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Thematic paper: Earth Observation for Smart City and Smart Region

GEOSCAPE

Effects of Transport Corridor Advancement on Agglomeration and Industrial Relocation – Dallas Fort Worth (US) case study

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Abstract

Cities serve as hubs for various activities that necessitate comprehensive transportation connectivity. This study examines the decadal urban agglomeration patterns from 2001 to 2020 and critically assesses the relationship between freeway developments, industrial relocation, and population density in the DFW (Dallas Fort Worth) metropolitan area. Landsat satellite imageries, US census, and open-source GIS datasets have been utilized in the study. The Maximum Likelihood Classification (MLC) algorithm helped generate the vector database, using which Land Use/Land Cover (LULC) variations were assessed. The calculated overall accuracies of the classified images for 2001, 2011, and 2020 were 93.12%, 91.87%, and 93.12%, respectively. Eventually, buffer generation techniques and summary statistics helped detect potential boom hotspots. Our results indicate that the highway advancement project lures industries, leading to population migration. The LULC variations suggest that the increase in highway infrastructure resulted in a surge in built-up and a decrease in open spaces in District-3 of DFW. From our study, we find that 79.16% of old industries are located near old freeways, while 78.84% of new industries are located near new freeways. Further, our industrial area to road area comparison clearly shows that industrial relocation was driven by transportation advancements over time. Our results also confirm that this relocation of industries fostered a massive population influx during the following decades.

Highlights for public administration, management and planning:

- LULC maps show significant urban advancement in the selected transportation corridor from 2001 to 2020. The built-up area sharply increased from 2001 to 2011.
- 79.16% of old industries are located near old freeways, while 78.84% of new industries are located near new freeways.
- Relocation of industries near transportation corridors fostered a massive population influx in the study area during the following decades; likewise, industrial relocation followed the pattern of transportation advancements.
- Scholars in developing countries can rely on freely available software packages and satellite imagery for data mining and analyzing urban planning issues when Census or any other official survey-based GIS files are challenging to obtain.

Keywords

Urban agglomeration, Transportation, LULC, Buffer analysis, GIS

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1 Introduction

Rapid population development and urbanization have resulted in an ever-increasing demand for travel in major cities around the world in recent decades, creating considerable challenges to urban transportation systems (Diao et al. 2021). Cities rely on transit to stay afloat; hence, the transportation system is the city's lifeblood (Vuchic 1981).The transportation network is a complex system (Lu & Tang 2004). The growth of the transportation system can be explained in terms of the city's socioeconomic development and the region's geographical location (AlQuhtani & Anjomani 2021). The four components of the urban transportation network system are the facility network, route network, organization network, and demand network. Human contact in social and economic activities, as well as urban architecture, is dependent on entangled networks. The traffic nodes form a facility network, the traffic lines form a route network, and the combination of nodes and lines forms an organization network in the context of the urban transportation network, which includes an urban road network, an urban public transportation network, an urban external transportation network, and passenger and cargo transportation hubs (Jia et al. 2019).

Transportation infrastructure advancements and innovation are closely related to transportation costs, impacting the volume and pattern of commerce, industrial structure, and factor pricing across the region. One of the instant aftereffects of highway expansion is corridor development (Dincer et al. 2019). As a highway advancement project is approved, industries aim to relocate to cheaper agricultural properties, resulting in the steady transformation of rural areas into industrial/residential/suburban plots (Thünen 1826). Property prices decline with an increase in distance from the key commercial landuses (Bluestone et al. 2008). Also, localities near the transit corridors develop rapidly, owing to which estate cost hikes with immediacy to transport corridors (Clark 1951; Newling 1969; McCann 2013).

Land occupancy is in the direction of flourishing commerce throughout time, according to the sector replica. This model split land uses into Central Business Districts, which housed poor residents, an industrial unit, which housed manufacturing enterprises, and high, medium, and low-income residential zones, which housed individuals from various socioeconomic classes (Hartshorn et al. 1992). Industries began to relocate near transit corridors as a result of the creation of a highway network, drawing people to the newly created infrastructure and raising land prices along the corridors. Marshallian Externalities state that expansion of an area is a direct cause of industrialized establishments, leading to a snowball effect (Fujita 2010). Entrepreneurs look for probable areas to reposition the industries in the optimism of plummeting extreme shipment expenses, thereby preferring an area near the vicinity of well-advanced transit systems, which eventually nurtures local advancement near the conveyance link nominated to reposition the businesses (Chapman & Walker 1991).

Our study intends to detect decadal modifications in Land Use/ Land Cover (LULC) with decadal expansion in highway infrastructure within the study area. By employing Remote Sensing and Geographic Information System (GIS) techniques, we establish a link between highway infrastructure projects, relocation of industrial sectors, and population influx in a specific area. Our study also tries to highlight the application of Remote Sensing and Geographic Information Systems in Urban and Regional Planning.

2 Literature Review

Cities have been the engine of progress, creativity, and commerce since civilization. Cities currently shelter more than half of the world's population and play a significant role in bringing people together to boost productivity (Glaeser 2011). In the literature, the evolution of spatial economics emphasizes the types of economic activity that take place, and the impact of geographical variation associated with prices and costs has been studied (Alonso 1960; Straszheim 1975; Fujita 2010). Von Thünen's (1826) classic book "The Isolated State" laid the foundation of spatial economics. It also represents the earliest and most ambitious attempt to establish a generic location theory. Fujita (2010) presented an evolution from Von Thünen (1826)'s locational theory to New Economic Geography (NEG) (Fujita & Mori 2005) with a focus on the development of general local theory.

Earle Draper, one of the earliest city planners in the southeastern United States, introduced the term sprawl in 1937 (Black 1996). The past few decades have seen an increasing trend toward "edge cities," with various job centers dispersed throughout many metropolitan areas, while residential expansion and suburbanization consolidated during the twentieth century (Ding & Bingham 2000, p.838). Edge cities are typically low-density employment zones that follow low-density suburbanization (Glaeser & Kahn 2003). The establishment of edge cities or decentralized employment nodes presents efficiency and equality concerns and can be evaluated against the potential for lost agglomeration possibilities in the metropolitan core. Edge cities are low-density residential areas that give birth to business operations. The monocentric city model

(Alonso 1964) describes urban spatial characteristics as the result of a trade-off between commuting costs and land rents. The model reflects the basic notion that downtown real estate is much more expensive than comparable land in the suburbs, but it does not provide significant insight into the development of the urban landscape's microstructure (Huang 1996).

While some studies have concentrated on patterns of dense employment subsectors on the fringes of cities (Brueckner 1979; Glaeser & Kahn 2001), others have investigated patterns of dense employment subsectors within cities. Edge cities pose challenges for urban pattern models based on transportation or sorting. Their growing empirical importance has prompted the development of alternative polycentric city models that endogenize the formation of employment centers outside of the central business district (Brueckner 1979; Henderson & Mitra 1996; Anas et al. 1998).

The concept of Marshallian external economies has been explained as scale economies due to the agglomeration of economic activities. Abdel-Rahman and Fujita (1990) compared a monopolistic competition method to the study of city size to the usual approach owing to external economies in their research. Urban land use and transport are closely interlinked. The spatial dispersion of human activities creates the need for travel, and good transport is the underlying principle of transport analysis and forecasting. A huge amount of literature is available that examines the development of cities and attempts to link the transport and land use interactions (Webster et al. 1988; Martínez 1995; Wegener & Fürst 2004; Ding 2019). The gravity model was the first spatial interaction model, later replaced by statistical mechanics and information theory for spatial behavior (Erlander & Stewart 1990). Technical theories like urban mobility systems are one of the most popular approaches to addressing this two-way interaction of land use and transportation in metropolitan regions (Gakenheimer 1999; Liu et al. 2009; Tsay & Herrmann 2013; Ceder 2021), economic theories based on cities as markets (Williamson 1995; Henderson & Wang 2007; Seale 2016; Baum-Snow et al. 2020), and social theories emphasis society and urban space (Gotham 2000; Bretagnolle et al. 2002; Musterd 2006; Gössling et al. 2016).

3 Research aims and questions

Researchers in the USA have contributed a lot to urban planning literature. The credit partly goes to a massive robust databases prepared by several government agencies like the United States Census Bureau, Bureau of Transportation Statistics, etc. Sadly, researchers in under-developed nations do not have such an advantage; thus, informing urban planning theory and research in the context of these countries becomes extremely difficult (Anderson et al. 1996; Jenks et al. 2000; Ewing & Rong 2008; Cervero 2013). This study has relied on a minimal survey and gathered data for achieving its objectives and informing its readers. Thus, the study's main contribution is to inform planners in developing nations about adopting robust methods of generating spatial data from satellite imagery. Adopting this approach will help them bridge the prevalent data barriers and contribute significant research to the urban planning field in the context of developing nations (Glaeser 2011). Further, very few scholars have performed automated feature extraction of objects like roads using satellite images. However, such studies have extensively relied on high-resolution satellite images and expensive software packages like e-cognition developer and many others. Through the channel of our study, we inform that freely available satellite images (like Landsat) and free software packages (like SNAP) help perform such tasks as well. Thus, adopting freely available data and software like those used in this study will help take general research to the next level by allowing users of different disciplines to learn the abilities of Remote Sensing and GIS software platforms and use them for common applications in their respective fields. Keeping the reviewed literature and the targeted purpose of study, we pose the following research question for investigation:

- How did the study area's urban dynamics change during the two decades, i.e., 2001−2020?
- How does transportation infrastructure development impact the locational choices of industries and people?
- How effective are semi-automated image classification techniques in answering the above research questions? How effective are freely available software packages and free satellite images in answering these research questions?

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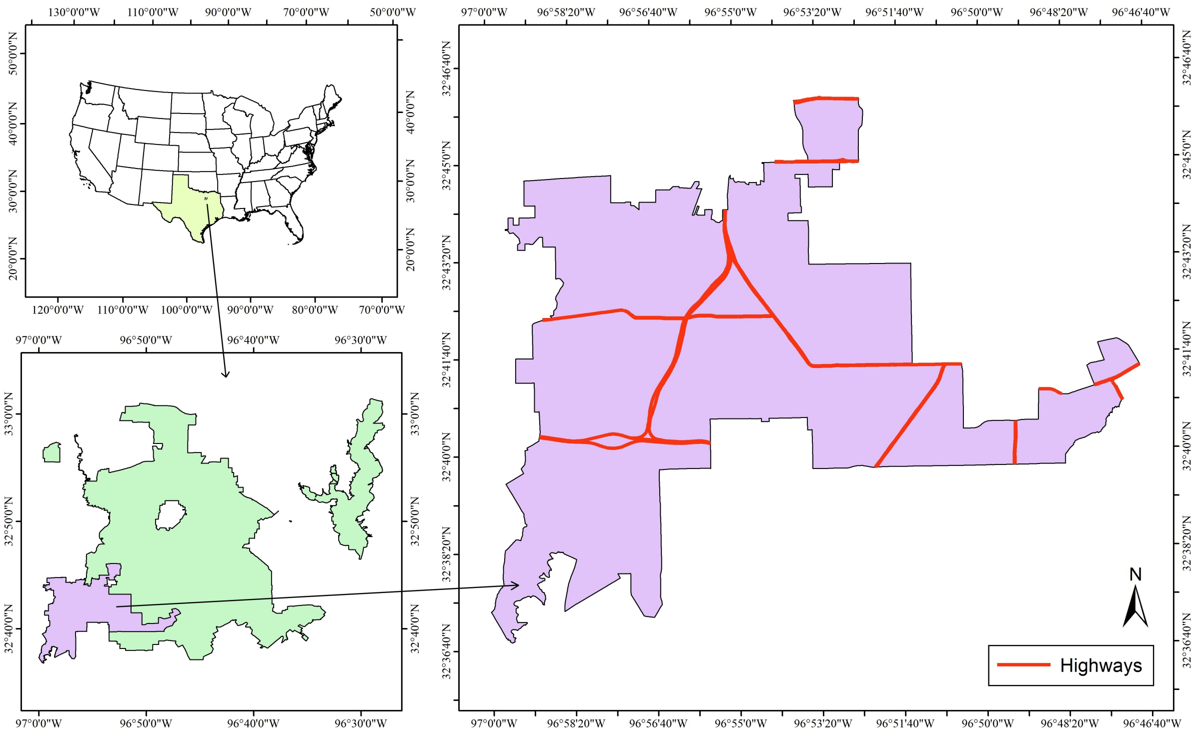

Fig. 1 Study Area

4 Data and methods

4.1 Study Area

The study area selected for the research was City Council District-3 of Dallas, illustrated in Fig. 1. The motivation behind selecting this region was because this district has expanded freshly, with freshly authorized transportation infrastructure projects; there will be a more likely chance of industrial relocation in that area. Thus, this district was deemed to be the best location for the study.

4.2 Data Employed

The cartographic boundary for the 2001 Census Tract was gathered from the US Census Bureau's MAF/TIGER geographic database (US Census Bureau 2001). The industry point shapefile containing the information on the specific type of industries and their years of establishment was gathered from DFW's local MPO, North Central Texas Council of Government (NCTCOG)'s Open Data Portal, which is called the Regional Data Center. Table 1 informs about the details of various satellite images used for performing the LULC classification within the study area.

4.3 Methodology

The methodology employed in the study is depicted in Fig. 2. The Landsat series data (Landsat 4-5 TM for 2001 and 2011, Landsat 8 OLI for 2020) was downloaded from Earth Explorer. The Maximum Likelihood Classification (MLC) algorithm helped classify the satellite images using SNAP. MLC compensates for the over-classification of image objects

Table 1 Details about the satellite images used during the study

Sl. No.	Sensor Name	Imagery ID	Acquisition Date
1.	Landsat 8 OLI	LC08_L1TP_027037_20201005_20201015_01_T1	5th October, 2020
2.	Landsat 4-5 TM	LT05_L1TP_027037_20110810_20160831_01_T1	10th August, 2011
3.	Landsat 4-5 TM	LT05_L1TP_027037_20010424_20200906_02_T1	24th April, 2001

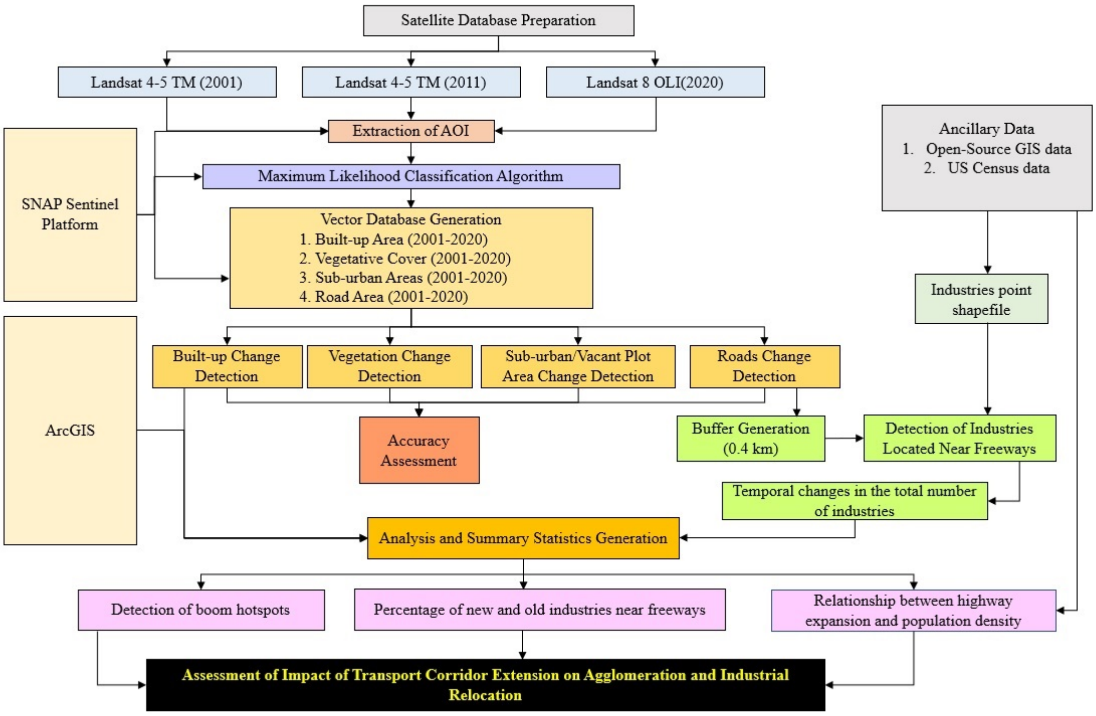

Fig. 2 Methodology

highly represented in the training data and other classes (Hagner & Reese 2007). For executing the classification, detection, and training, several testers were chosen for every class, i.e., built-up, vegetation, suburban regions, and roads. Then MLC helped retain the object information in a classified image (Rana & Kharel 2019). In this study, we combine the open spaces and suburban areas into one component (suburban regions) to account for the under-classification of the satellite images. Subsequently, change detection examinations were carried out for the entire area to foresee the overall variations in land cover.

The accuracy of the classified images was assessed by employing 160 testing sites obtained from Google Earth's archive of historical images. This archive helps historians and urban planners reconstruct the rise and fall of cities, communities, and individual structures in the recent past. Using this module of the Google Earth application, we may measure historical LULC changes (Myers 2010). Using Google Earth's historical time slider, which manages the presentation of historical imaging files, we can evaluate the progression of time at ancient sites; however, this module of the Google Earth application has been unexplored yet (Luo et al. 2018).

The following equations helped evaluate the accuracy of the classified images:

$$User\ Accuracy\ (UA) = \frac{CCP}{TCP} \cdot 100 \quad (1)$$

$$Producer\ Accuracy\ (PA) = \frac{CCP}{TRP} \cdot 100 \quad (2)$$

$$Overall\ Accuracy\ (OA) = \frac{CCDP}{TS} \cdot 100 \quad (3)$$

$$\kappa = \frac{(TS \cdot TCS) - \sum(CT \cdot RT)}{TS^2 - \sum(CT \cdot RT)} \quad (4)$$

Here, CCP = Correctly Classified Pixels in each category; TCP = Total Classified Pixels in that category; TRP = Total Reference Pixels in that category; CCPD = Correctly Classified Pixels (Diagonal); TS = Total Sample; TCS = Total Correctly Classified Samples; CT = Column Total; RT = Row Total; κ= Kappa Coefficient.

Next, the built-up layer was overlayed along with the transportation network shapefiles, and summary statistics were calculated which helped locate areas where high built-up variations were observed within the study area during the time frame of 2001 to 2020. We assume that all roads built before the year 2000 as old and those constructed after 2000 as new roads. Because a smaller buffer zone suggests a more focused influence and helps study road characteristics by concentrating on local land usage, estimating the tally of individuals,

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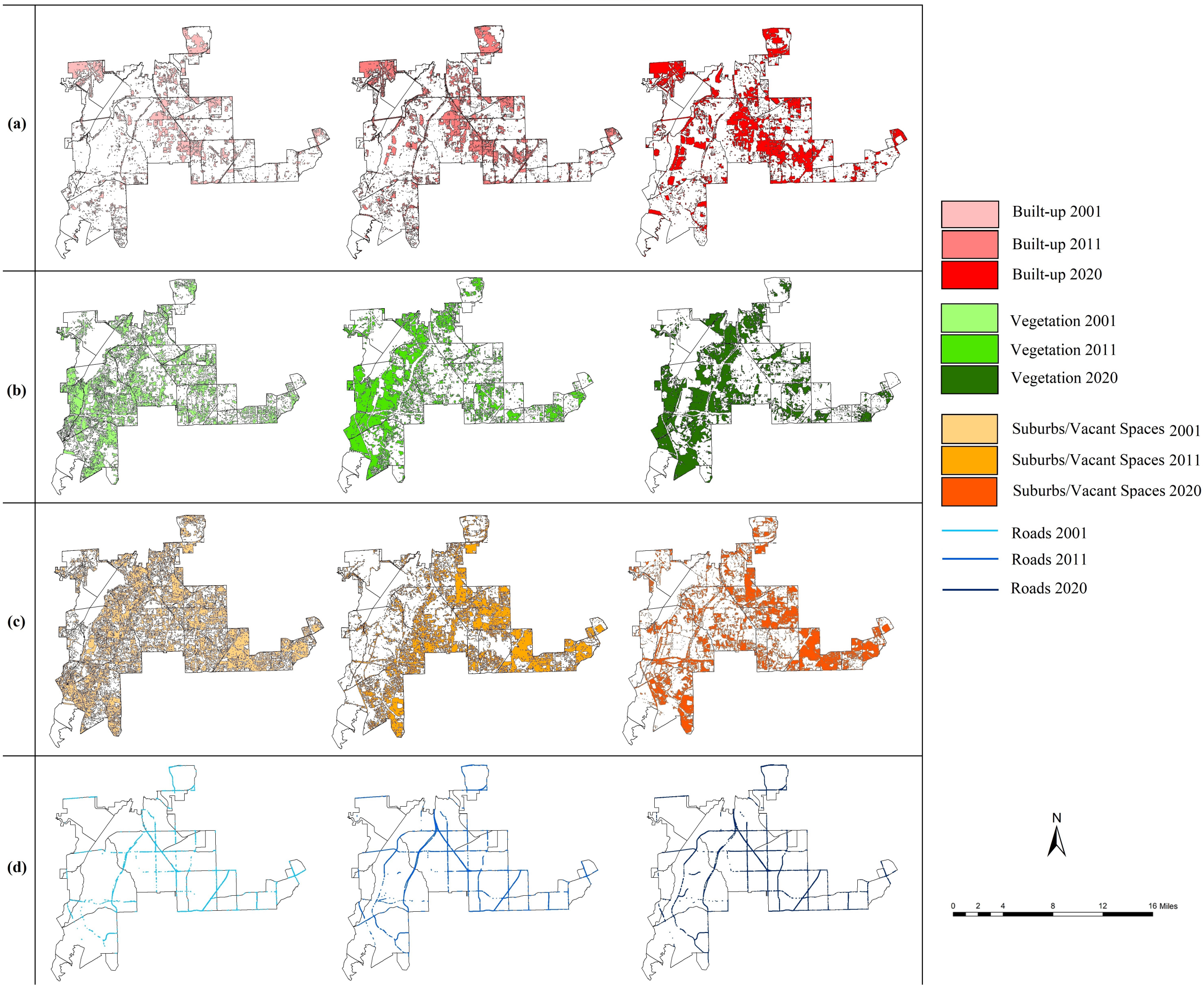

Fig. 3 Change Detection Study (2001−2020)

households, jobs, industries, and other aspects inside a 0.4 km (0.25 mi) buffer zone of a stop location is reasonable (Xia et al. 1999). A study on Oregon's Bus Rapid Transportation (BRT) aimed at determining investments drawn to transit and transportation investments found a higher job/industrial growth within 0.25 miles of BRT stations compared to other areas (Nelson et al. 2013). Likewise, based on these studies, we assume a radial distance of 0.4km buffer around the highway to ensure that all industrial clusters located close to freeways are detected accurately. According, we create a buffer of 0.4km around the transportation network using a buffer analysis tool to detect industries relocated within a radius of 0.4km from the freeways. Eventually, summary statistics helped quantify the total area occupied by industries and freeways; this helped derive the plot between the total area occupied by relocated industries and the total freeway area. The booming built-up was calculated by comparing the increase/decrease in the built-up area within each census tract to the increase/decrease in the road area for that census tract for the three decades. The census tracts with the highest built-up recorded within three decades had the highest booming built-up and vice-versa.

5 Result and Discussion

Change detection analysis was conducted for District 3 of DFW using ML classifiers. Part (a) in Fig. 3 depicts the built-up change (2001−2020), Part (b) the changes in vegetation cover (2001−2020), Fig. 3(c) depicts suburban/vacant plot changes (2001-2020), and Fig. 3(d) depicts the changes in road networks (2001−2020) in District-3 of DFW.

The substantial increase in highway infrastructure in District 3 of the DFW area resulted in a considerable surge in built-up areas and a decrease in suburban/vacant plots. Fig. 4 depicts LULC variations in District 3 of the DFW metropolitan region over the last two decades. The results il-

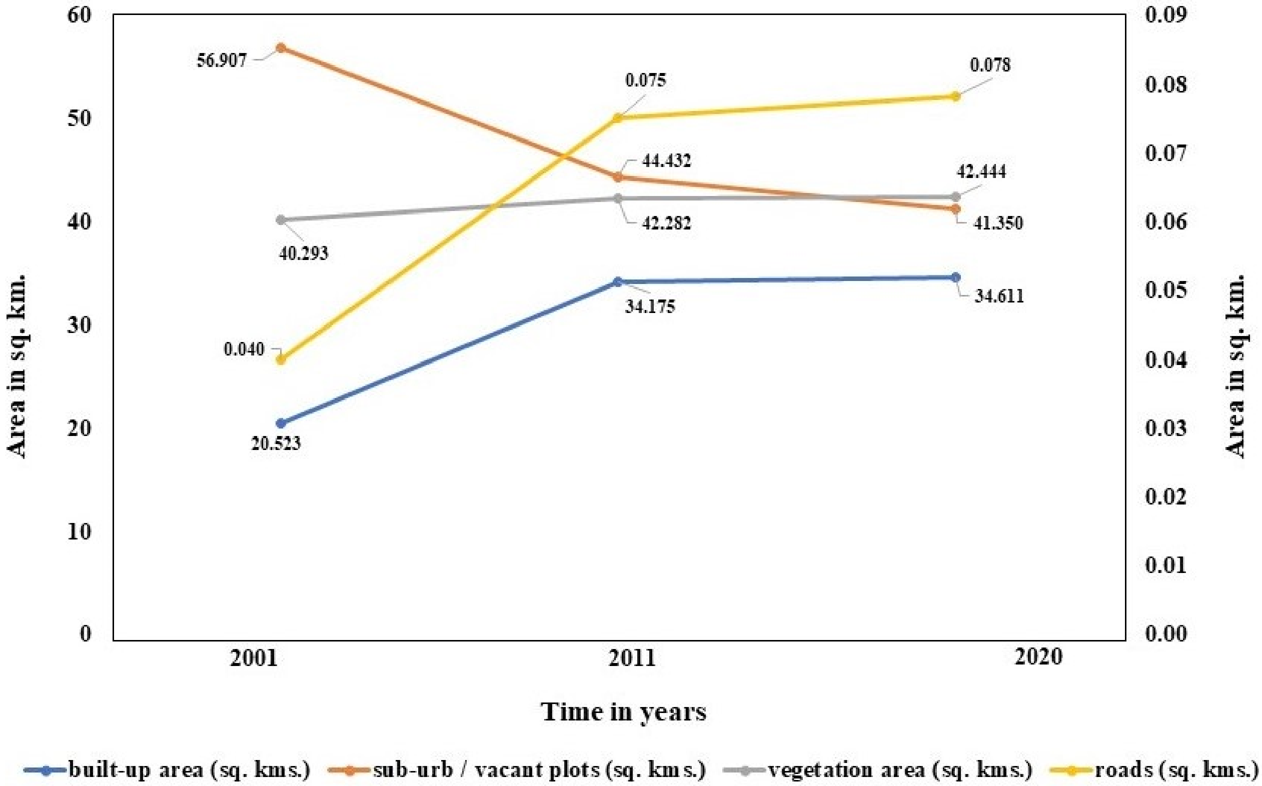

Fig. 4 LULC variations in District 3 of DFW

Table 2 Confusion Matrix

Time	Class	Built-up	Vegetation	Suburb Open Space	Road	(User)	UA
2001	Built-up	37	1	1	1	40	92.5
	Vegetation	0	37	3	0	40	92.5
	Suburb Open Space	0	2	38	0	40	95
	Road	2	0	1	37	40	92.5
	(Producer)	39	40	43	38	***OA* = 93.12%**	
	PA	94.87	92.5	88.37	97.36	**κ = 0.90**	
2011	Built-up	36	0	2	2	40	90
	Vegetation	1	37	2	0	40	92.5
	Suburb Open Space	0	1	38	1	40	95
	Road	2	0	2	36	40	90
	(Producer)	39	38	44	39	***OA* = 91.87%**	
	PA	92.31	97.36	86.36	92.30	**κ = 0.89**	
2020	Built-up	38	0	2	0	40	95
	Vegetation	0	38	1	1	40	95
	Suburb Open Space	1	1	37	1	40	92.5
	Road	2	1	1	36	40	90
	(Producer)	41	40	41	38	***OA* = 93.12%**	
	PA	92.68	95	90.24	94.73	**κ = 0.90**	

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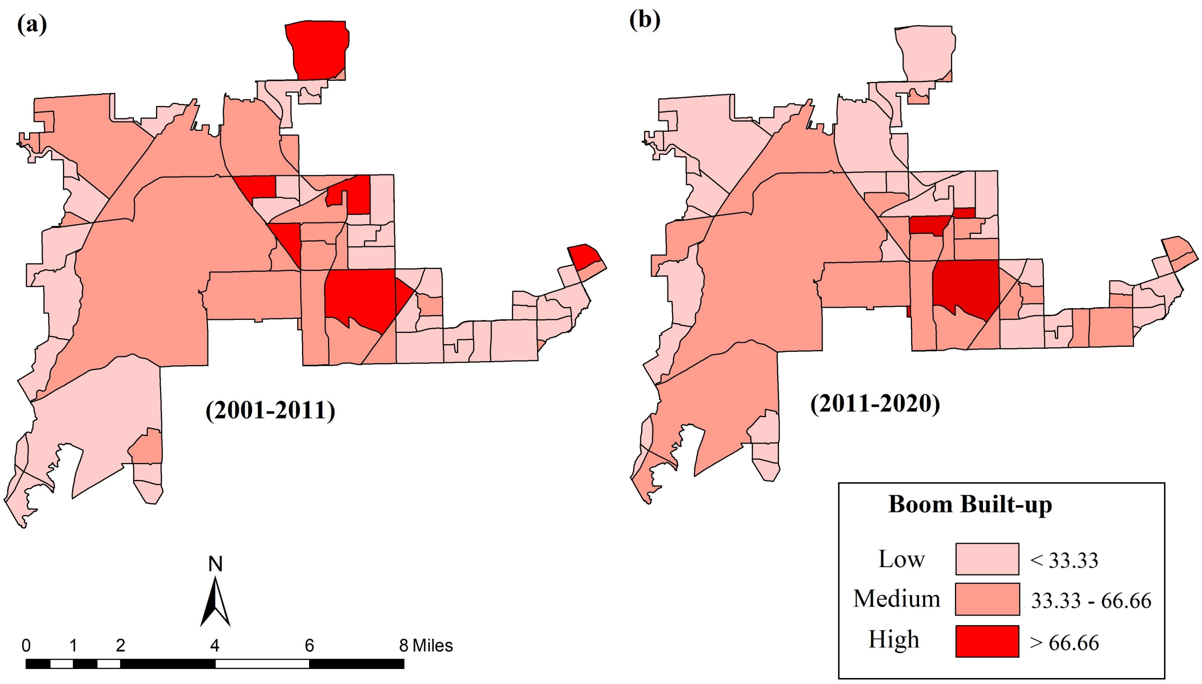

Fig. 5 Metropolitan boom hotspots

lustrate the human/industrial agglomeration fostered by freeway development (Rephann 1993). Interestingly, the change in area in square kilometers for all the four classes was much more during the time frame 2001−2011 than during 2011−2020. This shows that urban dynamics is an all-inclusive phenomenon. If space occupancy increases during a particular period, there will be a competition in space occupancy due to less space available; this phenomenon causes space occupancy to stagnate during the following period (Wu et al. 2014).

Fig. 4 illustrates a swift growth in metropolitan areas from 2001 to 2010, while a stagnant growth was recorded in the next decade. The trend depicts the upsurge in property costs during 2001 to 2011, owing to which the building construction may have stagnated.

A confusion matrix was generated using the cross-referenced training samples to identify the degree of misclassified pixels during the image classification (Baig et al. 2022). Table 2 illustrates the confusion which helped calculate the overall accuracy and kappa coefficient. The analysis of the generated confusion matrix resulted in an overall accuracy of 93.12%, 91.87%, and 93.12% for the years 2001, 2011, and 2020. Their corresponding kappa coefficient (κ) was 0.90, 0.89, and 0.90.

The booming built-up hotspots calculated from the data on built-up, population density, and road lengths showed that district 3 of the DFW metropolitan area was under speedy expansion during both the decades (Fig. 5). Part (a) in Fig. 5 shows the metropolitan boom hotspot (2001−2011) and Part (b) in Fig. 5 shows the metropolitan boom hotspot (2011−2020).

Part (a) in Fig. 6 highlights that highway expansion fosters industrial relocation. According to our study, 79.16% of old industries were located near old freeways while 78.84% of new industries were located near new freeways. From this observation, we concluded that most industries were located near highways.

Part (b) in Fig. 6 depicts the ratio between industrial area occupancy and road area. Fig. 6(b) shows that most industries were set up near transit corridors, showing a strong positive relationship between transportation infrastructure and industrial relocation. The little skewness in the results in Fig. 6(b) is because only one district was selected for this study. However, the highway corridor expands beyond the district; so, we found such skewness in our observations.

Fig. 7 shows the plot between the natural log of road area in each census tract to the natural log of the population density for that tract. The graph plotted in Fig. 7 shows that with the increase in the total road area in a census tract, there is an increase in population density within that census tract, which confirms that highway expansion leads to population agglomeration.

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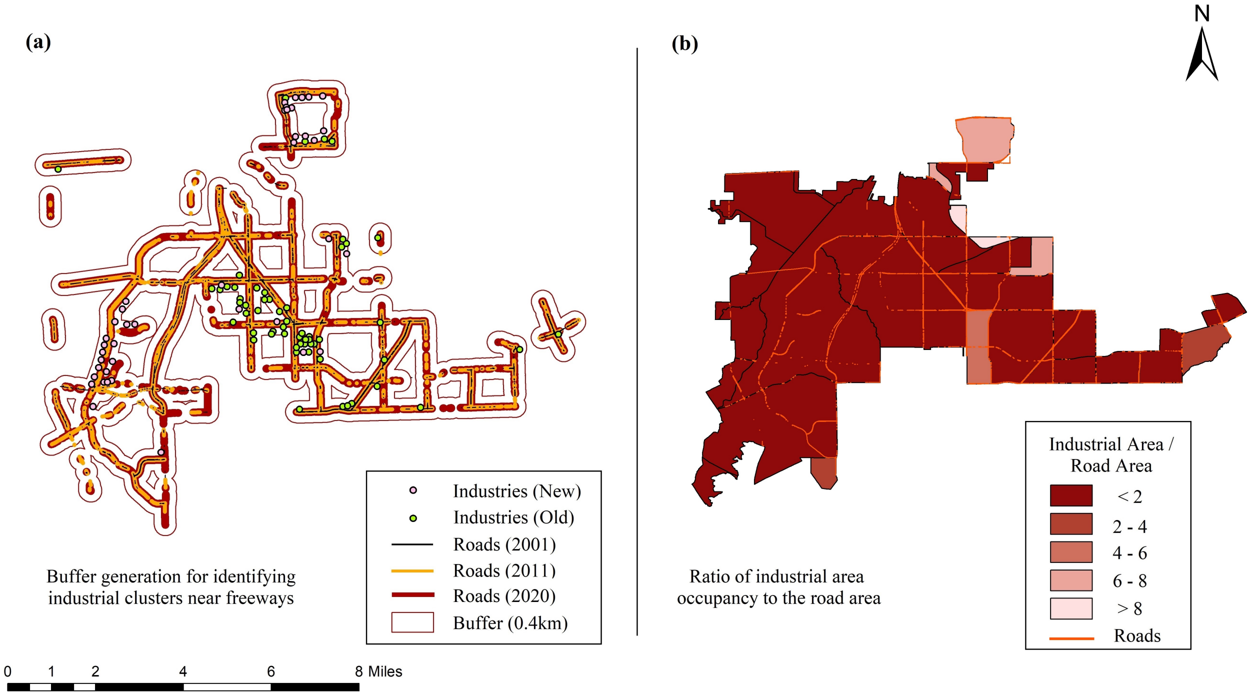

Fig. 6 Impact of highway corridors on relocation of industries

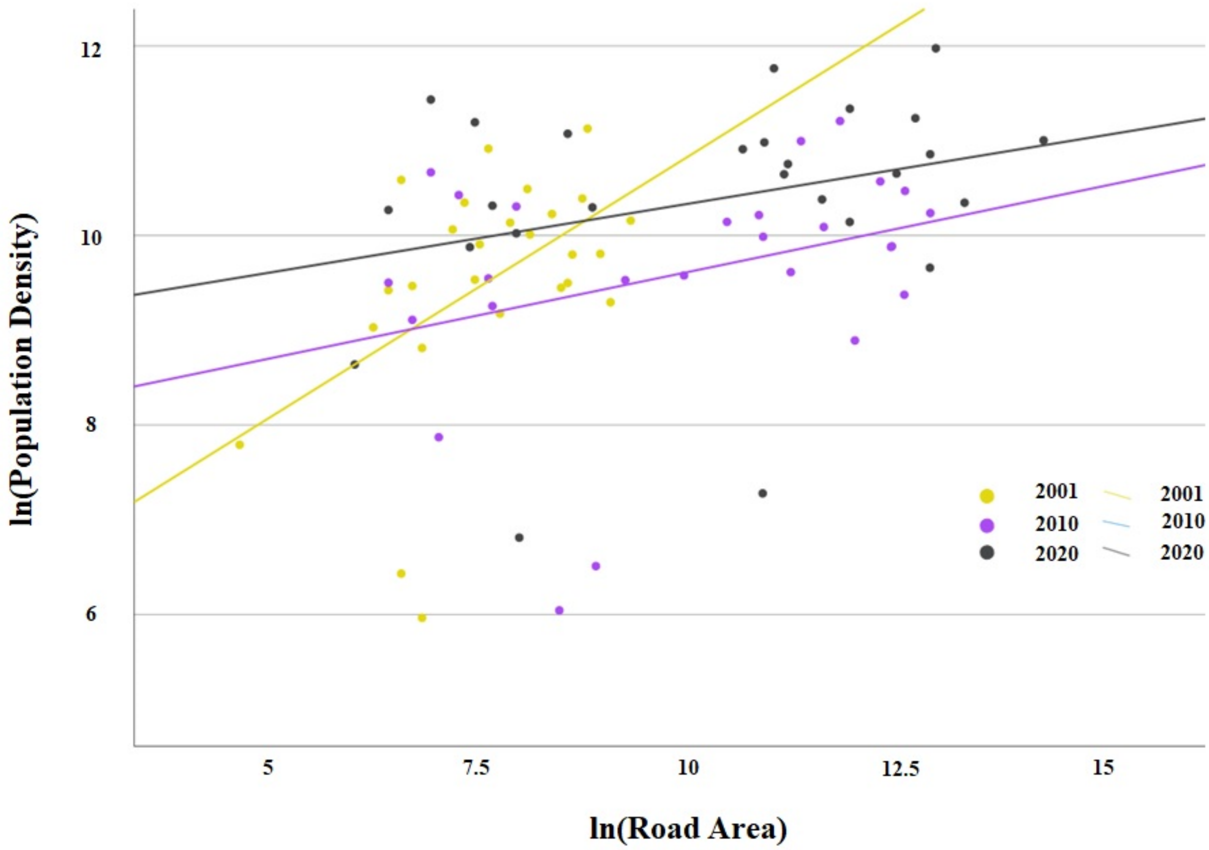

Fig. 7 Plot of highway expansion vs. population density (2001–2020)

Also, we conclude from Fig. 6, and 7 that highway expansion, industrial relocation, and population agglomeration are interrelated.

6 Conclusions

This research compared decadal urban growth and decadal freeway expansions within the study area. Our study found that transportation development fosters urban growth. Our study confirms that urban expansion co-occurs with transportation infrastructure advancements. Our LULC analysis reported significant urban advancement in the selected transportation corridor from 2001 to 2020. We report a sharp increase in built-up area from 2001 to 2011, while there was not much increase recorded in the built-up statistics from 2011 to 2020. This reduction in the increase in the built-up area in the district attributes to two factors: i) significantly less advancement in transportation networks during 2011–2020, ii) less availability of land due to the increased built-up density during 2001–2011.

Our analysis reports that the relocation of industries near transportation corridors fostered a massive population influx in the study area during the following decades. Our calculation of the ratio of industrial area occupancy to road area shows that industrial relocation follows the pattern of transportation advancements. Our comparison of highway expansion vs. population density (2001-2020) further explains that population influx also follows transportation infrastructure advancements. These results are the evidence for the assertion that transportation infrastructure advancement draws industries near its corridors. This phenomenon, in turn, generates new employment. As a result, the area where these developments occurred might experience a population influx.

This research highlights the applications of geospatial data in urban studies. Such technologies integrated with automated learning approaches will become a boon to metropolitan planners. Easy and valuable data generation eliminates the need for manual digitization of image objects (Kharel et al. 2019), thereby closing the time and labor barriers usually unavoidable in geospatial studies. The document targeted forecasting decadal variations in urban landform correspondingly compared to decadal alterations in transportation networks within the study area. Classification algorithms were generated using Remote Sensing & GIS skills. However, there are limitations to our study. We account for the under-classification of image objects by combining two major feature classes (suburban areas and open spaces) due to our study's freely available satellite images and free software platforms to inform the significance of our research. Our results may also be skewed due to mismatches in spectral reflectance values and typical sampling error, considering the time frames during which the satellite took the images. We discovered that using publicly available data and open software platforms may broaden the usefulness of Remote Sensing and GIS applications to different disciplines. Manual supervision and updating of the freshly created database can help resolve these issues.

7 Implications for the Broader Research Community

As urban infrastructure improves, so does the region's economic development, which is a benefit of a capitalist society. Local job employment will increase, and more citizens will find work. However, several drawbacks must be addressed. The first and most apparent is the disturbance in the ecosystem/landscape interconnectivity (Borisova et al. 2015). Such disturbances can disrupt natural ecosystems of flora and wildlife, causing many species to become extinct. Likewise, instances have been reported where wild animals interfere with the human environment, due to which there has been disturbances in the human habitat, generally termed as human-animal conflicts. These conflicts can be of many types – elephant damaging smallholder crops (Graham & Ochieng 2008), vehicle-deer collisions (Sullivan & Messmer 2003), human casualties due to bear attacks (Rajpurohit & Krausman 2000), wolf-human conflicts (Kumar & Rahmani 1997), and many others (Peterson et al. 2010). Similarly, as massive traffic routes emerge, the carbon trap expands, resulting in a thermal impact inside the urban zone. This is attributed to road-heat traps and increased industrial and transportation-related pollutants. Urban planners and environmental scientists must do more studies in these areas to develop better solutions for addressing such problems.

People want to reside in homes located away from the central business area to avoid the filth and congestion of the central city as the transportation corridor increases. However, as anticipated by Von Thünen's (1826) model, there has been a massive conversion of agricultural land into residential and commercial properties, resulting in increased urban sprawl. Urban sprawls are the engines that drive socioeconomic and ethnic segre-

gation, which is all too frequent in modern American urban environments (Chapman & Walker 1991). This massive chasm in society confines the impoverished to the highly populated core regions, where there are limited job prospects. On the other hand, industries and affluent residents shift to less expensive houses in the suburbs. Social scientists and urban planners must collaborate to develop policies that will assist in alleviating the sufferings of low-income minorities who live in the core city.
Similarly, other urban issues need immediate attention. However, studying such issues is not as easy as conceived. Further, funding for studying such issues varies disproportionately amongst different organizations and countries. Additionally, this disproportionality extends because of the disparities in data availability, considering diverse study environments. In such circumstances, the application of freely available resources, like those utilized in this study, can help close this enormous, labor-intensive, and time-consuming data collection barrier. Adopting such resources will increase research efforts on the highlighted urban issues and help address the broader urban planning research community. Computer scientists, mathematicians, and data analysts may work further to develop freely available software packages and algorithms for making Remote Sensing and GIS applications more advanced and reliable so that other fields of research can be informed accordingly.

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