examining the relationship between the changes in land uses and accessibility variables determined within the scope of the study's second objective.

In this study, linear regression analysis was done using the enter method in Stata. In this context, categorical variables such as the distance (100, 300, 600 and 1000 meters) and the change in urban land use (residential, urban green, industrial and commercial and other) obtained with GIS were modelled as dummy variables. The data (n=52, f=236) collected from 52 stations built within phase 3 were arranged, and since the study's second objective focused on the change in land uses, data did not change (f=80) were not included in the analysis. Contrary to the equation stated in Chapter 3.6.1.1 for land use change analysis (%), the size difference in land uses was focused.

The following equation is used to calculate the size difference in land uses:

$$\Delta\ (Land\ use\ size\ (ha)\ difference)\ = \{(land\ size\ (ha)\ of\ 2018) - (land\ size\ (ha)\ of\ 2006)\} \qquad (3.2)$$

If the result is positive, the size (ha) of land uses has increased compared to the previous year.

If the result is negative, the size (ha) of land uses has decreased compared to the previous year.

The size difference data in land uses are used in regression analysis with the following regression analysis equation:

$$Y = a + bX + \epsilon \qquad (3.3)$$

Y- is the dependent variable
X- is the independent variable
a- is the intercept/constant
b- is the slope/coefficient
ϵ- is the residual (error term)

3.7 Conclusion

This section has created a conceptual framework on the gap identified in the literature review, which is the second chapter of the study. In this direction, the aim and objectives of the study have been stated. The case study has been determined according to the aim and objectives, and information was given about the spatial and statistical analyses using secondary data sources. The following chapter helps understand the impact of the Metrolink LRT investment on urban land uses by sharing the results on how this impact changes with proximity to LRT stations.

4. RESULTS

4.1 Introduction

This section presents the results of spatial analysis with GIS (ArcGIS) and statistical analysis with linear regression (STATA) using the data sources specified in the methodology chapter, following the aim and objectives of the study. In the first part of the results section consisting of three parts, the change caused by the Metrolink LRT in urban land cover between 1990-2018 is examined in different periods, and spatial analysis results are included. The second part contains the spatial analysis results of the change in land use caused by the Metrolink LRT stations (52 stations built in phase 3) between 2006-2018. In the third part, the regression analysis results of the relationship between the change in land use and the accessibility to LRT stations are given.

4.2 The Impact of Metrolink LRT Line on Urban Land Cover (Corridor Effect)

2000 m buffer zone was determined along the Metrolink LRT line, and the land cover change that occurred before, during and after the construction processes has been examined. The buffer zone was divided into 0-500, 500-1000, 1000-1500 and 1500-2000 meters according to their different accessibility levels. Variation of land cover by years is provided in Figures 4.1, 4.2, 4.3 and 4.4.

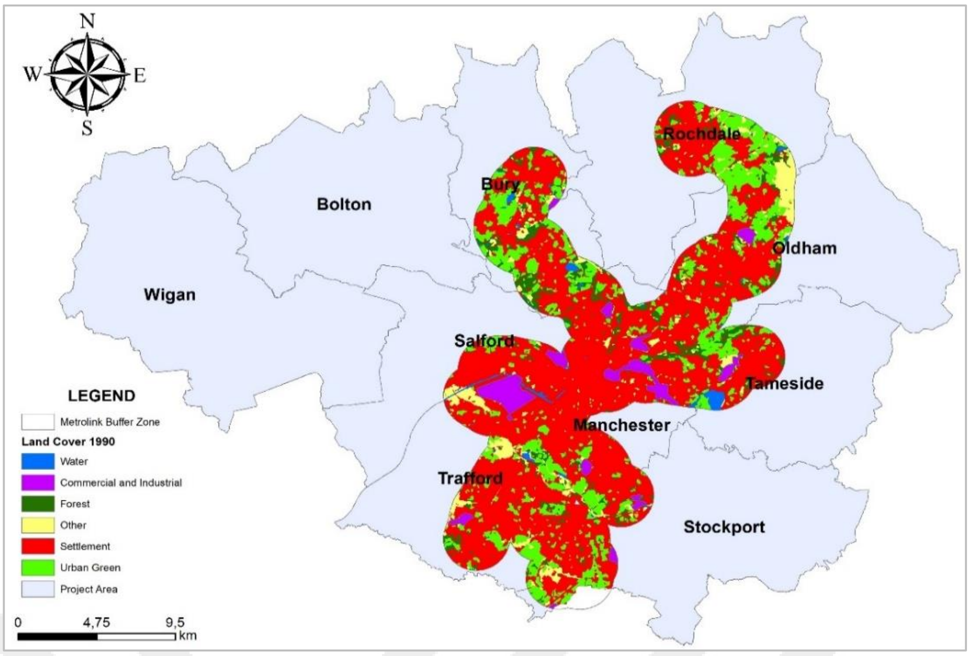


Figure 4.1 Land cover of the buffer zone (2000 m) around the Metrolink LRT in 1990 *(Source: Elaborated by the researcher using ArcGIS software based on 1990 Land Cover data by EDINA Digimap Service, https://digimap.edina.ac.uk)*

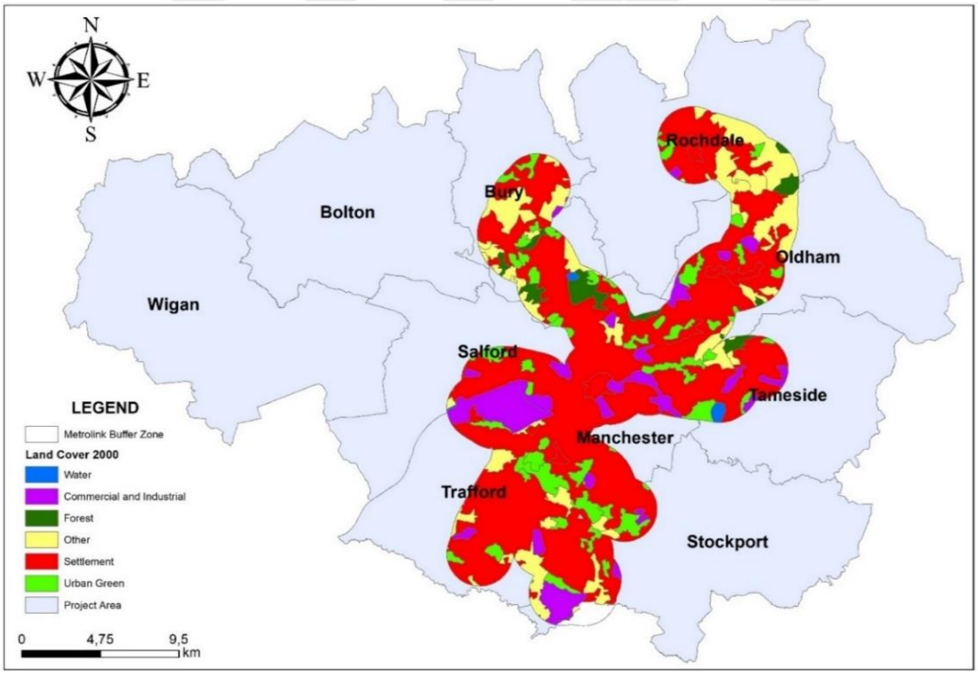


Figure 4.2 Land cover of the buffer zone (2000 m) around the Metrolink LRT in 2000 *(Source: Elaborated by the researcher using ArcGIS software based on 2000 Land Cover data by Copernicus/CORINE, https://land.copernicus.eu/)*

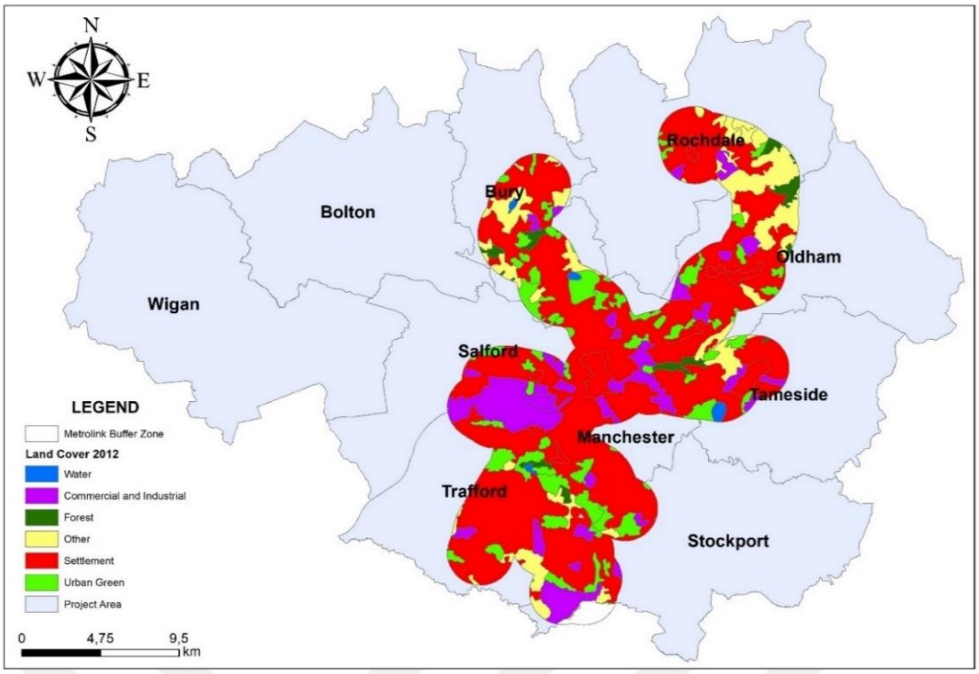


Figure 4.3 Land cover of the buffer zone (2000 m) around the Metrolink LRT in 2012 *(Source: Elaborated by the researcher using ArcGIS software based on 2012 Land Cover data by Copernicus/CORINE, https://land.copernicus.eu/)*

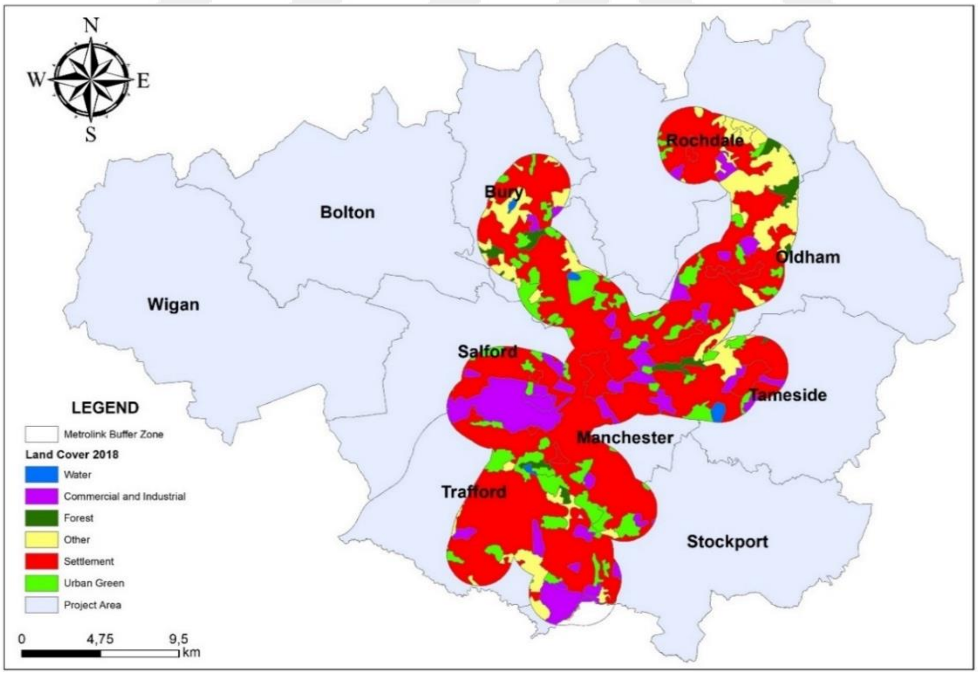


Figure 4.4 Land cover of the buffer zone (2000 m) around the Metrolink LRT in 2018 *(Source: Elaborated by the researcher using ArcGIS software based on 2018 Land Cover data by Copernicus/CORINE, https://land.copernicus.eu/)*

In the buffer zone (2000 m) determined for the impact of Metrolink LRT, a change occurred in land cover between 1990-2018. The change of land cover in the buffer zone by years and its classification according to uses are given in Table 4.1.

Table 4.1 Land cover change in the buffer zone around the Metrolink LRT from 1990 to 2018

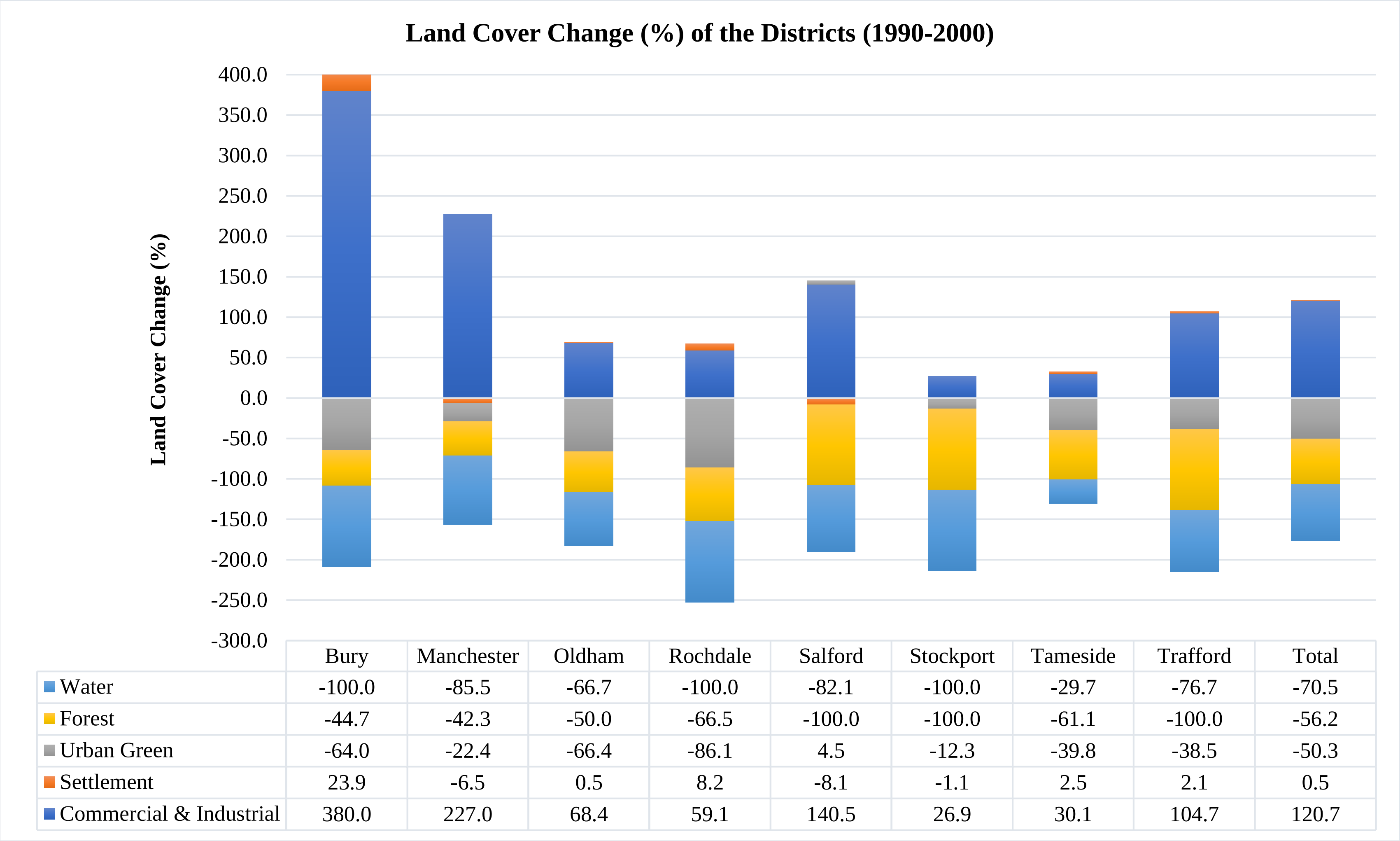
Land Cover	**Area (ha)**						
	1990	**2000**	**Change (%) 1990-2000**	**2012**	**2018**	**Change (%) 2012-2018**	**Change (%) 1990-2018**
Industrial & Commercial	1,346	2,970	120.65	3,951	3,980	0.73	195.69
Forestry	2,032	890	-56.20	665	665	0.00	-67.27
Settlement	21,492	21,593	0.47	21,329	21,405	0.36	-0.40
Urban Green	6,498	3,232	-50.26	3,782	3,713	-1.82	-42.86
Water Body	410	121	-70.49	173	173	0.00	-57.80
Other	1,910	4,882	155.60	3,788	3,752	-0.95	96.44
Total	33,688	33,688	0.00	33,688	33,688	0.00	0.00

(Source: Elaborated by the researcher using land cover data detailed in Chapter 3)

When Table 4.1 is examined, the industrial and commercial areas increased by 195.69%. The other land uses in the total area increased by 96.44% between 1990 and 2018, within the total area of 33,688 hectares. The increase in industrial, commercial and other land uses caused forest areas in Greater Manchester to decrease from 2,032 hectares to 665 hectares, urban green areas from 6,498 hectares to 3,713 hectares and water bodies from 410 hectares to 173 hectares. In the same period, the share of settlement areas within the total area remained almost constant.

4.2.1 Land cover change: 1990-2000

When the period between 1990 and 2000 is examined, it is determined that there is a change in land cover, and land cover change of the districts in the buffer zone (Bury, Manchester, Oldham, Rochdale, Salford, Stockport, Tameside and Trafford) is given in Figure 4.5.



	Bury	Manchester	Oldham	Rochdale	Salford	Stockport	Tameside	Trafford	Total
Water	-100.0	-85.5	-66.7	-100.0	-82.1	-100.0	-29.7	-76.7	-70.5
Forest	-44.7	-42.3	-50.0	-66.5	-100.0	-100.0	-61.1	-100.0	-56.2
Urban Green	-64.0	-22.4	-66.4	-86.1	4.5	-12.3	-39.8	-38.5	-50.3
Settlement	23.9	-6.5	0.5	8.2	-8.1	-1.1	2.5	2.1	0.5
Commercial & Industrial	380.0	227.0	68.4	59.1	140.5	26.9	30.1	104.7	120.7

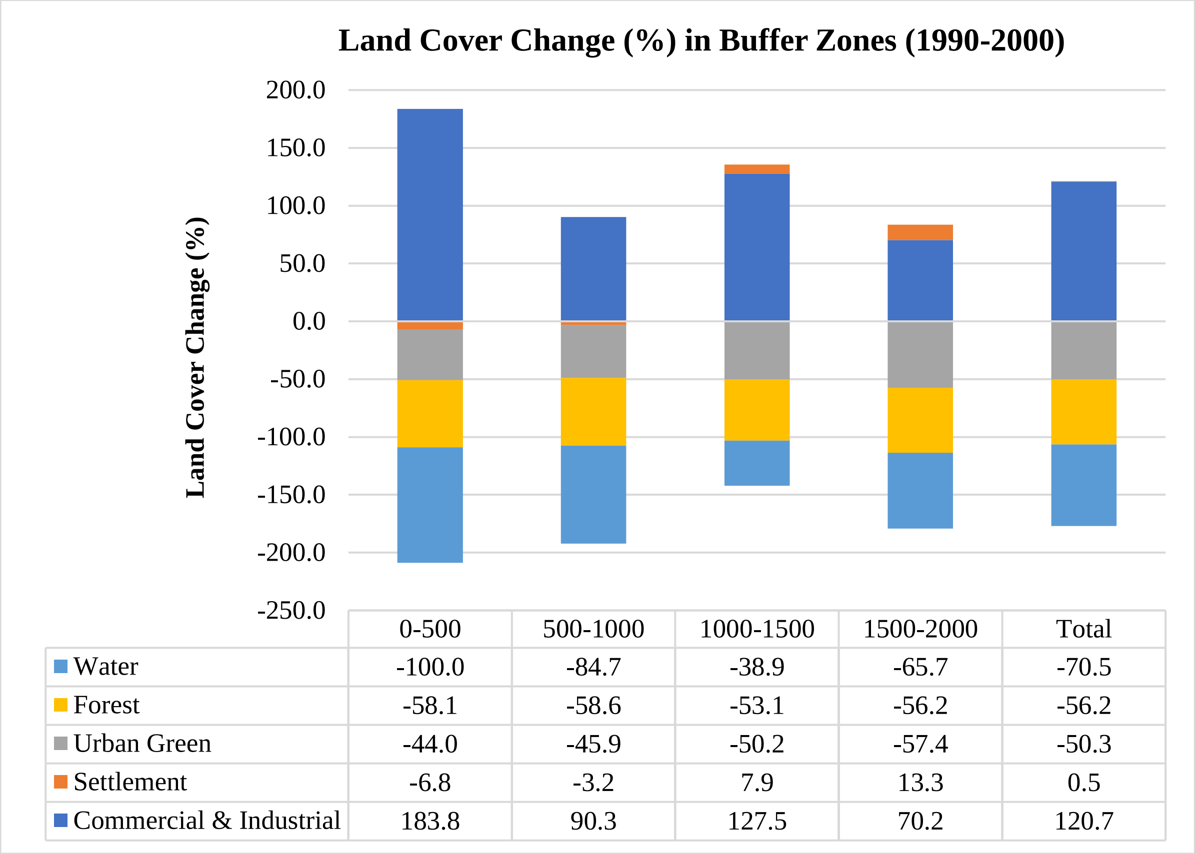
Figure 4.5 The land cover change (%) of the districts in the buffer zone (1990-2000)

When Figure 4.5 is examined, the most significant change in land cover in Greater Manchester is seen in industrial and commercial areas, with an increase of 120.7%. Industrial and commercial areas, which were 1,346 hectares in 1990, reached 2,970 hectares in 2000. The most significant increase is seen in Bury, increasing industrial and commercial areas from 5 hectares in 1990 to 24 hectares in 2000 by 380%. The lowest increase was seen in Stockport with 26.9%.

Settlements in Greater Manchester increased as low as 0.5% from 21,492 hectares to 21,593 hectares, with Bury having the highest incidence with 23.9%. The districts with the most significant decrease in settlement areas were Salford with 8.1% and Manchester with 6.5%.

In addition, there is great environmental damage in this period, and urban green in Greater Manchester decreased by 50.3%, forestry areas by 56.2% and water bodies by 70.5%. Urban green areas, which were 6,498 hectares in 1990, decreased to 3,232 hectares in 2000. The most significant decreases are seen in Rochdale with 86.1% and Oldham with 66.4%. In the same period, forestry areas in Salford, Stockport and Trafford districts and water bodies in Bury, Rochdale and Stockport districts were destroyed with a 100% decrease. Details of the land cover change by Greater Manchester districts between 1990 and 2000 on a size basis are provided in Table A.2 in the appendix.

A change in the land cover is observed in the buffer zones at the distances of 0-500, 500-1000, 1000-1500 and 1500-2000 meters from the LRT line, and this change is given in Figure 4.6.



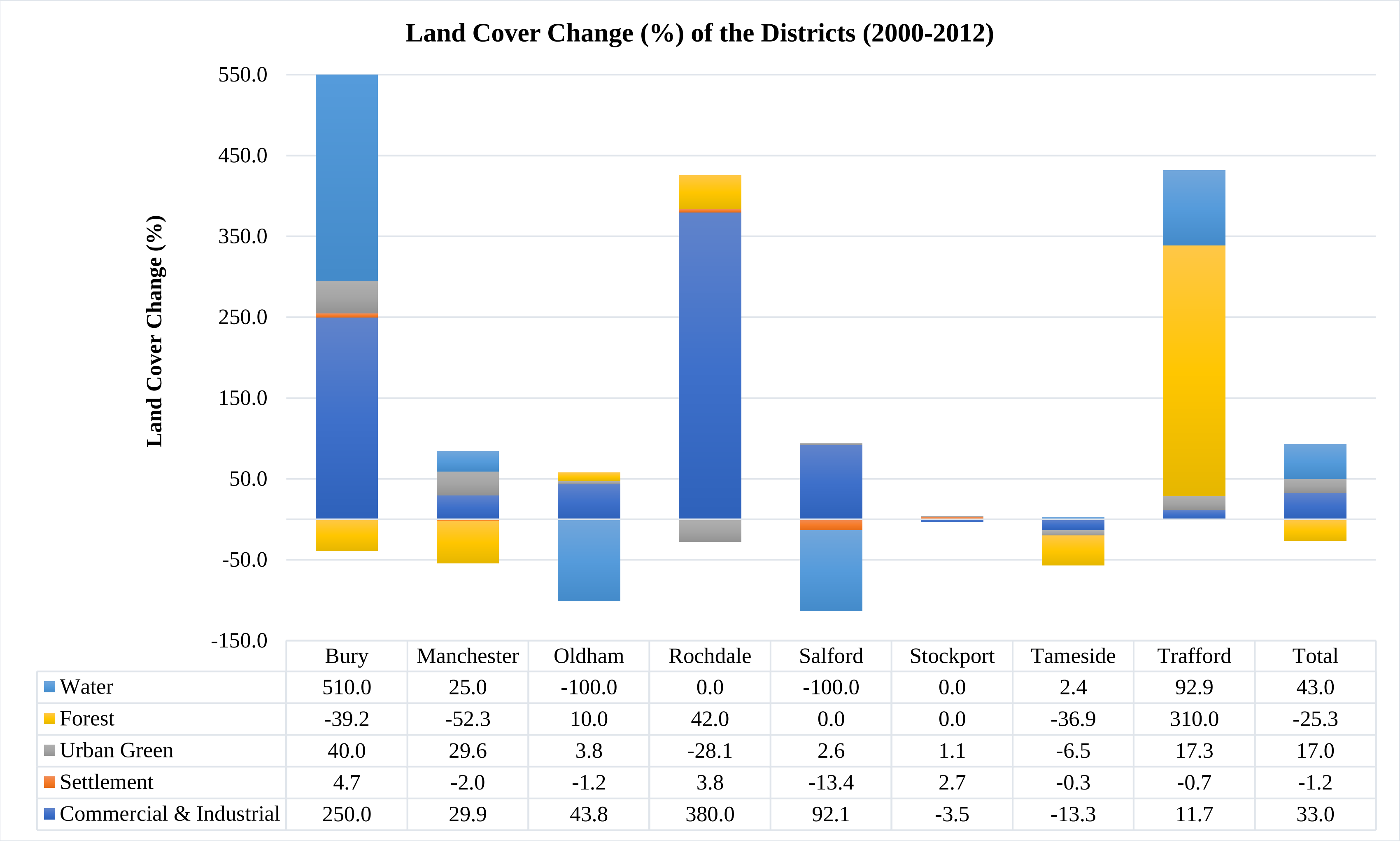
	0-500	500-1000	1000-1500	1500-2000	Total
🟦 Water	-100.0	-84.7	-38.9	-65.7	-70.5
🟨 Forest	-58.1	-58.6	-53.1	-56.2	-56.2
⬜ Urban Green	-44.0	-45.9	-50.2	-57.4	-50.3
🟧 Settlement	-6.8	-3.2	7.9	13.3	0.5
🟦 Commercial & Industrial	183.8	90.3	127.5	70.2	120.7

Figure 4.6 Land cover change (%) in buffer zones (1990-2000)

When Figure 4.6 is examined, it is seen that land cover change increases in the regions with the highest access to the LRT line (0-500 meters). The most significant change in the first 500 meters of the Metrolink LRT line is seen in industrial and commercial areas, with an increase of 183.8%. At the same distance, urban green (44%), forest (58.1%) and water bodies (100%) decreased substantially. In the buffer zone, industrial and commercial areas increase volatilely, while settlement areas decrease up to 1000 meters and then increase. Urban green, forest areas and water bodies along the designated buffer zone have also decreased continuously.

4.2.2 Land cover change: 2000-2012

When the period between 2000-2012 is examined, it has been determined that Metrolink LRT has experienced significant developments with line extensions and accordingly, there has been a change in land cover. The land cover change of the districts in the buffer zone is provided in Figure 4.7.



	Bury	Manchester	Oldham	Rochdale	Salford	Stockport	Tameside	Trafford	Total
■ Water	510.0	25.0	-100.0	0.0	-100.0	0.0	2.4	92.9	43.0
■ Forest	-39.2	-52.3	10.0	42.0	0.0	0.0	-36.9	310.0	-25.3
■ Urban Green	40.0	29.6	3.8	-28.1	2.6	1.1	-6.5	17.3	17.0
■ Settlement	4.7	-2.0	-1.2	3.8	-13.4	2.7	-0.3	-0.7	-1.2
■ Commercial & Industrial	250.0	29.9	43.8	380.0	92.1	-3.5	-13.3	11.7	33.0

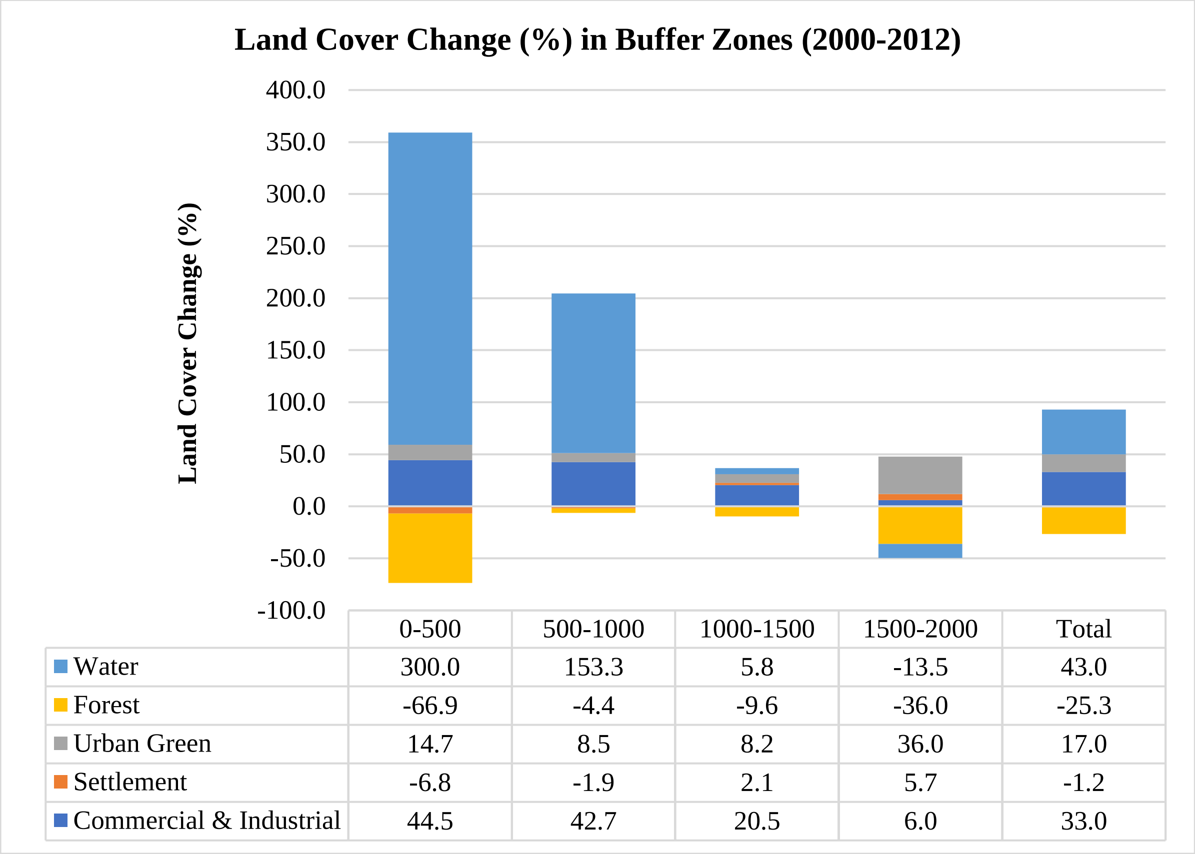
Figure 4.7 The land cover change (%) of the districts in the buffer zone (2000-2012)

When Figure 4.7 is examined, the most significant change in land cover in Greater Manchester is seen in water bodies with an increase of 43% and in industrial and commercial areas with an increase of 33%. Industrial and commercial areas, which were 2,970 hectares in 2000, reached 3,951 hectares in 2012. The most significant increase was observed in the Rochdale district, increasing industrial and commercial areas from 35 hectares in 2000 to 168 hectares in 2012 by 380%. The district with the most significant decrease in industrial and commercial areas is Tameside with 13.3%.

Settlements in Greater Manchester decreased from 21,593 hectares to 21,329 hectares with a 1.2% change. This decrease is most prominent in Salford, decreasing from 1,956 hectares to 1,694 hectares by 13.4%. The districts with an increase in residential areas are Bury with 4.7%, Rochdale with 3.8% and Stockport with 2.7%.

In addition, in this period, unlike the 1990-2000 period, urban green areas increased by 17%, and water bodies increased by 43%. Urban green areas, which were 3,232 hectares in 2000, increased to 3,782 hectares in 2012. The most significant increases in urban green were seen in Bury with 40% and Manchester with 29.6%, while it decreased by 28.1% in Rochdale. In the same period, the most significant increase in forest areas is in Rochdale with 42%, and the most significant decrease is in Manchester with 52.3%. In Oldham and Salford districts, water bodies were destroyed. Details of the land cover change by Greater Manchester districts between 2000 and 2012 on a size basis are provided in Table A.3 in the appendix.

A change in the land cover is observed in the buffer zones at the distances of 0-500, 500-1000, 1000-1500 and 1500-2000 meters from the LRT line, and this change is given in Figure 4.8.



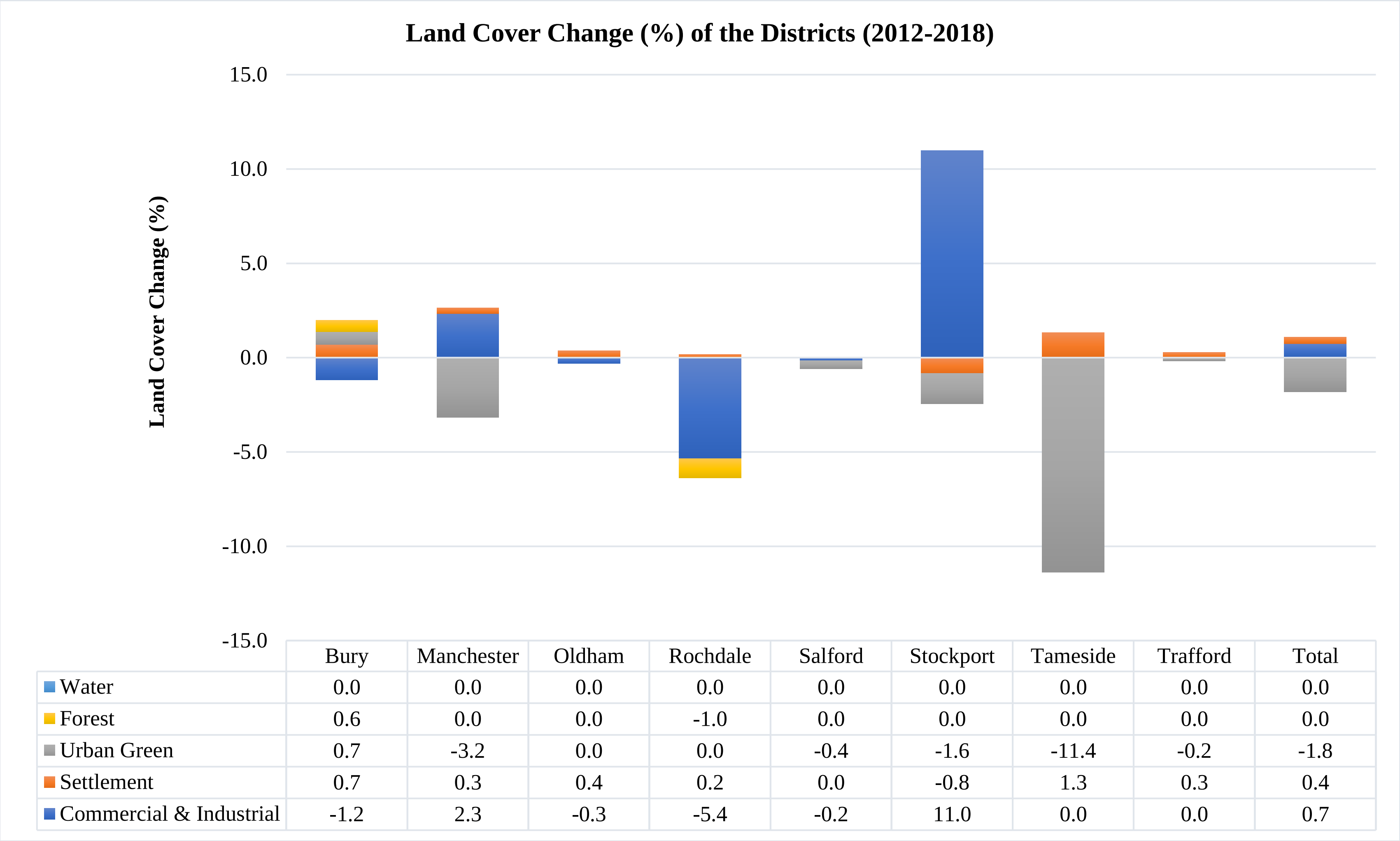
	0-500	500-1000	1000-1500	1500-2000	Total
🟦 Water	300.0	153.3	5.8	-13.5	43.0
🟨 Forest	-66.9	-4.4	-9.6	-36.0	-25.3
⬜ Urban Green	14.7	8.5	8.2	36.0	17.0
🟧 Settlement	-6.8	-1.9	2.1	5.7	-1.2
🟦 Commercial & Industrial	44.5	42.7	20.5	6.0	33.0

Figure 4.8 Land cover change (%) in buffer zones (2000-2012)

When Figure 4.8 is examined, it is seen that land cover change increases in the regions with the highest access to the LRT line. The water bodies in the first 500 meters of the Metrolink LRT line increased significantly by 300%. Similarly, industrial and commercial areas increased by 44.5%, and urban green areas increased by 14.7%. As in the 1990-2000 period, settlement areas (6.8%) and forest areas (66.9%) have decreased in this region. While industrial and commercial areas suppress the distance of 0-1500 meters with high increases, it increases at lower rates at 1500-2000 meters. As in the 1900-2000 period, while the settlement areas decreased to the first 1000 meters, they increased between 1000-2000 meters. Forestry areas along the designated buffer zone have decreased continuously.

4.2.3 Land cover change: 2012-2018

When the period between 2012-2018 is examined, it has been determined that there has been a change in land cover, but this change is not as significant as the previous periods. The land cover change of the districts in the buffer zone is provided in Figure 4.9.



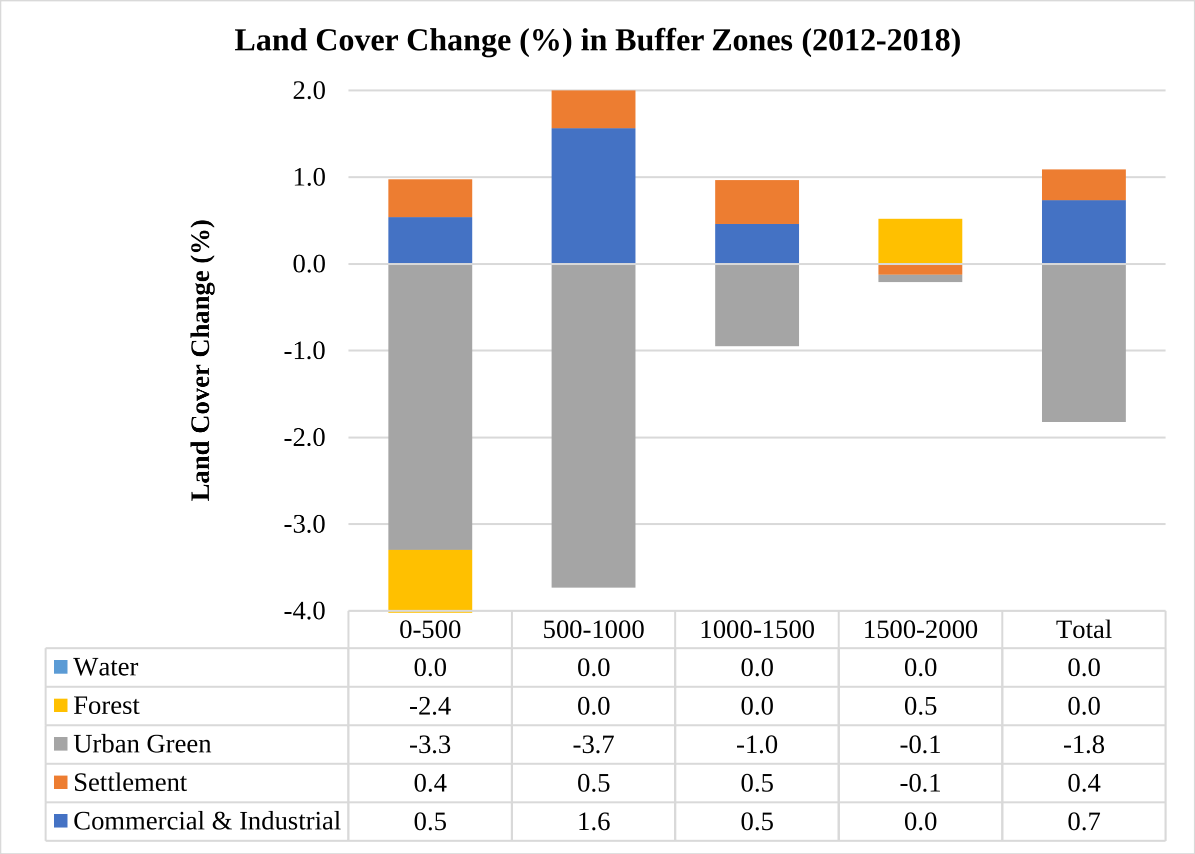
	Bury	Manchester	Oldham	Rochdale	Salford	Stockport	Tameside	Trafford	Total
🟦 Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
🟨 Forest	0.6	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0
⬜ Urban Green	0.7	-3.2	0.0	0.0	-0.4	-1.6	-11.4	-0.2	-1.8
🟧 Settlement	0.7	0.3	0.4	0.2	0.0	-0.8	1.3	0.3	0.4
🟦 Commercial & Industrial	-1.2	2.3	-0.3	-5.4	-0.2	11.0	0.0	0.0	0.7

Figure 4.9 The land cover change (%) of the districts in the buffer zone (2012-2018)

When Figure 4.9 is examined, the most significant change in land cover in Greater Manchester is seen in urban green areas with a decrease of 1.8%. Industrial and commercial areas increased by 0.7% in the same period, while no change was observed in water bodies. The most significant change in industrial and commercial areas, which increased from 3,951 hectares to 3,980 hectares, is in Stockport, increasing 11%. Industrial and commercial areas have decreased in Rochdale (5.4%), Bury (1.2%), Oldham (0.3%) and Salford (0.2%).

Settlements in Greater Manchester increased from 21,329 hectares to 21,405 hectares. The most significant increase is in the Tameside district with 1.3%. In the same period, the most significant decrease in urban green areas is seen in Tameside with 11.4%, while there is no change in the urban green area in Oldham and Rochdale. While no changes were observed in the forestry area in most districts, the size of the water bodies did not change in all of the districts. Details of the land cover change by Greater Manchester districts between 2012 and 2018 on a size basis are provided in Table A.4 in the appendix.

A change in the land cover is observed in the buffer zones at the distances of 0-500, 500-1000, 1000-1500 and 1500-2000 meters from the LRT line, and this change is given in Figure 4.10.



	0-500	500-1000	1000-1500	1500-2000	Total
■ Water	0.0	0.0	0.0	0.0	0.0
■ Forest	-2.4	0.0	0.0	0.5	0.0
■ Urban Green	-3.3	-3.7	-1.0	-0.1	-1.8
■ Settlement	0.4	0.5	0.5	-0.1	0.4
■ Commercial & Industrial	0.5	1.6	0.5	0.0	0.7

Figure 4.10 Land cover change (%) in buffer zones (2012-2018)

When Figure 4.10 is examined, it is seen that land cover change increases in the regions with the highest access to the LRT line. Small increases are observed in industrial and commercial areas and settlement areas at 500 meters. Urban green areas and forestlands have decreased by 3.3% and 2.4%, respectively. Unlike the 1990-2000 and 2000-2012 periods examined within the scope of the study, while the residential areas increased to the first 1500 meters, they decreased between 1500-2000 meters.

4.3 The Impact of Accessibility to Metrolink LRT Stations on Changes in Land Uses (Phase 3)

In order to examine the change in land use around the Metrolink LRT stations, 52 stations built within the scope of phase 3 were determined. In this context, the focus was on 2006, before phase 3 became operational, and 2018, when its long-term effects could be examined.

Land uses in the buffer zone determined in 2006 and 2018 are provided in Figures 4.11 and 4.12.

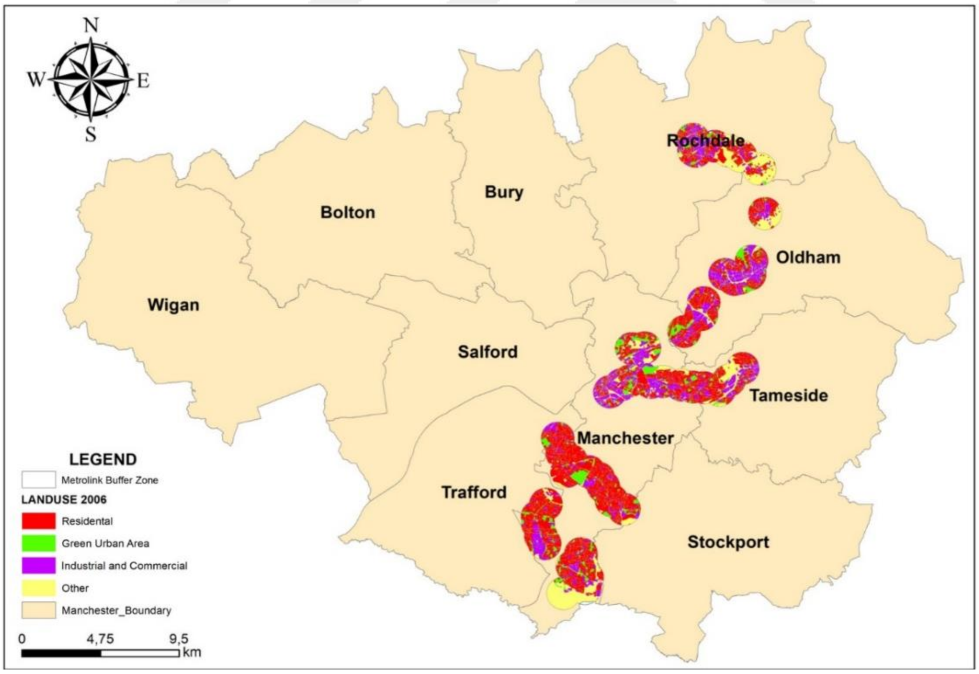


Figure 4.11 Land use of the buffer zone (1000 m) around the Metrolink LRT stations in 2006 *(Source: Elaborated by the researcher using ArcGIS software based on 2006 Land Use data by Copernicus/Urban Atlas, https://land.copernicus.eu/)*

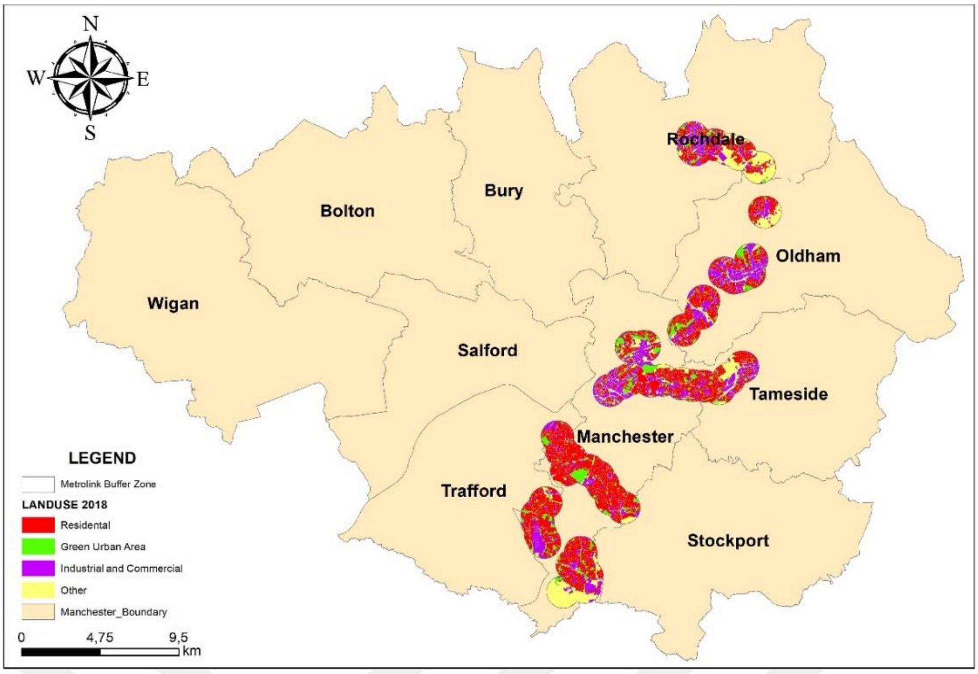


Figure 4.12 Land use of the buffer zone (1000 m) around the Metrolink LRT stations in 2018 *(Source: Elaborated by the researcher using ArcGIS software based on 2018 Land Use data by Copernicus/Urban Atlas, https://land.copernicus.eu/)*

When the change in land use in the determined buffer zone (1000 m) between 2006-2018 is examined, land use in Greater Manchester has changed within the scope of phase 3-line extensions, and the results are given in Table 4.2.

Table 4.2 Land use change in the buffer zone around the Metrolink LRT stations, 2006-2018

Land Use	**Area (ha)**				
	2006	**(%)**	**2018**	**(%)**	**Change (%) 1990-2000**
Industrial & Commercial	1,908	21.00	1,962	21.58	2.83
Residential	4,232	46.55	4,254	46.79	0.52
Urban Green	711	7.82	714	7.85	0.42
Other	2,241	24.64	2,162	23.77	-3.53
Total	9,092	100.00	9,092	100.00	0.00

(Source: Elaborated by the researcher using land-use data detailed in Chapter 3)

When Table 4.2 is examined, industrial and commercial uses, which were 1,908 hectares in 2006, reached 1,962 hectares with the change of 2.83% in the area of 9,092 hectares. Residential areas increased by 0.52%, and urban green areas increased by 0.42%. In contrast, other land uses decreased by 3.53%, from 2,241 hectares to 2,162 hectares.

The change in land use of LRT stations constructed within the scope of phase 3 between 2006-2018 according to buffer zones with different accessibility (high, medium, low, weak) is given in Table 4.3.

Table 4.3 Change in land uses according to buffer zones with different accessibility

	Urban Land Use (ha) 2006-2018							
Land Use	**0-100**		**100-300**		**300-600**		**600-1000**	
	2006	**2018**	**2006**	**2018**	**2006**	**2018**	**2006**	**2018**
Green Urban	12.47	15.69	69.55	69.15	247.62	252.70	617.31	607.19
Industrial and Commercial	49.19	49.85	401.44	408.45	930.62	939.42	1,223.77	1,255.24
Residential	58.55	58.02	560.38	565.50	1,868.46	1,880.90	3,003.02	3,009.84

(Source: Elaborated by the researcher using land-use data detailed in Chapter 3)

When Table 4.3 is examined, the most obvious increase in the highly accessible area (0-100m) is unexpectedly seen in urban green areas with 25.82% and increased from 12.47 hectares to 15.69 hectares. When the change in industrial and commercial areas was examined, a low increase was observed with a change of 1.34%. In the same region, the residential area, which was 58.55 hectares in 2006, decreased by 0.9% to 58.02 hectares.

Industrial and commercial areas have increased slightly by 1.74% as in the highly accessible area in the medium accessible area (100-300m). Similarly, a low increase of 0.91% in residential areas has been determined. On the other hand, urban green areas have reached 69.15 hectares from 69.55 hectares, decreasing 0.57%.

When the change in land use in the low accessible area (300-600m) is examined, an increase is observed in urban green areas, as in highly accessible areas. There is a slight increase of 0.94% in industrial and commercial areas compared to the previous periods. When the residential areas in the same region were examined, an increase was observed in contrast to the highly accessible area.

Industrial and commercial areas have increased by 2.57% in the weak accessibility (600-1000m). Unlike high and low accessible areas, urban green areas decreased by 1.64% in the weak accessible area. When the residential areas in this region are examined, it has increased from 3,003.02 to 3,009.84 hectares with a slight increase.

Changes in land use in the same period were examined according to the districts and given in Table 4.4.

Table 4.4 Change in land uses according to buffer zones with different accessibility and Greater Manchester Districts

Districts	**Land-use**	**Change in land use (%) 2006-2018**			
		0-100	**100-300**	**300-600**	**600-1000**
Manchester (n=36)	Industrial and Commercial	-90.76	57.31	66.18	36.72
	Urban Green Area	-91.06	3.98	-34.51	-35.02
	Residential	8.63	34.06	22.52	45.55
Oldham (n=11)	Industrial and Commercial	-93.69	207.52	182.95	26.36
	Urban Green Area	-96.09	48.24	-24.67	-52.18
	Residential	16.13	-2.05	28.95	31.98
Rochdale (n=7)	Industrial and Commercial	-96.49	1053.60	359.86	48.67
	Urban Green Area	-98.13	-20.99	-58.34	-57.87
	Residential	5.84	58.97	13.89	-10.84
Stockport (n=4)	Industrial and Commercial	0.00	0.00	-96.33	-92.88
	Urban Green Area	0.00	-97.69	-75.84	-43.61
	Residential	0.00	0.00	0.00	14.84
Tameside (n=6)	Industrial and Commercial	0.00	-14.52	-8.98	-33.57
	Urban Green Area	58.82	-28.55	15.99	-30.70
	Residential	0.00	2.48	0.65	3.21
Trafford (n=7)	Industrial and Commercial	0.00	177.14	-71.61	-61.07
	Urban Green Area	-74.42	56.78	15.30	-48.47
	Residential	48.47	48.67	23.20	45.50

(Source: Elaborated by the researcher using land-use data detailed in Chapter 3)

When Table 4.4 is examined, the largest increase in the highly accessible area (0-100m) was seen in urban green areas, causing an increase of 58.82% in Tameside, and residential areas, causing an increase of 48.47% in Trafford. On the other hand, the most significant decreases are seen in urban green areas with 98.13% and industrial and commercial with 96.49% in Rochdale. It has been found that there has been no change in Stockport.

The largest changes in the medium accessible area (100-300m) were observed in industrial and commercial areas with a 1,053.60% increase in Rochdale and with 207.52% increase in Oldham. On the other hand, the most significant decreases in the determined region have been observed in urban green areas. Urban green areas in Stockport have decreased by 97.69% and in Tameside by 28.55%.

A significant increase was seen in industrial and commercial uses in Rochdale (359.86%) and in Oldham (182.95%) in the area with low accessibility (300-600m). When the decrease in the size of land use was examined, it was found that there were decreases in the industrial and commercial uses in Stockport with 96.33% and in Trafford with 71.6%. Unlike high and medium accessible areas, the change in land use in the low accessible area has been observed in many districts.

The most significant change in the weak accessible area (600-1000m) was observed in industrial and commercial areas in Rochdale with an increase of 48.67%, followed by an increase in residential areas with changes of 45.55% in Manchester. The most significant decreases in land use in 2018 compared to 2006 were in the industrial and commercial areas of Stockport (92.88%) and Trafford (61.07%). Land-use change has been observed in all the districts within the buffer zone. The descriptive analysis of the data used in the regression analysis is given in Table 4.5.

Table 4.5 The descriptive analysis of the data used in the regression analysis

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Change in land use	236	.544348	27.5826	-64.54638	65.92795

As given in Table 4.5, the mean of 236 data used in regression analysis is 0.54. In the data set where the standard deviation is 27.58, the minimum value is -64.54, and the maximum value is 65.92. The relationship between the changes in land uses, and buffer zones with different accessibility were examined in the research, and the results of linear regression analysis are given in Table 4.6.

Table 4.6 Linear regression results

	Beta	**t**	**p-Value**	**F**	**p-Value**	**Adj. R^2**
Land Use: reference category = other				15.64	**0.000***	0.2721
Urban Green Area	-6.465083	-1.25	**0.213**			
Industrial and Commercial	11.45658	2.78	**0.006***			
Residential	23.5608	5.56	**0.000***			
Buffer Zone (m): reference category = 100m						
300m	27.55474	4.51	**0.000***			
600m	28.37885	5.46	**0.000***			
1000m	26.56853	5.22	**0.000***			
Constant	-33.12177	-6.36	**0.000***			
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity ➔ p=0,9519						
Jarque-Bera normality test ➔ 1.969 Chi(2) p=0.3737						

(Source: Elaborated by the researcher using STATA software by using the land-use change data produced as a result of spatial analysis)

Linear regression analysis result between change in urban land use and different accessibility levels is as followed:

$$\textit{Change in Land Use} = -33{,}12 - 6.47{*}\ \textit{Urban Green Area} + 11{*}\textit{Industrial and Commercial} + 23.56{*}\textit{Residential} + 27.55{*}\textit{300 Buffer Zone} + 28.38{*}\textit{600 Buffer Zone} + 26.57{*}\textit{1000 Buffer Zone} \tag{4.1}$$

As given in Table 4.6, the model established with the independent variables included in the study was found to be statistically significant (F=15.64: p=0.000). The urban green area land use variable, one of the categorical variables in the model, was found to be statistically insignificant. However, all other variables were found to be statistically significant.

The area change of those within the 300m buffer zone is 27.55 units higher than those without an area change. The area change of those within the 600m buffer zone is 28.38 units higher than those without an area change. The area change of those within the 1000m buffer zone is 26.57 units higher than those without an area change.

The change in industrial and commercial land use is 11.47 units higher than that of non-industrial and commercial. The change in residential land use is 23.56 units higher than that of non-residential. In addition, the R^2 value of the independent variables, which is the explanatory power of the dependent variable, was calculated as 0.27. The independent variables explain 27% of the change in the change value. When the model assumptions were examined, it was found that the errors were normally distributed (Jarque-Bera normality test 1.969 Chi (2) p=0.3737) and that there was no problem of varying variance (Breusch-Pagan / Cook-Weisberg test for heteroskedasticity).

The change value of industrial and commercial land use within the 300m buffer zone is 39.01 (11.46+27.55). The change value of industrial and commercial land use within the 600m buffer zone is 39.83 (11.46+28.37). The change value of industrial and commercial land use within the 1000m buffer zone is 38.03 (11.46+26.57).

The change value of residential land use within the 300m buffer zone is 51.11 (23.56+27.55). The change value of residential land use within the 600m buffer zone is 51.93 (23.56+28.37). The change value of residential land use within the 1000m buffer zone is 50.13 (23.56+26.57).

4.4 Conclusion

In this chapter, the spatial analysis with GIS results on the impact of the Metrolink LRT line on the urban land cover between 1990-2018 and the urban land use of the stations built as part of phase 3 between the years 2006-2018 has been shared. In addition, how the accessibility of Metrolink LRT stations determined according to LUPTAI affects the changes in land uses has been answered by statistical (regression) analysis using Stata. In the next section, the results obtained are critically discussed with the support of the relevant literature.

5. DISCUSSION

5.1 Introduction

This chapter includes the analysis and discussion of the research results shared in Chapter 4. In this context, the impacts of the Metrolink LRT on Greater Manchester and the changes in land use and land cover have been examined with the transit-oriented development (TOD) model. Also, the effect of the accessibility factor on the changes in land uses has been discussed.

5.2 Transit-Oriented Development (TOD) in Greater Manchester?

As presented in the literature review (Chapter 2), the most common definition of TOD is to reach mixed land uses such as commercial, residential and industrial facilities without driving, by public transport or on foot (Renne, 2009; Houston *et al*., 2015; Wood *et al*., 2016). In this sense, TOD aims to locate the land uses and support them with urban planning policies to maximize access to public transport stops/stations.

Pacheco-Raguz (2010) stated that LRT investments are essential for urban transportation, but their impact on the urban area is unclear. He also emphasized that LRT investments can only affect urban development if they significantly affect accessibility in the region. The impact of LRT investments on urban development consists of two stages (Hall and Marshall, 2002). The first stage is the development of the infrastructure in the region and then the revival of economic activities. The second stage is the regulation and continuation of investments with plans and relevant policies such as TOD. Therefore, the impact of Metrolink LRT on urban development in Greater Manchester and the role of the TOD should be examined. In this context, the change in industry and commerce, urban green, residential areas, and environmental elements in the area determined around the Metrolink LRT have been determined. Its change with different accessibility has been explained.

5.2.1 The impact of the Metrolink lines and stations on land use

Between 1990 and 2018, the land cover changed in the buffer zone determined along the Metrolink LRT lines before (1990), during (2000-2012) and after construction (2018). Similar changes were observed in the land uses around the stations determined within the Metrolink phase 3-line extension between 2006-2018. As a result of the line and station analyses, similar impacts were observed in the urban area. In their studies conducted in Minneapolis, Goetz *et al*. (2010) examined the impact of the Hiawatha LRT line on the station and the designated buffer zone and concluded that there were no extensive changes in land use, except for small-scale changes, one year after the completion of the line. In contrast, the Metrolink LRT has caused significant changes in urban land use and land cover. Therefore, the land cover in the designated area appears to have been affected by the completion of Metrolink's phases 1, 2, 3 (3a and 3b) and 2CC, as well as the construction work of the new Trafford line, which is an important step for TOD by accelerating urban development in Greater Manchester.

When the industrial and commercial land uses around the Metrolink LRT line and the station were examined, an increase was detected along the line, compatible with the literature. As with the Metrolink LRT investment, the increase in commercial activities around the LRT shows that the economy is reviving with the production and sale of value-added products in the region (Abdullah *et al*., 2020). When LRT1 in Manila is examined, it is seen that commercial activities in the region have increased after the investment (Pacheco-Raguz, 2010). Similarly, the Houston LRT had a low impact on urban development but caused a significant increase in commercial areas. However, it was still insufficient for TOD as it did not sufficiently encourage mixed land uses (Lee and Sener, 2017).

The impact of the Metrolink LRT on industrial areas is similar to Hiawatha LRT. It has been determined that the change in vacant land and industrial uses in Hiawatha is seen more significant than other uses and generally seen in high-income neighbourhoods (Hurst, 2011). However, since the economic conditions of the neighbourhoods where the change was observed were not considered in this study, no information was given about the change according to the economic status of the neighbourhoods. In contrast, Ma *et al*. (2018), in their study examining the impact of LRT located in Changchun city on urban land uses, concluded that LRT had a negative impact on industrial areas, which decreased after the investment. In this respect, the effects of Changchun city LRT are different from the Metrolink LRT.

Greater Manchester's environmental factors such as forestry, urban green areas, and water bodies decreased significantly during the 1990-2018 period. When the literature is examined, it is seen that the impact of LRT investments on environmental factors has not been adequately examined. In this respect, this study contributes to understanding the impact of LRT investments on environmental factors.

This study determined that the Metrolink LRT did not cause a significant change in residential areas. In this direction, similar results were obtained with the Houston and Manila LRT investments, and no significant change was observed in the high-density residential areas along the LRT line during the 1990-2018 period (Pacheco-Raguz, 2010; Lee and Sener, 2017). However, different results were obtained from other studies. For example, the impact of Changchun city LRT investment on residential areas was greater than the impact on industrial areas (Ma *et al.*, 2018). Similarly, Hiawatha LRT caused an increase in density in residential areas, causing a transition from low density to high density (Hurst, 2011). In this respect, Metrolink LRT shows contradictory results with Changchun city and Hiawatha LRT investments. In this context, Greater Manchester has adopted the TOD approach with Metrolink LRT as it encourages mixed uses around the line and station. However, it is insufficient because the residential areas do not increase significantly around the line and station.

The land cover change observed in the 2012-2018 period was not as significant as in the 1990-2000 and 2000-2012 periods. The reason for this is that districts with phase 3-line extensions have already been built. Indeed, confirming this, Pacheco-Raguz (2010) stated that the complete construction of the area where the LRT line is applied, the already high accessibility before the LRT or the complexity of zoning, land availability and construction reduced the extent of the change in land uses.

5.3 The Role of Accessibility on Land Use Change

Accessibility was defined as the potential for the increased opportunity because of the interaction (Hansen, 1959). Similarly, Dalvi and Martin (1976) stated that the potential created by the benefit of location in reaching a place is accessibility. Therefore, accessibility has potential for land use and urban transport and is extremely necessary to examine their cyclical relationship (Giuliano, 2004). In this study, which examines the effect of accessibility on land uses, Handy and Niemeier's (1997) locational accessibility approach, which measures the attractiveness of a place relative to other places, has been adopted. Therefore, accessibility has been defined by proximity.

In the Metrolink LRT line analysis, the land cover change was examined together with the distance from the LRT line in the periods 1990-2000, 2000-2012 and 2012-2018. In this context, it was concluded that the change in land uses increased in areas with the highest accessibility to the LRT line (0-500 meters). In the highly accessible area, industrial and commercial areas have increased in all periods of Metrolink. While industrial and commercial areas increased up to 1500 meters in the buffer zone, they decreased afterwards. Thus, it is understood that industrial and commercial areas prefer places with high access to public transportation, which destroys environmental factors. On the other hand, residential areas decreased by 1000 meters, as in most Metrolink periods, and preferred the areas with less accessibility.

In the Metrolink LRT station analysis, land-use changes at different accessibility levels (high, medium, low, weak) determined by LUPTAI were examined. In this context, an increase has been detected in industrial and commercial areas at all accessibility levels. The districts with the most significant increase were Oldham and Rochdale, where phase 3 was held. Thus, it can be concluded that the line extensions have increased the accessibility of the northern districts and become a new centre of attraction for industry and commercial uses. Also, industrial and commercial areas have moved from the east of Manchester to the districts to the north. While different changes were observed in the urban green, an increase was observed in residential areas after the medium accessible zone, which meets the housing needs of the rapidly developing industrial and commercial areas north of Manchester.

Regression analysis examining the relationship between accessibility and change in land uses in Greater Manchester shows that change in land uses most occurs in the medium accessible area at 300-600 metres. This shows that increased accessibility to LRT stations increases land-use changes, while less change occurs in the low accessible areas. The most obvious change takes place in a medium accessible area instead of a highly accessible area because residential areas very close to public transportation lose some value due to the negative effects of noise and crowds (Hess and Almeida, 2007).

Different results have been obtained in the literature for the effect of accessibility on land use. Proximity and accessibility to Manila LRT1 did not affect urban land uses (Pacheco-Raguz, 2010). Similarly, no land-use changes were detected during the construction and operation of the METRO Blue Line in Minneapolis, with only minor changes observed in industrial and residential areas during the pre-construction period (Hurst and West, 2014). Contrary to these studies, in the buffer zone determined around the Metrolink LRT stations, the most changed land use has been residential areas. The region where the residential areas have changed significantly was the medium accessible area (300-600), while the region with the least change was the weak accessible area (600-1000). Then, a significant change was detected in the industrial and commercial areas, and the region with the most significant change was in the medium accessible area (300-600), while the least change occurred in the weak accessible area (600-1000).

5.4 Conclusion

In this dissertation, the TOD approach and accessibility have been examined to understand the impacts of Metrolink LRT investments on urban land use. It has been concluded that accelerating change in land uses in areas with the highest access to the Metrolink LRT line is an important step for TOD. In addition, the TOD approach has been adopted in Greater Manchester as it encourages mixed land uses around the line and station. However, it is insufficient as the residential areas have not increased significantly and should be supported by the necessary TOD policies.

6. CONCLUSION

6.1 Main Findings of the Research Objectives

This dissertation aimed to analyse the impact of the Greater Manchester Metrolink light rail transit (LRT) investment on urban land use and the effects of line extensions on the urban land-use change between 1990 and 2018. In line with this aim of the dissertation, two objectives were determined.

The first objective was to understand the impact of the Metrolink LRT on urban land use and land cover, focusing on residential, commercial and industrial, urban green areas, and other land uses. In order to achieve this objective, Metrolink LRT pre-construction (1990), construction (2000 and 2012) and post-construction (2018) land cover data, as well as phase 3 pre-construction (2006) and post-construction (2018) land use data were used. In addition, transport infrastructure data on the Metrolink LRT lines and stations were obtained in different formats (shapefile, OSM, CSV file). Land use data and transportation infrastructure data were overlapped in the Geographical Information Systems (GIS). In spatial analysis, linear and circular buffer analysis tool was used, which helps analysis and visualization by giving fast and objective results to compare land uses in different years, considering the period before and after the Metrolink LRT investment.

According to spatial analysis, it was determined that the Metrolink LRT lines and stations cause changes in the urban area with similar effects. The increase in industrial, commercial and residential areas in the buffer zone has led to the destruction of environmental elements. While the largest changes in land cover were observed during Metrolink's pre-construction and construction period, these changes decreased significantly in the post-construction period. Examining Metrolink's stations built under phase 3, industrial and commercial areas experienced an increase in all accessibility levels and markedly increased in Manchester's northern districts of Rochdale and Oldham. Urban green areas have shown different variations in different accessibility levels. When the settlements are examined, it has increased in the region more than 600 meters from the stations. This can be expressed as the increase in industrial and commercial areas in the highly accessible area prefers the low and less accessible region where the land is more suitable and cheaper to meet the housing needs. In addition, it has been concluded that the completed line extensions accelerated the land cover change in the following periods.

The second objective of the dissertation was to understand the impact of accessibility to the Metrolink LRT on changes in urban land use. In order to achieve this objective, statistical (linear regression) analysis was used to understand the impact of accessibility to the Metrolink LRT stations on changes in urban land use using the enter method in Stata. Regression analysis is very effective in examining the effects of different variables such as different accessibility levels on changes in land use in urban areas where economic activities are carried out. In this context, categorical variables such as the distance (100, 300, 600 and 1000 meters) and the change in urban land use (residential, urban green, industrial and commercial and other) obtained with GIS were analysed.

As a result of the regression analysis, it was concluded that urban green areas were not affected by the change in accessibility, while all other variables were affected. The change in land uses in the buffer zone determined between 300-600 meters is higher than in other buffer zones. Land-use change is lowest in the 600-1000m where accessibility is weak. Thus, it is concluded that the change in land uses accelerates in the region where accessibility to the LRT stations increases. In addition, it has been determined that the change in residential areas in all buffer zones is more significant than the change in industrial and commercial areas. In this context, the most apparent change in the residential areas is seen in the medium accessible zone (300-600m). Similarly, the most significant change in industrial and commercial areas is seen in the medium accessible zone (300-600m).

6.2 Policy Implications

The findings of this research have important policy implications for the urban planning discipline. The significant policy implications of the study are as follows:

- With this study, the impacts of LRT investments on urban areas have been analysed and concluded that areas close to the LRT lines and stations play an essential role in urban development and growth with their accessibility potential and the attraction effect. In this context, urban planners and policymakers should encourage urban development towards public transport and make it available to all people in a way that does not cause gentrification. At this stage, to make the most of the benefits of TOD in the urban area, urban development should be supported by using participatory methods and tools aimed at the interests of the stakeholders and the public in the cities.

- While designing new development areas needed due to rapid growth in cities, urban planners should consider the land use densities in the region, and policies should be developed in this direction. In addition, at the planning stage of urban development, railway transportation and all other transportation modes should be integrated with the urban space by paying attention to spatial relations. In this context, uses such as trade, education and health, which people frequently use for their daily needs, can be located in regions with the highest accessibility and where there is more than one mode of transportation. As a result, the accessibility factor should be considered in urban planning, and the TOD model should be encouraged with complementary policies.

6.3 Recommendations for Further Research

By considering the findings of the dissertation, key recommendations for further research can be summarised as follows:

- This study has examined the changes in land uses/cover (increase-decrease) caused by the Metrolink LRT. By also analysing the land conversion between land uses/covers, it could be understood which uses replace which uses in cities and could give an idea about the new needs in that region and could be used as a tool in urban planning.
- This study mainly used land use/cover change and accessibility variables to analyse the land use impact of Metrolink LRT. Using other variables such as population, socio-economic indicators, etc., could help understand the different impacts on the urban area.
- Also, the diversification of land uses (single and multi-family dwellings, vacant land, etc.) and obtaining more up-to-date building-scale land use data could have helped examine the impacts of LRT on different land uses.

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APPENDICIES

Table A.1 The reclassified land use/cover categories

Legend*	**Data****
Settlement	Continuous Urban Fabric (S.L.:>80%
	Discontinuous Dense/Medium/Low/Very Low-Density Urban Fabric (S.L.: 50%-80%, 30%-50%, 10%-30%, <10%)
	Isolated Structures
Commercial and Industrial	Industrial, Commercial, Public, Military and Private Units
Forest	Forests
Water Body	Wetlands
	Water
Urban Green	Herbaceous Vegetation Associations
	Open Spaces with Little or no Vegetation
	Arable Land (Annual Crops)
	Permanent Crops
	Pastures
	Complex and Mixed Cultivation Patterns
	Orchards at the Fringe of Urban Classes
	Green Urban Areas
	Sports and Leisure Facilities
Other	Fast Transit Roads and Associated Land
	Other Roads and Associated Land
	Railways and Associated land
	Port Areas
	Airports
	Mineral Extraction and Dump Sites
	Construction Sites
	Land without Current Use

(Source: The researcher elaborated on the *land use and land cover data collected from EDINA Environment Digimap Service, Copernicus/CORINE (CLC), Copernicus/Urban Atlas)*

*The legend used in this research is based on Corine Land Cover Classes.

**This is the legend of the data; not all legend items are expected to be suitable for Greater Manchester.

Table A.2 Land cover change by districts of Greater Manchester (1990-2000)

	Land Cover (ha)														
Districts	**Commercial & Industrial**			**Settlement**			**Urban Green**			**Forest**			**Water**		
	1990	**2000**	**Change (%)**	**1990**	**2000**	**Change (%)**	**1990**	**2000**	**Change (%)**	**1990**	**2000**	**Change (%)**	**1990**	**2000**	**Change (%)**
Bury	5	24	380.0	2,026	2,511	23.9	1,160	418	-64.0	476	263	-44.7	75	0	-100.0
Manchester	322	1,053	227.0	6,990	6,538	-6.5	1,408	1,092	-22.4	577	333	-42.3	55	8	-85.5
Oldham	133	224	68.4	3,024	3,038	0.5	1,315	442	-66.4	320	160	-50.0	18	6	-66.7
Rochdale	22	35	59.1	1,491	1,613	8.2	997	139	-86.1	206	69	-66.5	21	0	-100.0
Salford	131	315	140.5	2,128	1,956	-8.1	222	232	4.5	67	0	-100.0	56	10	-82.1
Stockport	67	85	26.9	700	692	-1.1	211	185	-12.3	73	0	-100.0	7	0	-100.0
Tameside	173	225	30.1	1,540	1,578	2.5	359	216	-39.8	167	65	-61.1	118	83	-29.7
Trafford	493	1,009	104.7	3,593	3,667	2.1	826	508	-38.5	146	0	-100.0	60	14	-76.7
Total	**1,346**	**2,970**	**120.7**	**21,492**	**21,593**	**0.5**	**6,498**	**3,232**	**-50.3**	**2,032**	**890**	**-56.2**	**410**	**121**	**-70.5**

(Source: Elaborated by the researcher using land-use data detailed in Chapter 3)

Table A.3 Land cover change by districts of Greater Manchester (2000-2012)

Districts	Land Cover (ha)														
	Commercial & Industrial			**Settlement**			**Urban Green**			**Forest**			**Water**		
	2000	**2012**	**Change (%)**	**2000**	**2012**	**Change (%)**	**2000**	**2012**	**Change (%)**	**2000**	**2012**	**Change (%)**	**2000**	**2012**	**Change (%)**
Bury	24	84	250.0	2,511	2,629	4.7	418	585	40.0	263	160	-39.2	0	51	0.0
Manchester	1,053	1,368	29.9	6,538	6,406	-2.0	1,092	1,415	29.6	333	159	-52.3	8	10	25.0
Oldham	224	322	43.8	3,038	3,002	-1.2	442	459	3.8	160	176	10.0	6	0	-100.0
Rochdale	35	168	380.0	1,613	1,674	3.8	139	100	-28.1	69	98	42.0	0	0	0.0
Salford	315	605	92.1	1,956	1,694	-13.4	232	238	2.6	0	0	0.0	10	0	-100.0
Stockport	85	82	-3.5	692	711	2.7	185	187	1.1	0	0	0.0	0	0	0.0
Tameside	225	195	-13.3	1,578	1,573	-0.3	216	202	-6.5	65	41	-36.9	83	85	2.4
Trafford	1,009	1,127	11.7	3,667	3,640	-0.7	508	596	17.3	0	31	0.0	14	27	92.9
Total	**2,970**	**3,951**	**33.0**	**21,593**	**21,329**	**-1.2**	**3,232**	**3,782**	**17.0**	**890**	**665**	**-25.3**	**121**	**173**	**43.0**

(Source: Elaborated by the researcher using land-use data detailed in Chapter 3)

Table A.4 Land cover change by districts of Greater Manchester (2012-2018)

	Land Cover (ha)														
	Commercial & Industrial			**Settlement**			**Urban Green**			**Forest**			**Water**		
Districts	**2012**	**2018**	**Change (%)**	**2012**	**2018**	**Change (%)**	**2012**	**2018**	**Change (%)**	**2012**	**2018**	**Change (%)**	**2012**	**2018**	**Change (%)**
Bury	84	83	-1.2	2,629	2,647	0.7	585	589	0.7	160	161	0.6	51	51	0.0
Manchester	1,368	1,400	2.3	6,406	6,425	0.3	1,415	1,370	-3.2	159	159	0.0	10	10	0.0
Oldham	322	321	-0.3	3,002	3,013	0.4	459	459	0.0	176	176	0.0	0	0	0.0
Rochdale	168	159	-5.4	1,674	1,677	0.2	100	100	0.0	98	97	-1.0	0	0	0.0
Salford	605	604	-0.2	1,694	1,694	0.0	238	237	-0.4	0	0	0.0	0	0	0.0
Stockport	82	91	11.0	711	705	-0.8	187	184	-1.6	0	0	0.0	0	0	0.0
Tameside	195	195	0.0	1,573	1,594	1.3	202	179	-11.4	41	41	0.0	85	85	0.0
Trafford	1,127	1,127	0.0	3,640	3,650	0.3	596	595	-0.2	31	31	0.0	27	27	0.0
Total	**3,951**	**3,980**	**0.7**	**21,329**	**21,405**	**0.4**	**3,782**	**3,713**	**-1.8**	**665**	**665**	**0.0**	**173**	**173**	**0.0**

(Source: Elaborated by the researcher using land-use data detailed in Chapter 3