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Estimation of Demand for Urban Land Uses: A Case Study of Türkiye

Kentsel Arazi Kullanım Talebinin Tahmini: Türkiye Üzerine Bir Çalışma

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Öz

Geçtiğimiz yıllar içerisinde, farklı yerler ve bölgeler hızlı bir kentleşmeyle karşı karşıya kalmıştır. Hızlı kentleşmenin bir sonucu olarak kentsel doku önemli ölçüde değişirken, akademisyenler aynı zamanda, trafik sıkışıklığında, metropol alanlardaki kirlilikte, kamu hizmetlerinde azalmada ve altyapının eskimesinde bir artışa dikkat çekmişlerdir. Bu göstermektedir ki; arazi kullanım değişikliğinin toplum ve çevre üzerinde olumsuz etkileri olabilmektedir. Bu olumsuz etkiler kamu idareleri üzerinde çok büyük bir baskı oluşturmaktadır. Sürdürülebilir olmak için ve ekosistemlerin doğru işleyişi için, korunması veya sürdürülmesi gereken doğal unsurların ve kısıtlamaların yanı sıra kalkınma için kullanılabilecek kaynakların kısıtlamalarıyla birlikte belirlenmesi gerekmektedir. Bu nedenle, gelecekteki kentsel genişlemenin doğru tahminleri, sürdürülebilir büyüme ve çevrenin korunması için gereklidir. Birleşmiş Milletler (BM), kentleşmenin sürdürülebilirliğini tahmin etmek için Sürdürülebilir Kalkınma Hedefi 11.3.1 göstergesi olan "arazi tüketim oranının nüfus artış hızına oranı"nın kullanılmasını tavsiye etse de özellikle gelecekteki kentsel genişlemeyle ilgili olarak şehir düzeyinde hala yetersiz doğru tahminler ve değerlendirmeler mevcuttur. Sürdürülebilir Kalkınma Hedefleri çerçevesinde kentsel sürdürülebilir kalkınma hedeflerinin gerçekleştirilmesinin önündeki temel engel, önümüzdeki yıllarda kentleşme sürdürülebilirliğinin dinamiklerinin sınırlı anlaşılması olmuştur. Bu makale, kentsel kullanımlar için arazi kullanımı değişikliklerini incelemekte ve ayrıca seçilen örnek çalışma alanında, yani Türkiye'nin NUTS3 (istatistik için karasal birimlerin terminolojisi) bölgelerinde yani şehirler düzeyinde konut ve endüstriyel/ticari arazi kullanımlarının projeksiyonu için farklı yöntemler uygulamaktadır. Yoğunluk ölçümleri, trend ekstrapolasyonu ve regresyon analizi, arazi kullanımını tahmin etmek için kullanılan söz konusu istatistiksel yöntemlerdir. Bulgular, geçmiş değişiklikleri yansıtmak için seçilen metodolojileri kullanmanın önemli bir belirsizliğe yol açtığını göstermektedir. Doğrusal regresyon doğu, kuzey ve batı için en yüksek konut arazi kullanım değerlerini; yoğunluk ölçümü ise kuzeybatı ve güney bölgeleri için en yüksek değerleri tahmin etmiştir. Endüstriyel/ticari arazi kullanım talebine ilişkin en yüksek değerler doğu ve kuzey için doğrusal regresyon yöntemiyle, kuzeybatı, güney ve batı bölgeleri için ise doğrusal eğilim ekstrapolasyonu yöntemiyle tahmin edildi. Sonuçlar, seçilen değişkenlerdeki varyasyondan ve çalışma bölgesinin mekânsal organizasyonundan önemli ölçüde etkilenebilir. Bu nedenle, Türkiye'deki arazi kullanımı değişikliklerini tahmin etmek amaçlı kullanılabilecek en uygun modeli seçmek için gelecekteki bir araştırma odağı olarak doğrulama analizi temel olacaktır. Mevcut analizin sonuçları, Türkiye bölgesel bağlamında arazi yönetimi ve kentsel arazi kullanımının sürdürülebilir büyümesi için kamu idareleri ve yerel makamlar tarafından benimsenebilir.

Anahtar Kelimeler: Kentsel Arazi, Arazi Kullanım Talebi, Arazi Kullanım Projeksiyonu, İstatistiksel Yöntemler, Türkiye

ABSTRACT

Over the past few decades, urbanisation has rapidly developed in various locations. While the urban landscape has changed dramatically as a result of rapid urbanisation, academics have also noted an increase in congestion, pollution in metropolitan areas, a reduction in public services, and aging infrastructure. These indicate that land use change can have adverse impact on society and environment and therefore it puts enormous pressure on governments. To be sustainable, the resources that can be used for development must be identified, together with their restrictions, as well as the natural elements and constraints that must be maintained or sustained for the correct functioning of ecosystems. Therefore, accurate estimates of future urban expansion are essential for sustainable growth and the preservation of the environment. While the UN advice utilising the SDG indicator 11.3.1 "the ratio of land consumption rate to population growth rate" to

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estimate and predict the sustainability of urbanisation, there are still insufficient accurate projections and useful evaluations available at the city level, particularly with regard to future urban expansion. The main obstacle to informing the realisation of urban sustainable development goals under the framework of SDGs has been the limited understanding of the dynamics of the urbanisation sustainability in the next decades. This article examines the land use changes for urban uses, and further applies different methods for the projection of residential and industrial/commercial land uses in the selected case study area i.e. NUTS3 (nomenclature of terrestrial units for statistics) regions of Turkey which demonstrate a city level analysis. Density measures, trend extrapolation and regression analysis are the subject statistical methods used for projecting the land use. The findings show that using the chosen methodologies to project past changes leads in significant uncertainty. Linear regression estimated the highest residential land use values for east, north and west; density measure estimated the highest values for north-west and south regions. Regarding the industrial/commercial land use demand, highest values were projected by linear regression method for east and north, by linear trend extrapolation method for north-west, south, and west regions. The results are significantly influenced by the variation in selected variables, and spatial organization of the study region. Therefore, validation analysis as a future research focus will be essential to select the most appropriate model that can be used to project the land use changes in Turkey. The results from the current analysis can be adopted by the government and local authorities for the land management and sustainable growth of urban land use in the Turkish regional context.

Keywords: Urban Land, Land Use Demand, Land Use Projection, Statistical Methods, Turkey

1. Introduction

Urbanisation is speeding up as a result of the world's rising population accompanied by social and economic development. Today more than 50% of world's population lives in urban areas and it is projected to increase to 66% by 2050 (UN, 2014a). The rapid population growth has been impacting on urban land use which is influenced by economic, social, and biophysical forces. The various socioeconomic sectors that affect the land-use system are affected by these influences in diverse ways. Urbanization is usually driven by factors like economic growth, land use accessibility, political framework, and urban planning (Tong et al., 2021). Agriculture is greatly impacted by general agro-economic, technological and specific geo-physical factors while change in natural landscape typically occur from agricultural perspective and policy actions (Koomen et al., 2015; Zhao et al., 2018). The impact of these forces varies across space and time, and these influence the spatial distribution of different land uses. Given an urban space, population centers are increasingly competing for available land with other critical uses such as agriculture, environmental preservation, and other ecosystem services as built-up areas expand. The literature on land cover/use change states that the dynamics of land use due to urban land expansion exhibit variation over space and time (Liang et al., 2018; Dadashpoor et al., 2019; Song et al., 2021; Hussain and Karuppannan, 2023). While some areas see urban growth including Western and Southern European core cities, others are noted for having the greatest population reductions such as Eastern European cities starting from the mid1990s (Kabisch and Haase, 2011). However, the development of the urban land does not necessarily stagnate or slow down as a result of this stagnancy. Whether it is a growing or stagnating region, the projected land use information is essential to apply correct and relevant policies for the development of a sustainable land management system. Therefore, this research focuses on projecting future developments of urban land uses for the selected case study of Turkey.

Larger regional and temporal dynamics, encompassing macroeconomic and demographic changes, frequently have an impact on changes in land quantity. Therefore, a sufficient economic background is required for the forecast of changes in land use. Economic models ''offer a basis for representing competitiveness among various sectors, shifts in management and technology, and changes in demand as a result of trade or governmental actions" and therefore the subject models provide the basis of quantifying the factors that influence land use demand (Heistermann et al., 2006). To analyse historical population and urban area trends and to predict future urban land use demand, many methodologies were created. These approaches, which stem from several scientific backgrounds, concentrate on various research areas, datasets, and spatio-temporal scales. Each methodology has its special use and attention must be paid to select the most relevant technique for a particular case study application. Many factors influence the method selection including the context of forecast, the importance and accessibility of historical data, the desired degree of accuracy, the time period needed for forecasting, the value of the forecast to stakeholders, and the time available for analysis. Choosing the right estimation method might be challenging because it is unable to compare findings quickly. Time is needed to see whether forecasted values of land use are matching with the real data demonstrating related land use areas. The goal of this study is to generate annual projections of urban built-up areas at the NUTS3 regional level (i.e. city level) with an aim of assessing future urbanization sustainability aligned with the SDG indicator 11.3.1. The results will be presented based on the grouping of the NUTS3 regions.

Analysis of future demand for residential and industrial/commercial land is crucial as it provides evidence to support local and regional planning policies and decisions through provision of right quantity and quality of land to support the economy and population while allocating future land-use demand efficiently. Land-use planning can be described as a decision-making process that "facilitates the allocation of land to the uses that provide the greatest sustainable benefits" (UNCED, 1993). Therefore, allocation of scarce land resources by sustainable means is vital to accommodate qualities and limitations of each land-use component and to provide viable land use options (FAO, 1995). The issue of sustainable development is at the centre of urban studies given that population growth and consequential pressure on scarce land resources have associated with high social, economic and environmental costs (UNFPA, 2007, 2014).

In order to contribute to sustainable development goals, three different approaches including density measures, trend extrapolation and regression analysis are put forth. This is based on historical data of urban built-up area as well as population and GDP data are also considered. These three approaches are the commonly used methods in the literature applied to different case study areas for the urban growth forecasting (Hoymann, 2011; Batista e Silva et al., 2014; Ustaoglu et al., 2018; Jiang et al., 2022). Therefore, the focus will be on these methods that were applied to Turkey for the prediction of residential and industrial/commercial land uses. Two specifications need to be highlighted: First, the methods are consistently utilised given the same dataset. Second, the techniques are evaluated for their suitability in light of the varying development patterns of the demography and built-up land. In addition to filling the data gap of sustainability-related urban land demand for all country and city levels, the regional scale forecasts consider the applicability to city level analysis according to varying levels of urbanisation and economic trends. These forecasts can also benefit the spatially explicit urban expansion simulation as quantitative boundaries.

2. Literature Review

The research on statistical modelling of urban land use demand have adapted different approaches for different case study areas of varying scale to explicate the relationship between demand for urban property and the drivers of property demand (Sing, 2003; Arauzo-Carod, 2005; Ng et al., 2008; Batista e Silva et al., 2014; Ustaoglu et al., 2018; Xu et al., 2022). The studies presented mixed results and the literature have not yet reached to a consensus on the spatial scale of analysis (i.e. to use high resolution or coarser scales) and the key factors influencing the urban land use demand. Case studies at local level provide evidence on the key drivers of urban land use demand by utilising high-resolution data. The use of local data would bring more accurate results since the variables lie closer to the local spatial units where individual choices affect the urban development process (Jacobs-Crisioni et al., 2014). However, local studies are highly specific in contexts, actors, main processes, resolution and scale (Burgi et al., 2004). By contrast, the use of a coarser scale in a macro model can lead to a more generalised insight considering that the analysis of real property demand and the drivers can be generalised and transferred across places (Rindfuss et al., 2007).

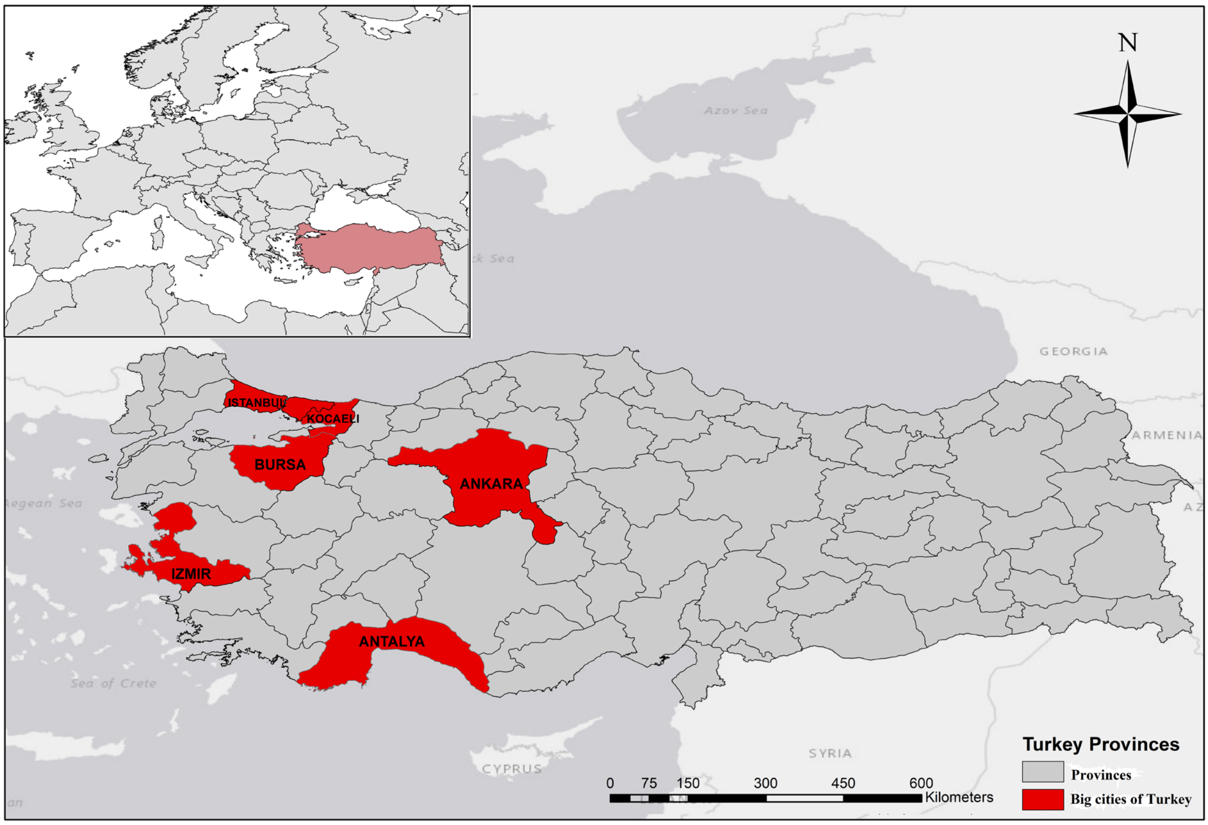
The multiple regression modelling technique has been applied in various studies with an objective of projecting demand for real property development. Examples range from all types of buildings in Australia (Jiang and Liu, 2014), industrial property demand in Singapore (Hua and Pin, 2000), private sector demand in the UK and Hong Kong (Akintoye and Skitmore, 1994; Sing et al., 2015), residential property demand and demand for industry in Hong Kong (Ng et al., 2008; Fan et al., 2011). This literature mainly focuses on the estimation and forecasting of real estate demand through complete time series data obtained for the variables considered in the analysis. A further example of regression analysis for the estimation of urban land demand is provided by Reginster and Rounsevell (2006). This study applied regression analysis approach for estimation of urban land demand in Europe to be utilised in different future scenarios related to different spatial development policies in Europe. Other research was developed in the context of various European Projects (i.e. PLUREL, SENSOR). An econometric model named NEMESIS was constructed in order to estimate an endogenously determined demand for different land uses for countries in the EU (Le Mouel et al., 2009). In the NEMESIS Model, investment in the real estate property market is determined as a function of rental price of real properties, sectorial production and technological progress. The demand for real estate properties was determined endogenously in the model through the integration of macro-economic sectors and various spatial variables at the micro-economic scale. Endogenously determined time-series parameters were utilised within the context of NEMESIS to estimate demand for residential, commercial and industrial land. The estimated demand for different land uses was passed to an operational land-use model for a land allocation process which downscaled aggregate regional demand into fine-scale grids (Jansson et al., 2008). A similar approach was also used for the allocation of land uses across different future scenarios developed in the PLUREL Project (Boitier et al., 2008).

There are few studies that actually assess existing approaches in the literature. Among the few ones, Hoymann (2011) and Batista e Silva et al. (2014) evaluated the validity of different approaches to project future urban land uses. The former study compared results of the residential demand predictions with the observed data through application of different statistical approaches including trend extrapolation, regression analysis, and density measures while the latter estimated demand for industrial and commercial land for the EU countries by using similar statistical approaches and compared prediction results with the observed data for each EU country. There are other methods such as agent-based models and input-output modelling used for the estimation of urban land use demand. An example of a former approach is Van Bronkhorst et al. (2014) that proposed an agent-based model to estimate future demand for various industrial sectors in the Netherlands and matches it with the existing supply. The quantified demand was allocated to different locations based on the location preferences of the firms through the application of their location choice model. Other examples of agent-based modelling are Parker and Meretsky (2004), Arsanjani et al. (2013) among others. The input-output modelling is another approach utilised to forecast urban land-use demand, which is integrated to land-use or transportation modelling framework to explain urban growth processes. Jun (2005) proposed a model where land-use demand is determined by interindustrial and interspatial relations of production, income generation and consumption through application of input-output multipliers. The model is eventually simulated based on different scenarios to examine the impact of government policy on regional and metropolitan economic activity (see also Jin and Wilson, 1993; Jun, 2004). Input-output approach is also utilised in general equilibrium models which provides integrated assessment of spatial and intertemporal interactions among different socio-economic and physical forces that drive land-use/land cover change. As an example, readers are referred to LUC model of IIASA that was developed for China (see Fischer and Sun, 2001).

There is vast research, which has explored estimation of demand for land for the future simulation of urban expansion within the land-use modelling framework. For instance, He et al. (2006) applied a new urban expansion scenario model which is based on a bottom-up cellular automata (CA) approach for the simulation of urban expansion in Beijing, China. In their study, urban land demands were obtained based on the estimates of land demand for residential, production and public service purposes within the urban expansion process. Estimated land demand was allocated through the land-use allocation module within CA process aiming at keeping the balance between demand and supply of the urban land. Likewise White and Engelen (2000); Barredo et al. (2003), Garcia et al. (2012), Qiang and Lam (2015) and Xu et al. (2023) integrated land-use factors with the dynamic CA modelling approach for simulations of urban growth at local or regional levels. CLUE and CLUE-s models are other examples of dynamic simulation modelling approach where externally derived relationships between land-use change and driving forces from cross-sectional analysis are fed into the model, which is operating at multiple scales. At the national scale land demand calculations are undertaken and there are regional and local scales to take driving forces into account. Besides the top-down allocation, a bottom-up modelling approach is implemented to feedback local changes to the regional and national level (see Verburg et al. 2004).

3. Case Study

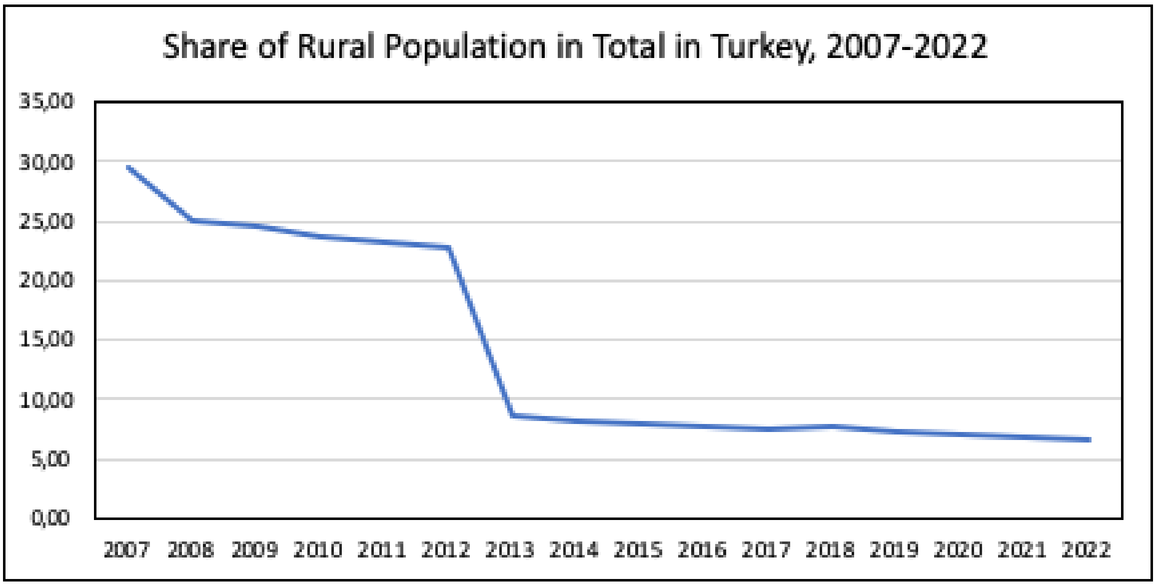
Turkey is a large country having population of more than 76 million and total surface area of 78 thousand square kilometres (see Figure 1). While forests, mostly in coastline and mountains areas, make up 15% of the total land area, agriculture covers 44% of the nation (OECD, 2017). 1.8% of the nation's total surface area of land is made up of developed land (OECD, 2017). Turkey's population has increased dramatically since the 1950s, and this population growth has been accompanied by rural-to-urban migration. The mechanization and commercialization of agriculture, as well as the resulting loss in rural employment prospects, has led in a migration of rural residents to cities and urban areas (Erman, 2001). For instance, percentage of rural population in total was 30% in 2007 and this percentage has decreased to 23 % in 2012, 8% in 2015, 7% in 2020, and 6.6% in 2022 (Figure 2).



Note: Red coloured cities are the biggest cities of Turkey in terms of socio-economic development. As of 2022, these cities have the following population numbers: Ankara: 5,782,285; Antalya: 2,688,004; Bursa: 3,194,720; İstanbul: 15,907,951; İzmir: 4,462,056; Kocaeli: 2,079,072 (TurkStat, 2022)

Fig. 1. The case study area

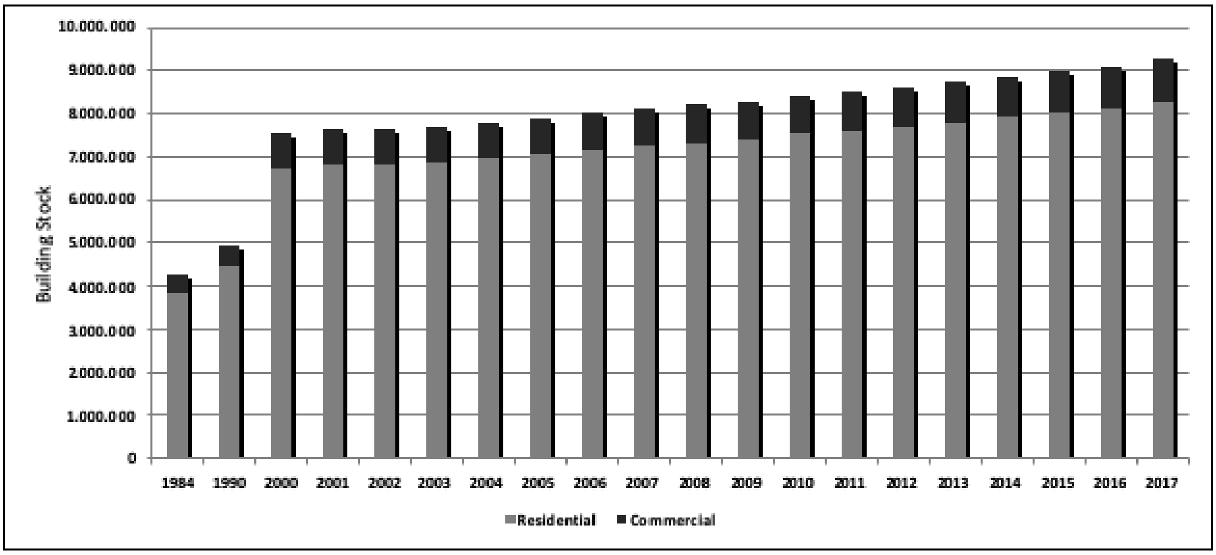
Due to the globalisation and neo-liberal policies of the 1980s, the national and municipal governments have adopted an entrepreneurial approach since the 1980s by introducing new urban standards that encourage private sector growth and investment (Ersoy, 2015). As a result, starting in the 1980s, Turkish cities saw a dramatic transformation from small-scale growth to big-scale built-up regions thanks to the engagement of major stakeholders and large organizations (Tekeli, 2009). The large-scale building activities included not just residential areas but also industrial and commercial activity (Figure 3). This massive construction has taken place in an unplanned manner over the past decades. In the 1990s, there were few formal employment possibilities and a scarcity of suitable land for housing developments near cities and metropolitan regions (Tekeli, 2010). Urban areas and metropolitan regions have expanded beyond their limits and evolved into increasingly complex spatial structures as a result of the urbanisation process. Turkey's rapid growth and unplanned urban expansion have resulted in serious socioeconomic and environmental issues (Ustaoglu and Aydınoglu, 2019). The most significant include unemployment, inequality in society, urban poverty, increasing emissions and environmental degradation, insufficient housing and infrastructure availability, unregulated urban development, and the resulting exploitation of land as a limited resource (MD, 2014).



Source: Rural population is calculated based on TURKSTAT database (Turkstat, 2022) which shows proportion of towns and villages population in total for the years between 2007 and 2022

Fig. 2 Rural population as a share of total population in Turkey

During the high growth period, social and economic development gaps between the coastal and interior areas remained large. In terms of Gross Value Added (GVA) per capita, the top five regions' income levels were more than two times higher than those of the last-placed regions (Turkstat, 2021). When compared to other regions in the nation, the Eastern Marmara, Aegean Coast, and Western Mid Anatolian Regions have the highest degrees of disparities in terms of socioeconomic and demographic development. Metropolitan areas, big cities, and a few significant centers are where most industrial output, innovation, and Research and Development (R&D) takes place. Manufacturing and tertiary economic activity, such as those in the financial, commercial, and service sectors, are concentrated in the Marmara and Aegean Regions, particularly Istanbul (OECD, 2016). Being the country's financial, economic, and cultural hub, Istanbul continues to draw people in pursuit of formal jobs and improved living conditions. The build-up of capital and industry in Istanbul and the neighbouring areas not only worsens regional socioeconomic development imbalances, but also has detrimental environmental effects.



Source: TurkStat Statistical Indicators (TurkStat, 2014; 2023)

Fig. 3. Change in residential and commercial uses in Turkey between 1994 and 2017

Turkey's population increased by 46.8% between 1990 and 2018, going from 56.4 to 82.8 million people. Its urban land cover expanded by almost 37%, from 855,000 to around 1,171,000 ha. This suggests that over the 1990-2018 period, Turkey's urban land cover increased at a rate lower than that of its population. This points to land densification in some regions as well as expansion of land in others (Ustaoglu and Aydınoglu, 2019). Along with the rate of urbanization, rising incomes, expanding economic possibilities, changes in social structures, and accessibility have led to a rise in demand for high quality infrastructure and housing, as well as urban fabric must be renewed by changes in land uses, density, and the intensity of urban functions (MD, 2014). The finest residential structures have primarily been found in low-density, automobile-oriented, sprawling areas on the outskirts of major cities (Ergun, 2004). These expensive new constructions are dominated by larger detached or semi-detached homes and are usually inhabited by people with high incomes (Dökmeci and Berkoz, 2000; Gokce and Chen, 2019). Population densities have decreased as a result of the low density, sprawling developments, especially in Istanbul and other major cities. Prospects for the future of land value growth have increased demand for new construction and increased the number of development right approvals. Unsustainable urban expansion has resulted in "unsustainable way of living, a high likelihood of disasters, destruction of cities' distinct identities, and limitations in infrastructure, transportation, and social space" among other negative effects (MD, 2014:126).

4. Data and Methods for Land Use Demand Quantification

4.1. Data

The source for residential and industrial/commercial land use data is the CORINE Land Cover (CLC). The CLC data has a spatial resolution of 100m, and the dataset has been provided by European Environment Agency (EEA, 2022). The CLC data obtained from EEA had been selected for the present study because it is the most up-to-date source, offering extensive land-use data for the entire country in the post-1990. The CLC dataset provides consistent time-series maps for Turkey covering the 1990, 2000, 2006, 2012 and 2018 periods. The CLC data contains a list of 44 land cover classes. Settlement and urban infrastructure are classified into four categories (discontinuous urban fabric, continuous urban fabric, urban recreation uses, and industrial/commercial uses). For the aim of this study, continuous urban fabric and discontinuous urban fabric were aggregated and these form the residential land use. Industrial/commercial land uses were directly obtained from the CLC dataset as these represent the aggregated land uses for commercial and industrial sectors. Besides the use of CLC data obtained from EEA, the analysis makes use of socioeconomic data (such as economic variables and population) that was gathered at the NUTS3 level, which in Turkey is equivalent to the provincial level. The socio-economic variables used for the calculation of the density measures and linear regression estimates include population and GDP that were used for the estimations of residential and industrial/commercial land, respectively. The corresponding values of the socio-economic indicators for the year 2023 are based on population projections for 2023 obtained from Turkish Statistical Institute (Turkstat, 2023) and GDP projections for the post-2020 period obtained from IMF. Pre-2023 population and GDP data were also obtained from Turkstat (2023).

4.2. Methods

4.2.1. Land Use Change Analysis

The land use change of the built-up land was quantified based on the land use dynamics model given as follows:

$$\Delta LU_i = \sum LU_{it_2} - \sum LU_{it_1} \quad (1)$$

Where ΔLU_i is the change in land use type i over the time period t_2-t_1; LU_{it2} and LU_{it1} are the area of the land use type i at time t_2 and t_1, respectively. The land use changes were computed at the NUTS3 level i.e. city level initially and then grouped at the national and regional levels for the years 1990, 2000 and 2018. These years represent the most recent decades where there is data of land cover/use obtained from the CLC dataset. At the regional level, the urban-rural typologies defined by Turkstat (2023) were used to specify the regions (Figure 4). Turkstat (2023) defines rural grid cells that are outside of urban clusters with a low population density and urban clusters are contiguous grid cells with a high population density. After the classification of grid cells these were overlayed onto NUTS3 level regions. A classification based on the following shares were made. Densely populated areas are defined as regions that have at least 50% of their population living in urban centre grids; intermediate density areas are the regions that do not meet the criteria of densely populated areas and thinly populated areas; thinly populated areas are regions that have more than 50% of their population living in rural grid cells.

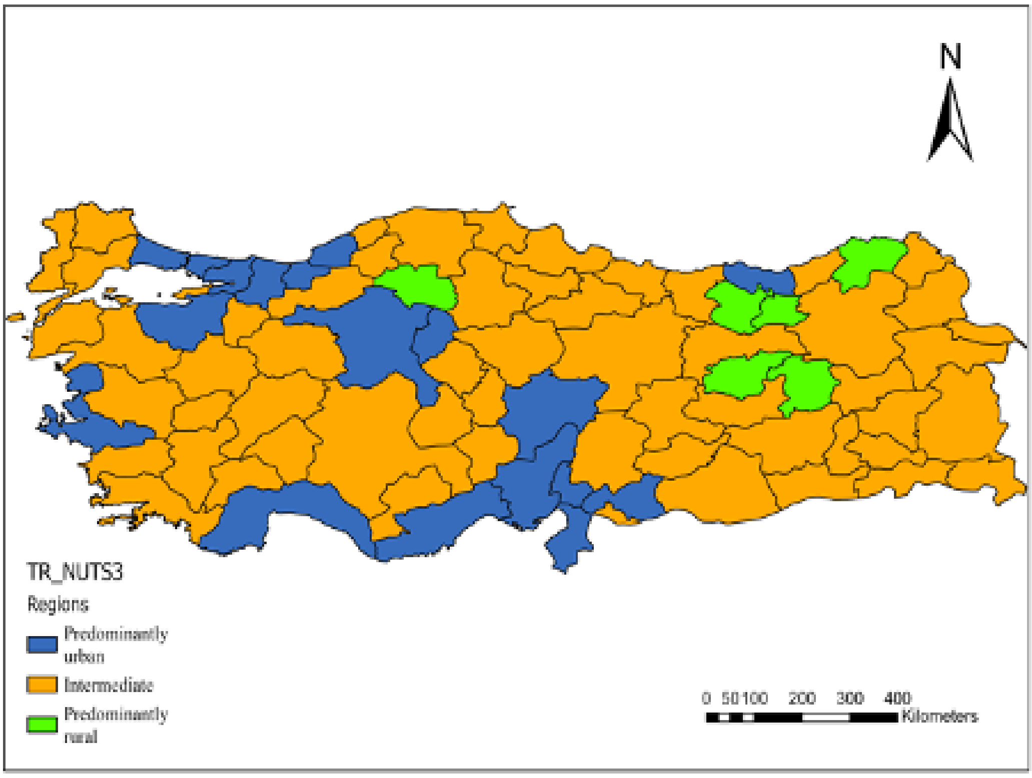


Fig. 4. Urban-rural typology of NUTS3 regions based on Turkstat (2023) classification

4.2.2. Land Use Demand Projection

Because of the sustainability considerations of urban development of the different regions in Turkey, three different approaches were used for the projections of urban land uses of residential and industrial/commercial land for the post-2020 period: These are trend extrapolation, density measures, and linear regression. Trend extrapolation method assume no structural change of underlying drivers of land-use change; and therefore, despite the method is valuable for the short-term analysis of change; it is not suitable for the medium-to-long-term analysis (Hoymann, 2011). The mean demand for built-up area from 1990 to 2012 was applied to the years from 2012 to 2023 in order to calculate the built-up area through trend extrapolation. Here around 10 years of time interval was considered between the known data points and the projection year. Known data points are 1990, 2000, and 2012 and projection year is 2023. Therefore, there is more homogeneous distribution of known data points and data for the projected year. Trend extrapolation methods include a linear extrapolation and an exponential extrapolation model. The formulation of linear extrapolation is given in eq. (2) (Hoymann, 2011; Batista e Silva et al., 2014):

$$L_{t_2} = L_{t_1} + \left(\left(\frac{L_{t_1} - L_{t_0}}{t_1 - t_0} \right) \times (t_2 - t_1) \right) + \varepsilon \tag{2}$$

where L is the area of residential or industrial land use; t_0 and t_1 are the start and ending years of the observed time period; and $(t_2\text{-}t_1)$ is the forecasting period. The estimation with exponential extrapolation method is based on two stages. First, observed X value between $(t_1\text{-}t_0)$ period is obtained (eq. 3); and next, X is used for predicting the land use for the period $(t_2\text{-}t_1)$ (eq. 4):

$$X_{t_0,t_1} = \left(\frac{L_{t_1}}{L_{t_0}} \right)^{\left(\frac{1}{t_1 - t_0} \right)} - 1 \tag{3}$$

$$L_{t_2} = \sqrt[\left(\frac{1}{(t_2 - t_1)} \right)]{(X+1)} \times L_{t_1} + \varepsilon \tag{4}$$

The density measure approach, on the other hand, is based on the ratio between a socio-economic variable and the area of the urban land use. Population and economic output (i.e. GDP) are the two variables that are commonly used in the studies explaining land-use change (Hoymann, 2011; Batista e Silva et al., 2014; Ustaoglu et al., 2018). Both variables are assumed to be positively related to land-use development. Following Hoymann (2011), in this study, to compute the density measure for residential land use, the ratio between population and residential land was applied to predict land use at time t_2 (eq.s 5 and 6).

$$LUD_{t_1} = \frac{P_{t_1}}{L_{t_1}} \tag{5}$$

$$L_{t_2} = \frac{P_{t_2}}{LUD_{t_1}} \tag{6}$$

In eq. (5), the density measure is assumed to be constant, and it does not reflect the structural changes of the long-term period but can be used for the short-term analysis. An alternative approach is the dynamic density measures that are based on estimations of future land-use densities. The dynamic measures that are mostly suitable for long-term analysis are not provided in this paper but can be explicitly reviewed in Klosterman et al. (2006). Similar to residential land densities, the density measure for industrial/commercial land use was computed as the ratio between economic output (G) and the area of industrial/commercial land in eq. (7). $LUD_{t1}$was used to predict the industrial land use at time t_2 (eq. 8) (Batista e Silva et al., 2014).

$$LUD_{t_1} = \frac{G_{t_1}}{L_{t_1}} \quad (7)$$

$$L_{t_2} = \frac{G_{t_2}}{LUD_{t_1}} \quad (8)$$

For the calculation of residential and industrial/commercial land uses by trend extrapolation method, the areas of residential and industrial uses from 1990 to 2018 were applied to the years of 1990 to 2023. Here the data from 1990 to 2018 is the observed values and the trend between this period was applied to predict the land areas for the year 2023. The year 2023 was chosen because it is the most recent year that land use data does not exist. Regarding land-use densities, the density measure of the year 2018 was utilised for the estimation of the residential and industrial/commercial land for the year 2023.

An alternative approach was used, namely the relationship with socio-economic growth, to predict urban cover/land-use change. In this regard, the growth of residential and industrial/commercial areas were related to population and GDP growth, respectively, using a linear regression model (Lopez et al., 2001). The formulation of the linear regression model is as follows:

$$y_i = \beta_0 + \beta_1 \sum_{i=1}^{n} x_j + u_i \quad (9)$$

Where y_i is the dependent variable (residential land), β_0 is the constant term, β_1 is the coefficient for independent variable x_i (population) and u_i is the error term. For the second model, dependent variable is industrial/commercial land and independent variable is GDP.

5. Results

5.1. Land Use Change Analysis

The land use change was examined based on the urban land uses which cover residential land, industrial/commercial land, urban green land, transportation infrastructure and dump sites, mineral and construction sites. The land use change statistics are summarised in Table 1. Land use changes at the NUTS3 level are also presented in Figure A1 in the Appendix. According to Table 1, the biggest changes are related to dump sites, mineral and construction sites, and industrial/commercial property. This is followed by residential land uses, transport infrastructure and urban green land. It can be followed that except rural regions, other regions are associated with the growth of built-up area between 2000-2018 period despite the negative effects of the 2001 and 2008 economic crises on the construction industry. Except transportation infrastructure, the largest land use changes are observed in intermediate regions and concerning transport infrastructure the largest changes are seen for the urban regions. The land use changes are the lowest for rural regions in the Country, most probably the reason is the small number of regions that were categorised as rural regions. Regarding the values of total developed land, there is a change of land development of 1,523km^2 for urban regions, 1,864km^2 for intermediate regions; and 36km^2 for rural regions. The change in total developed land amounts to 3,424km^2 at the country level.

Table 1. Urban land use change in Turkey for the years 2000 and 2018

Land cover (km2) (2018)	National	Urban regions	Intermediate regions*	Rural regions
Total residential land	9815.64	3565.45	6125.49	124.7
Total industrial/commercial land	2218.31	1127.21	1064.07	27.03
Total urban green land	522.99	295.7	226.95	0.34
Transportation infrastruture	766.62	400.63	359.08	6.91
Dump sites, mineral and construction	2227.53	815.79	1373.14	38.6
Total developed land	15551.09	6204.78	9148.73	197.58
Land cover (km2) (2000)				
Total residential land	8878.28	3133.35	5612.88	132.05
Total industrial/commercial land	1152.05	606.01	538.09	7.95
Total urban green land	432.66	264.98	167.27	0.41
Transportation infrastruture	501.44	262.19	236.09	3.16
Dump sites, mineral and construction	1162.67	414.92	730.08	17.67
Total developed land	12127.1	4681.45	7284.41	161.24
Land cover (km2) (1990)				
Total residential land	7651.99	2453.34	5087.79	110.86
Total industrial/commercial land	589.62	288.29	298.06	3.27
Total urban green land	308.91	202.69	105.81	0.41
Transportation infrastruture	250.25	101.08	148.08	1.09
Dump sites, mineral and construction	761.96	274.29	477.27	10.4
Total developed land	9562.73	3319.69	6117.01	126.03
Land cover change (%) (2000-2018)				
Total residential land	10.56	13.79	9.13	-5.57
Total industrial/commercial land	92.55	86.01	97.75	240.00
Total urban green land	20.88	11.59	35.68	-17.07
Transportation infrastruture	52.88	52.80	52.09	118.67
Dump sites, mineral and construction	91.59	96.61	88.08	118.45
Total developed land	28.23	32.54	25.59	22.54
Land cover change (%) (1990-2000)				
Total residential land	16.03	27.72	10.32	19.11
Total industrial/commercial land	95.39	110.21	80.53	143.12
Total urban green land	40.06	30.73	58.09	0.00
Transportation infrastruture	100.38	159.39	59.43	189.91
Dump sites, mineral and construction	52.59	51.27	52.97	69.90
Total developed land	26.82	41.02	19.08	27.94

Note: * if >50% and >80% share of population live in urban clusters, these are classified as intermediate regions.

5.2. Results from regression analysis

The linear regression analysis revealed two models given in equations (10) and (11) to estimate the urban land use for the year 2012 and the estimated coefficients from the 2012 were applied to project the built-up area of 2023. Only the population and GDP variables were included in the regression models given that these are the key socio-economic variables that can be used to estimate land use demand and the projected values of these variables were readily available for the year 2023. Parameters obtained for the residential land-use model are: R^2= 0.61; Adjusted-R^2=0.60; F(1,79)=120.47 (0.00) and the predicted model explaining residential land-use changes resulted in:

$$(resid\_land) = 5917.72 + 0.00563(pop) \quad (10)$$

Here, one unit change in population results in 0.00563 units change in residential land. This effect may seem to be relatively small and may stem from the specified functional form of the regression model. A log-linear model would have provided a higher R-squared value but for the ease of interpretation and prediction of future residential land, the existing model specification is more suitable. Further, the growth of industrial/commercial land is related to GDP growth using a linear regression model. Parameters of the subject model are: R^2= 0.68; Adjusted-R^2=0.67; F(1,79)= 161.95 (0.00) and the predicted model is given as follows:

$$(ind\_land) = 1296.76 + 0.00005(gdp) \qquad (11)$$

Here, one unit change in GDP results in 0.00005 units change in industrial land. The reason is the same with the one explained for the residential land. In this regard, alternative functional forms would have provided better estimates. But for the aims of this study, this functional form is more appropriate. Inclusion of more independent variables in eq.s (10) and (11) would also result in a higher R-square but for the purpose of the study, only the population variable and gdp were included in the subject models.

5.3. Land Use Demand Projections

Land use demand projections were undertaken at the provincial level (NUTS3 level) and will be summarised through aggregating the results based on five different regions that are presented in Figure 5. Grouping used in the analysis is based on locational distribution of regional development disparity index introduced by the Turkish Ministry of Development (see KB, 2013; Ustaoglu and Aydınoglu, 2019). Regional development disparity index is a composite indicator of 61 variables that are based on different socio-economic indicators including education, demography, employment, health, economic competitiveness, financial indicators, innovation, accessibility and quality of life indicators. The details of regional disparity index can be seen in KB (2013). In fact, Turkey has been subdivided into seven regions according to geo-physical factors and climatic conditions. In the current study, the concept of homogeneous regions was adopted which is based on groups of NUTS3 regions i.e. cities that have similar levels of social and economic development. Given the regional development index values and geographical proximity of NUTS3 regions, Turkey was grouped into 5 regions namely west, north-west, north, south and east regions (see Ustaoglu and Aydınoglu, 2019). Based on the

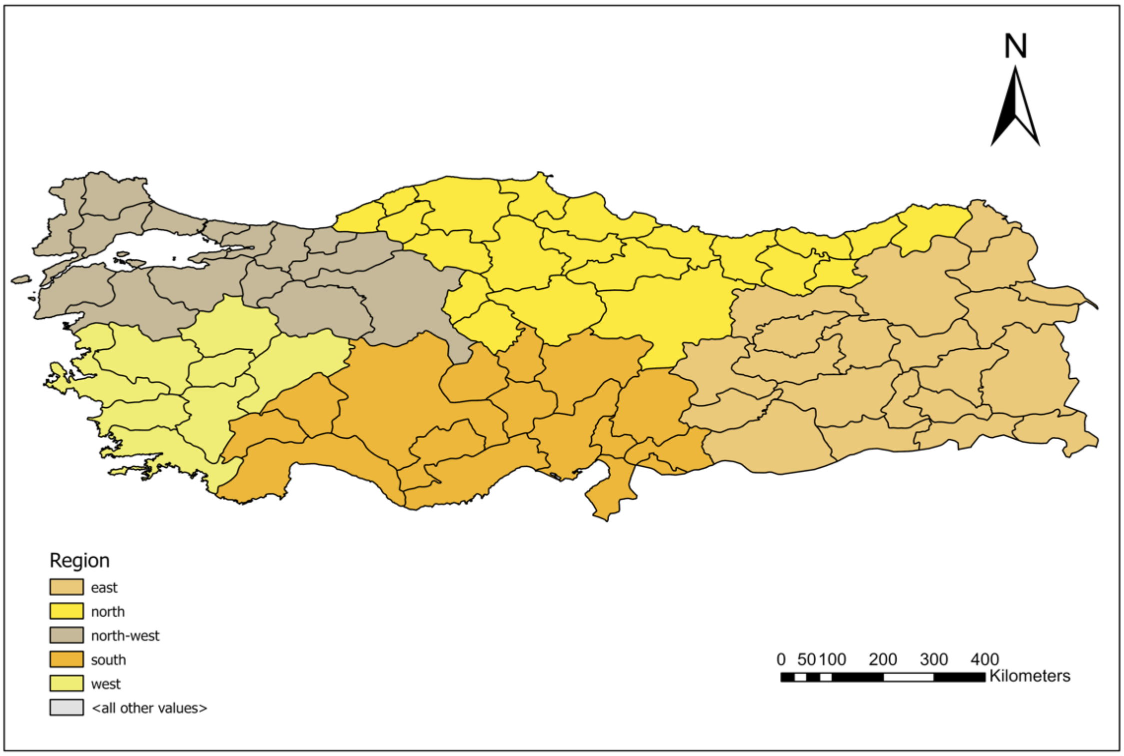


Fig.5. Representation of different regions used in the analysis

regional development disparity index, this grouping of the regions indicates that the cities in the groups show similar socio-economic and demographic characteristics and it is expected that there is similarity in the residential and industrial/commercial land development in each of these regions. For the subject reasons, the cities were grouped into 5 regions and the residential, commercial/industrial land growth trends are summarised for each of these regions. Given this spatial aggregation, the results for residential and industrial/commercial land projections are provided in Tables 2 and 3, respectively. The results obtained for each region through applications of three different approaches differ significantly from each other (Figures 6 and 7). The projected land from linear regression approach is the highest for east and north regions regarding both residential and industrial uses. For north, north-west and south regions, the estimated residential land from the density measure is the highest compared to all other estimated values. Except south and west regions, the estimates of residential land with trend extrapolation (exponential) method resulted in the lowest values (Figure 6). The lowest value for the residential land was obtained through the application of density measure approach for the west region and linear regression approach for the south region. Regarding industrial/commercial land estimates, linear regression approach resulted in the highest values for east and north regions (Figure 6). For the subject regions, the lowest values were obtained with the density measures and trend extrapolation approaches. For south, west and north-west regions, the highest values for industrial/commercial uses are linked with the linear trend extrapolation method while the lowest values were obtained from density measures and exponential trend extrapolation. It can be seen from Tables 2 and 3 that the projected land varies across the regions depending on the type of the projection method used. The distributions of urban land use prediction values at the NUTS3 level from regression analysis approach are presented in Figures 8 and 9. The city-based distributions of the predicted land use values obtained from the other methods can be obtained from the author. From Figure 8, the highest values of residential land are noted for İstanbul, Bursa and Ankara whereas the lowest values are found in the north, centre and east regions. Regarding the industrial land development (Figure 9), İstanbul, Ankara and İzmir have the highest predicted values and lowest values are observed in different provinces located in north, centre and east.

Table 2. Estimated land area (ha) for residential use

	Observed land (Ha) (2012)	**Estimated land (Ha) (2023)**			
Forecasting method		Density measure	Linear regression	Trend extrapolation (linear)	Trend extrapolation (exponential)
East	141589	147659	194765	149662	141536
North	117697	137104	186612	114110.	117781
North-west	270386	458829	298621	303173	270344
South	240083	285954	191631	268195	239933
West	135438	120254	197021	143091	135460

Table 3. Estimated land area (ha) for industrial/commercial use

	Observed land (Ha) (2012)	**Estimated land (Ha) (2023)**			
Forecasting method		Density measure	Linear regression	Trend extrapolation (linear)	Trend extrapolation (exponential)
East	18180	15466	37722	24039	18090
North	13620	35964	38183	17605	13564
North-west	80874	231278	94810	110660	80622
South	43229	39654	43434	57923	43120
West	31051	22942	27935	43503	30925

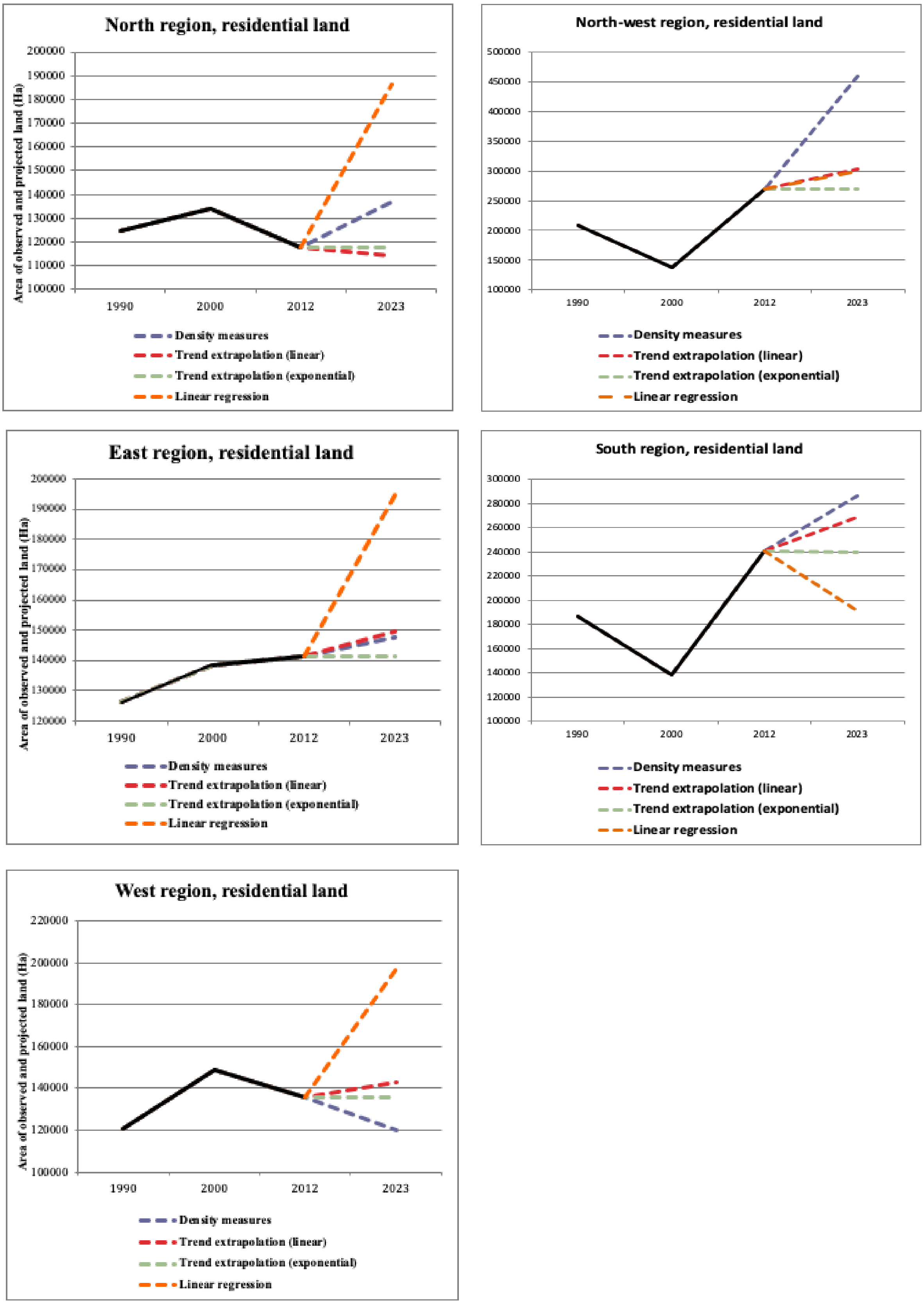


Fig. 6. Range of results for projecting the future residential land across regions

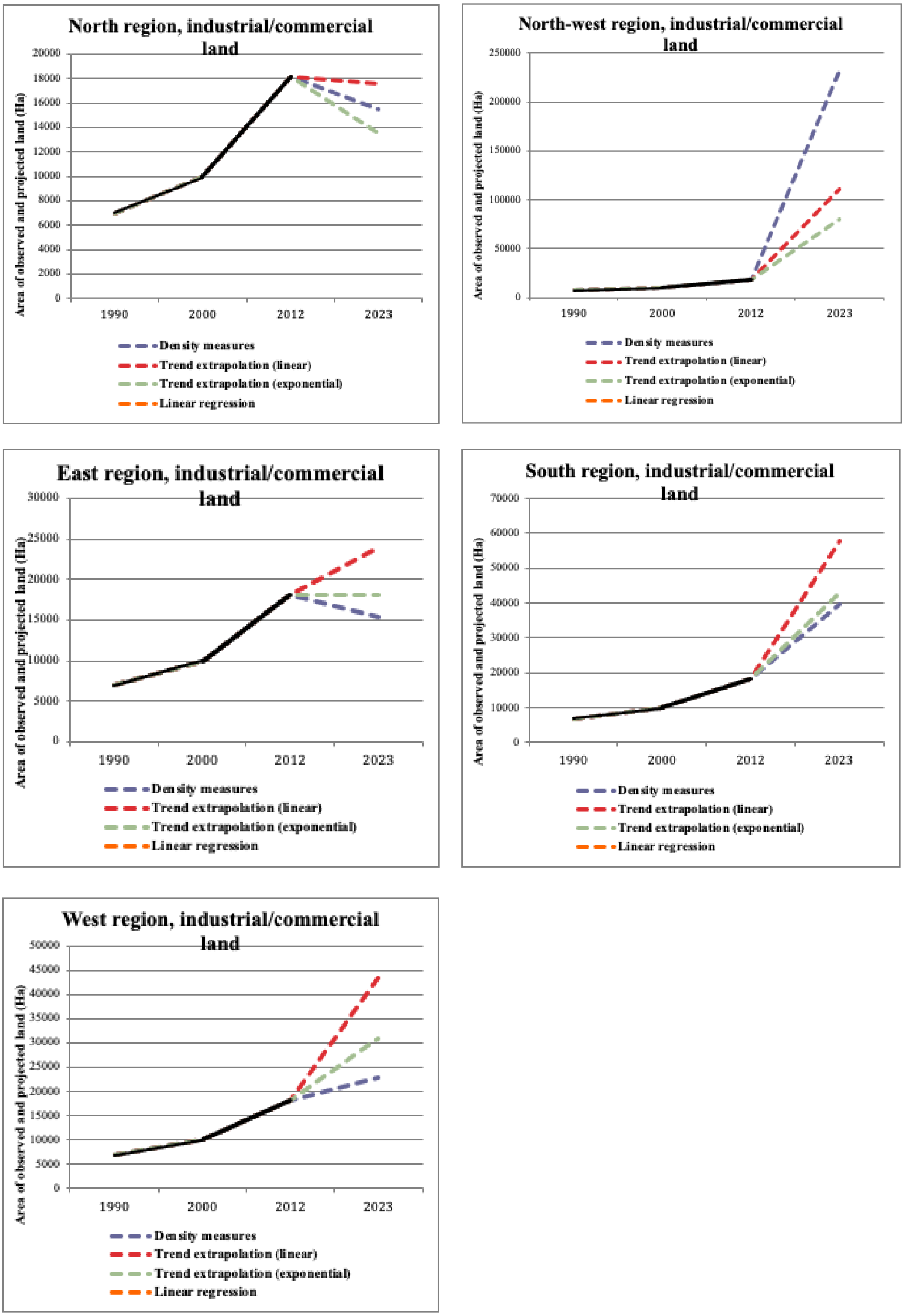


Fig. 7. Range of results for projecting the future industrial/commercial land across regions

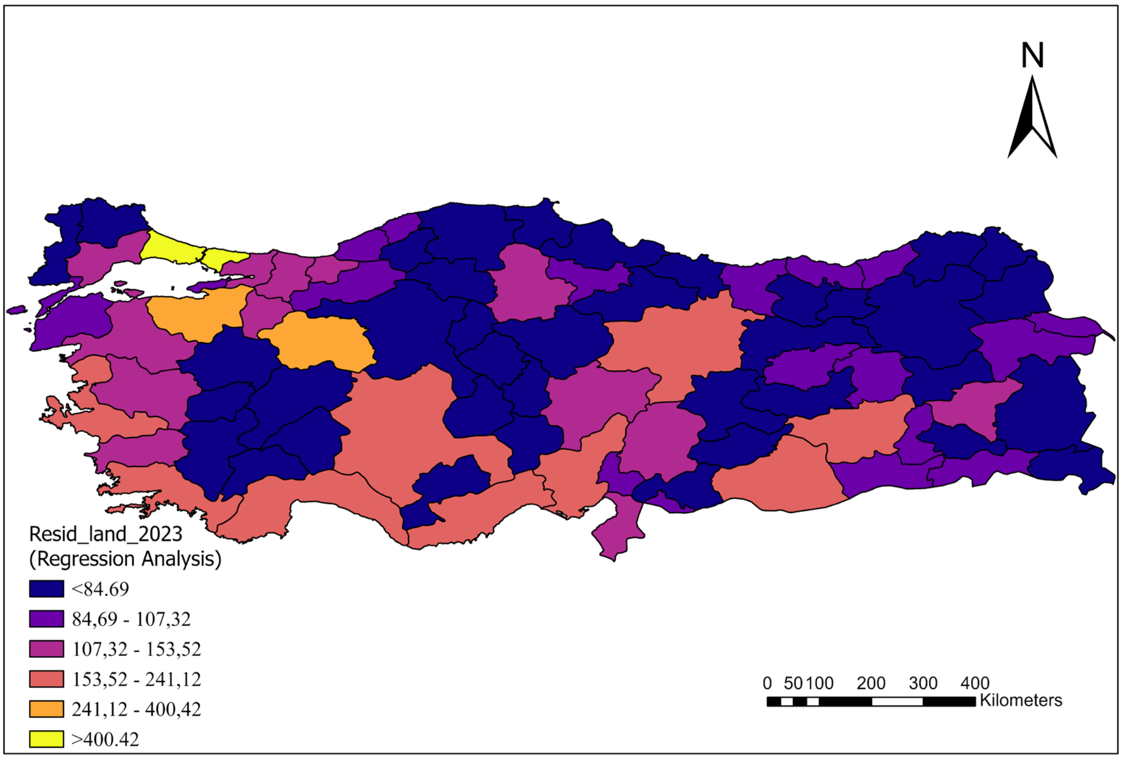


Fig.8. Distribution of predicted residential land use (in km^2) obtained from the regression analysis method

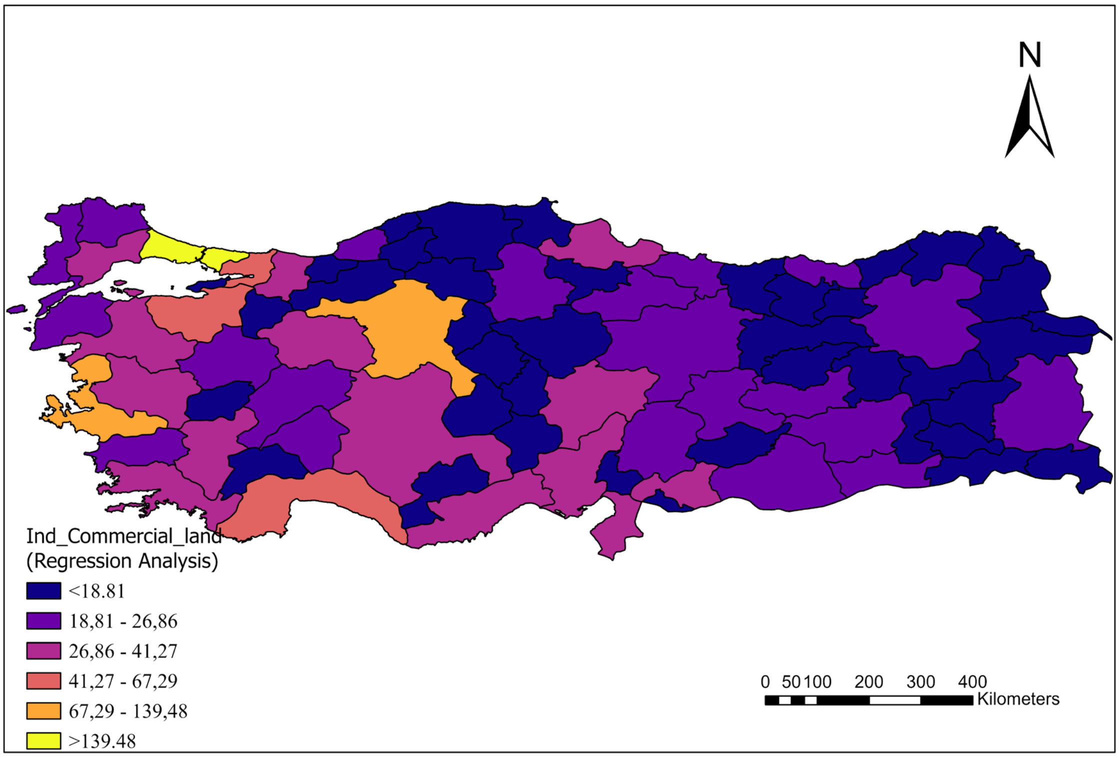


Fig.9. Distribution of predicted industrial/commercial land use (in km^2) obtained from the regression analysis method.

From Tables 2 and 3 it follows that given all the projection methods, north-west region which is the most developed area of Turkey accounts for the highest value for the new land use development. Istanbul, the most developed city of Turkey in terms of social and economic aspects is in the north-west region (Figure 1). Other highly developed cities such as Kocaeli, Bursa and Ankara (Figure 1) are also located in the subject region. Two other highly developed cities are İzmir and Antalya (Figure 1), former is located in the west and the latter is located in the south. Suburbanisation and urban sprawl type of development are prominent particularly in these biggest cities of Turkey. Therefore, the government and local authorities should develop plans and policies for the land management and sustainable urban development of these highly developed cities as well as the other regions in Turkey.

Finally, data on change in population and estimated residential land use is presented in Table 4. It can be seen that residential land estimated with density measure method is generally growing faster than population for the north, north-west and south regions. This points to low density development of urban areas which can be characterised as an unsustainable way of development. The trend extrapolation technique results in smaller estimates for the change of residential land use compared to change in population for the northern, eastern and western regions. For the north-west and southern regions change in residential land is close to change in population. Trend extrapolation (exponential) method projects negative change in residential land use in eastern, north-western and southern regions and projects positive but small changes in northern and western regions. The negative land use change implies that there is densification process rather than land expansion where higher density developments can be seen in an urban area.

Table 4. The comparison of population with estimated residential land use

	% Change in Population (2012-2022)	% Change in estimated residential land use (2012-2023)		
Forecasting method		**Density measure**	**Trend extrapolation (linear)**	**Trend extrapolation (exponential)**
east	8.98	4.29	5.70	-0.04
north	6.83	16.49	-3.05	0.07
north-west	14.04	69.69	12.13	-0.02
south	13.27	19.11	11.71	-0.06
west	20.58	-11.21	5.65	0.02

Note: Population data were obtained from Turkstat (2023)

6. Discussion and Conclusions

Turkey's overall level of urbanization is described as a relatively moderate increase in residential and recreational land and a twofold growth rate in industrial and commercial land, demonstrating the regions' industry-oriented development path. During the 2000-2018 period, industrial/commercial land accounted for the largest changes, followed by dump, mineral and construction site, residential land, transportation infrastructure and urban green land indicating that built-up land has been increasing despite the negative impacts of 2001 and 2008 economic crises on the building sector. The growth of GDP declined from 5% to 0.5% in 2007-2008 period and in 2009, GDP growth rate was -4.9% (OECD, 2010). It seems that the impact of the crises on the construction sector is a short-term impact and the sector had recovered in the following periods as demonstrated by the positive changes in the built-up land between 2000 and 2018. By using the land use change trends in the post-2000 period, this study's goal was to adopt several methods for estimating the demand for built-up area for the year 2023. Four different models were applied to project the land use demand for residential and industrial/commercial uses. Based on the availability of land cover/use data, the validation of the models can be undertaken as a future research focus.

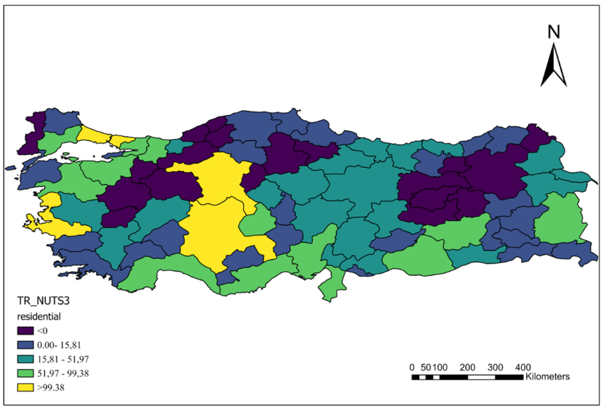
Future increases in land value will increase demand for new construction and increase the number of development right approvals. As a result, there has been unsustainable growth in cities that will contribute to many urban problems including environmental pollution, traffic congestion, social segregation, high risk of disasters and others. To address these issues, integrating decisions and policy making across different sectors is crucial for sustainable urban development. Despite the fact that land use demand projections will assist the policy making decisions, the Turkish research on the subject topic is scarce. This study aims to fill this gap by providing an example for the projection of urban land use demand at the regional level in Turkey. Different projections can be considered in the land use planning and policy making to ensure sustainability of urban and regional land development.

Tables 2 and 3 and Figures 6 and 7 summarize the findings and show the range of findings for the projection of historical land use changes in Turkey. The land use demand projections are highly uncertain. The diverse population growth within different regions is the primary factor influencing these imprecise predictions. The more dependent an approach is on population development, the greater the divergence from the observed expansion pattern. This can be a relevant effect for the density approach. Another reason may be the existence of outliers in the dataset. Overestimated regions can be those that are characterised by high population growth and densification which are not represented by the models. Regions experiencing population decline and urban expansion is also not correctly represented that can result in underestimation of the urban land use. Regarding the residential land use demand, linear regression estimated the highest values for east, north and west; density measure estimated the highest values for north-west and south regions. For the industrial/commercial land use demand, highest values were projected by linear regression method for east and north, by linear trend extrapolation method for north-west, south and west regions. The differences in population and GDP growth in different regions of Turkey is the key determinant of these questionable estimates. These estimates can therefore be used as different scenarios in the policy analysis and land use setting context concerning the residential and industrial/commercial land use for the year 2023. The estimated land demand from the regression analysis, density measures and trend extrapolation analysis can be fed into spatially explicit land-use models and can be spatially allocated through the use of land allocation modules. Land use models simulate the competition between various land uses based on physical and socio-economic drivers to provide information on the possible future state of the land system (White and Engelen, 2000).

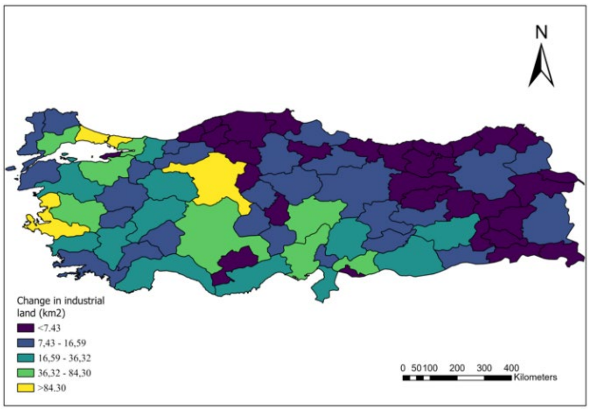
Regarding the uncertainty of the estimates, a number of issues have come to the forefront: Which projection method is the most appropriate in estimating the future land uses? Or what type of method is required to assess the ability of different approaches to project future land-use changes? In the current study, three different methods to predict the urban land uses were uncovered. However, the model validation was not undertaken which shows how the estimated values vary from the real values of urban land use. With the model validation approach, we can identify the methods that have the least deviation from real values, and we can select the most appropriate method for estimating the future land uses. The deviation between the predicted values and observed values is also highlighted by Zorlu and Yologlu (2022) that emphasize the importance of analysis on the subject topic. Future research is therefore needed to address these issues considering that these would be relevant in underpinning the factors driving land-use change and explaining the evolution of future land uses.

The main difficulty that has found during the stage of analysis was the input land cover/use data i.e. Corine Land Cover which provides relatively low thematic detail. This is related to the industrial/commercial land use where industrial, commercial and services uses were lumped into one single land use class. Therefore, these land uses were assessed as a single land use and the land use demand projections were computed for this single land use. It would be more appropriate to separate commercial land uses from the industrial uses and conduct the analysis at this level of detail. Despite these issues, CLC data has also advantages given that it is an extensive dataset providing consistent time-series spatial data for the whole country for the years 1990, 2000 and 2018. These dataset for the subject years were included in the current analysis for the future prediction of the urban land use. The accessibility of spatial maps at this detail is scarce and based on the provision of a more detailed spatial map for Turkey with a higher resolution, current analysis can be re-conducted for comparison purposes. The relationship between economic output and each of the industrial, commercial and services uses can be searched and these land uses can be projected individually for a specific future year. Does economic growth have impacted on land use or the other way around? Or is there a more complicated non-linear relationship between spatial distribution of land use and regional economic development? These questions, although not were the topic of this study, can be searched as part of a future research. The effect of spatial size on the outcomes of projection is another issue. The current analysis was undertaken using the NUTS3 level as the unit of the analysis and the results were summarised based on the homogeneous regions principles. Whether a finer scale will result in better projections or is it the coarser scale which may provide better outcomes are some of the research questions that need to be answered in future research.

Appendix



(a)



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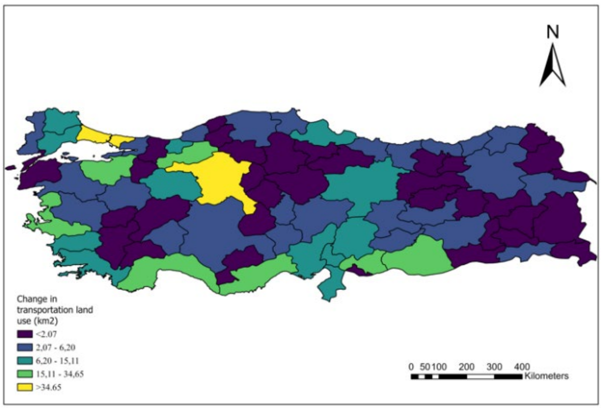

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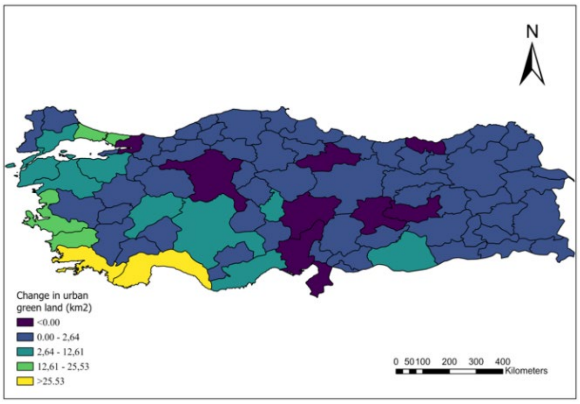

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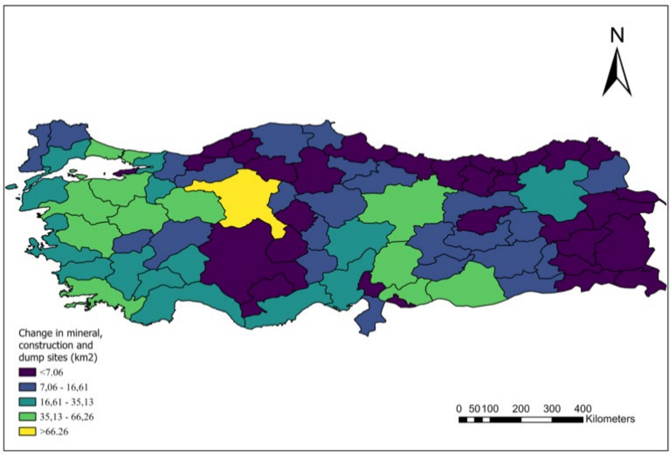

(e)

Fig. A1. Changes in (a) residential (b) industrial/commercial (c) transportation (d) urban green (e) mineral, construction and dump sites (in km^2) in Turkey between 1990 and 2018

Conflict of Interest

The author declares that she does not have a conflict of interest with herself and/or other third parties and institutions, or if so, how this conflict of interest arose and will be resolved, and author contribution declaration forms are added to the article process files with wet signatures.

Statement of Research and Publication Ethics

Research and publication ethics were considered within the study.

Ethical Approval

In this article, ethics committee approval is not required, and a consent form affirming that a wet-signed ethics committee decision is not necessary has been added to the article process files on the system.

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