Original Research

Monitoring Urban Sprawl Using Time-Series Data: Famagusta Region of Northern Cyprus

Kamyar Fuladlu1, Müge Riza1, and Mustafa Ilkan1

Abstract

Monitoring urban sprawl is a controversial topic among scholars. Many studies have tried to employ various methods for monitoring urban sprawl in cases of North American and Northern and Western European cities. Although numerous methods have been applied with great success in various developed countries, they are predominantly impractical for cases of developing Mediterranean European cities that lack reliable census data. Besides, the complexity of the methods made them difficult to perform in underfunded situations. Therefore, this study aims to develop a new multidimensional method that researchers and planners can apply readily in developing Mediterranean European cities. The new method was tested in the Famagusta region of Northern Cyprus, which has been experiencing unplanned growth for the past half-century. In support of this proposal, a detailed review of the existing literature is presented with an emphasis on urban sprawl characteristics. Four characteristics were chosen to monitor urban sprawl’s development in the Famagusta region. The method was structured based on a time-series (2001, 2006, 2011, and 2016) dataset that used remote sensing data and geographical information systems to monitor the urban sprawl. Based on the findings, the Famagusta region experienced rapid growth during the last 15 years. The lack of a masterplan resulted in the uncontrolled expansion of the city in the exurban areas. The development configuration was polycentric and linear in form with single-use composition. Together, the expansion and configuration manifested as more built-up area, scattered development, and increased automobile dependency.

Keywords

Famagusta, geographical information system, Mediterranean Europe, remote sensing, time series, urban sprawl

Introduction

A rapid increase in urban populations is widely associated with unplanned growth, which appears in a dispersed form (Shahraki et al., 2011). Although urban growth stands for economic prosperity, the sprawling of cities has destabilized environmental sustainability (Liu & Yang, 2015). In the last half-century, many Mediterranean European cities experienced transitions from compact to sprawled and polycentric forms. The main reasons are the lack of statutory planning and increased foreign ownership of real estate (Chorianopoulos et al., 2010; Salvati et al., 2013; Salvati & Morelli, 2014). Historically, Mediterranean European cities were recognized for their density, urban complexity, and social diversity, whereas the recent growth patterns of Mediterranean European cities reflect the expansion of territories manifested by other morphological criteria (Leontidou et al., 2007). According to the cultural perspective, contemporary Mediterranean European growth was designed based on the “thematization” of American sprawl (Muñoz, 2003). The early examples of sprawl, as mentioned in North American literature, occurred when wealthy families moved beyond the city boundaries to access amenities of the countryside and to escape urban issues, whereas Mediterranean European sprawl first happened when workers sought affordable housing close to industry and urban infrastructure in the urban periphery (Leontidou et al., 2007). The literature on Mediterranean European sprawl varies widely from that of Northern and Western Europe, North America, and many other regions. Famagusta, as a developing urban region in the Mediterranean, is not an exception and has had experiences similar to other Mediterranean European cities in developing countries. As a result, this study proposes a method for monitoring urban sprawl in cases of developing countries.

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Urban sprawl is a debated topic among scholars. Galster et al. (2001) stated that sprawl “is one name for many conditions” because characterizations of sprawl are not similar around the world (Galster et al., 2001; Hamidi & Ewing, 2014). One common agreement about sprawl is that it is a particular form of suburbanization (Behan et al., 2008; Burchell et al., 1998, p. 6; Downs, 1999; Galster et al., 2001). In addition, sprawl is a multidimensional phenomenon (Frenkel & Ashkenazi, 2008; Fuladlu, 2019, 2020; Fuladlu et al., 2018; Galster et al., 2001; Hamidi et al., 2015; Oueslati et al., 2015; Torrens, 2008). Although most sprawl was defined in relation to North American and Northern and Western European literature, recently sprawl literature about Mediterranean European cities has enriched the meaning by gathering information about the following features: sprawl’s impact is because of (a) the significance of urban form variations, (b) weak or absent regional planning, and (c) the incongruity between population and urbanity (Salvati & Morelli, 2014). Sprawl also can be defined conceptually as a land-use condition compared with the adjacent pattern at a particular time (Barnes et al., 2001; Galster et al., 2001). The majority of scholars agreed that sprawl is unplanned, land-consuming development that has low-density, single-use, automobile-dependent, and noncontiguous or leapfrog characteristics (Behan et al., 2008; Bhatta, 2010, p. 9; Bhatta et al., 2010; Burchell et al., 1998, pp. 6–8; Downs, 1999; Ewing, 1997, 2008; Frumkin, 2002; Fuladlu, 2019; Fuladlu et al., 2018; Gillham, 2007, p. 292; Hamidi et al., 2015; Harvey & Clark, 1965; Pendall, 1999; Sierra Club, 1998; Soule, 2006, p. 3; Torrens, 2008).

Similar to the variations in sprawl definitions, there is no consensus regarding sprawl’s impacts. For instance, Burchell et al. (1998, pp. 41–43) considered the environmental and social impacts of sprawl according to the following categories: (a) public and private capital and operating costs; (b) transportation and travel costs; (c) land and natural habitat preservation; (d) quality of life; and (e) social issues. Frumkin (2002) focus on the negative impacts of sprawl includes (a) direct effects of automobile reliance; (b) effects of land-use decisions; (c) social aspects of sprawl; and (d) environmental justice considerations. Despite its many negative impacts, urban sprawl has positive impacts like decreasing the risk of heatwaves (Mohajerani et al., 2017), and providing more personal and public open space to individuals and households. Besides, sprawl promises ownership of detached, single-family homes. Sprawl also offers low crime rates in comparison to compact development (Burchell et al., 1998, pp. 80, 93, 95). Sprawl has both negative and positive consequences; since it is considered uncontrolled development, the negative impacts outweigh the positive ones (Bhatta, 2010, p. 28). Mediterranean European literature does not focus on the negative impacts as heavily as North American literature, rather it considers the role of actors and processes more important to sprawl research (Chorianopoulos et al., 2010).

An absolute definition of urban sprawl with its diverse characteristics would be challenging. Relatedly, quantifying urban sprawl is difficult as well (Bhatta et al., 2010). Because there is not a clear definition of sprawl, authorities, in position to address the problem, are confused about how best to approach the problem. Therefore, before any action is taken in response to sprawl, the extent to which a city is “sprawling” must be determined. Moreover, monitoring sprawl’s development is necessary to avoid future undesirable development. Sprawling development is mainly monitored through Land Use and Land Cover (LULC) changes, which help to quantify results (Bhatta et al., 2010; Liu & Yang, 2015; Shahraki et al., 2011).

### Characteristics of Sprawl

The monitoring of sprawl is not straightforward mainly due to sprawl’s many definitions and the difficulty in choosing which parameters to use for calculating density (Pendall, 1999). Most early studies were limited to density analysis, since density was the prominent and often sole indicator of urban sprawl. However, later multidimensional methods proved the insufficiency of solo-dimension means (Hamidi et al., 2015). Galster et al. (2001) developed a pioneering multidimensional approach that monitored urban sprawl based on eight characteristics: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. The main problem of this method was its dependency on high-resolution census data. Moreover, the method was unfavorable since census data had to be partitioned into the cells within a square mile area. Later Ewing et al. (2003) introduced a method that combined several variables into four groups: residential density, land-use mix, degree of centering, and street accessibility. Hamidi et al. (2015), with the use of principal component analysis, offered an update to the Ewing et al. (2003) method. However, the main problems for both were that they were transportation-oriented and founded on a highly aggregated dataset, which used confusion metrics. Torrens (2008) initiated a toolkit to translate descriptive characteristics into quantitative form. He accommodated 42 characteristics of sprawl from micro- to macro-scales. Torrens tracked all aspects for 10 years for the total urban land and the sprawl areas. His method was reputable, but the use of different scales and metrics made it complicated to perform (Bhatta et al., 2010). Likewise, Oueslati et al. (2015) monitored urban sprawl in European cities with the use of various metrics, by applying the European Spatial Planning Observation Network (ESPON) dataset. While ESPON data are useful for a European research project, it cannot be utilized for non-European entities.

Frenkel and Ashkenazi (2008), with an unusual combination of sprawl indices, tried to monitor four metropolises (Jerusalem, Tel-Aviv, Haifa, and Be’er Sheva) of Israel. Their results also are not informative since their study relates to recent literature using multidimensionality and a strong
correlation between high sprawl rate, high population, and high growth rate. Moreover, Israel has urban planning problems like some other developing Mediterranean European cities. However, Frenkel and Ashkenazi reviewed five characteristics of sprawl, which have minimal overlap: growth rate, density, spatial geometry, accessibility, and aesthetic measures. Some of these characteristics are pertinent to the current study because they can be monitored in developing countries that lack census and administrative data. Therefore, the specifics of each characteristic’s application to this study are detailed.

**Growth Rate**

The growth rate characteristic indicates a change in the size of the population or the number of individuals in a particular place over a specific period. A growth rate indicative of sprawl is observed when the population growth rate in suburbia is higher than that of the urban core during the same period (Downs, 1999; Frenkel & Ashkenazi, 2008; Jackson, 1985; Oueslati et al., 2015). Rapid population growth increases housing needs. In combination with hastily made decisions, this causes uncontrolled development and sprawl (Bhatta, 2010, p. 20; Downs, 1999; Torrens, 2008) because growing populations must be accommodated somewhere, quickly (Torrens, 2008). Therefore, “uncoordinated growth” of the population, without concern for its consequences, results in urban growth that is unsustainable (Batty et al., 2003).

**Built Density**

Built density is a crucial factor for measuring sprawl (Downs, 1999; Ewing, 1997; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Gillham, 2007, pp. 290–291; Torrens, 2008). As Hamidi et al. (2015) mentioned, “low residential density is on everyone’s list of sprawl indicators.” Built density describes the average number of built units per unit of developable land (Shahraki et al., 2011). However, urban sprawl is a condition for a specific period of time when its built density does not increase or it decreases in comparison to the built density of the core of the urban area (Frenkel & Ashkenazi, 2008; Torrens & Alberti, 2000).

**Spatial Geometry**

Spatial geometry deals with geometric measures and can be adopted to ecological research or fractal geometry (Frenkel & Ashkenazi, 2008). Fundamentally, both ecological and fractal geometry measurements of the urban landscape are common in two forms: configuration and composition. Configuration is related to the geometry of the built-up area and is sometimes called continuity (e.g., Barnes et al., 2001; Galster et al., 2001), whereas composition is related to the degree of heterogeneity. The geometric configuration of sprawl refers to any irregular configurations, such as scattered or fragmented development (Galster et al., 2001; Torrens & Alberti, 2000). The more scattered or fragmented development is, the more costly and unsustainable it is (Torrens & Alberti, 2000). Barnes et al. (2001) called composition, diversity, and Galster et al. (2001) called it mixed uses. Composition deals with the percentages of the different LULC and represents the level of landscape heterogeneity (Frenkel & Ashkenazi, 2008).

**Accessibility**

Accessibility is an important factor in measuring sprawl since sprawl’s low density implies poorly accessible conditions, thus increasing automobile dependency (Fuladlu, 2020). The accessibility of sprawl development is analyzed mainly based on distance to the urban core and can be measured by factors such as number of travel lanes and road length. (Behan et al., 2008; Ewing, 1997, 2008; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Gillham, 2007, pp. 291–292; Torrens, 2008; Torrens & Alberti, 2000). With the use of a non-traffic method, Fuladlu (2020) concluded that increasing the built density may result in the decline of vehicle miles traveled.

**Monitoring Tools**

Sprawl can be monitored absolutely or relatively. An absolute monitor can sharply distinguish urban sprawl from compact development, whereas relative monitors can judge several attributes of urban sprawl in relation to each other or other dimensions. For example, the relative monitor can be based on different zones, cities, or times (Bhatta et al., 2010). In any case, a combination of methods and variables should be considered when measuring sprawl, rather than relying on a single technique. Therefore, a successful method would determine and combine adequate factors for sprawl monitoring.

A diverse array of techniques has been developed to monitor sprawl development. Time-series data, when studied for a specific area over discreet time periods, is a useful method to detect any LULC changes in numerical terms (Soule, 2006, pp. 273, 276). Some studies integrate Remote Sensing (RS) and Geographical Information System (GIS) while others use other metrics and indicators to demonstrate sprawl’s characteristics (Barnes et al., 2001). For decades, new dimensions of RS and its ability to integrate with GIS has created new opportunities in the field of urban morphology. Besides, RS and GIS, when used together, are recognized as a powerful and outstanding tool for monitoring alterations in the spatial distribution and pattern of LULC (Weng, 2001, 2002). Relatedly, the cost efficiency of this method makes it preferred for LULC detection (Liu & Yang, 2015; Ridd, 1995). Another positive argument for RS and GIS is derived from the accessibility of data collected by thousands of satellites orbiting the planet. Although some studies have criticized this method due to its limited ability to distinguish accessibility patterns (Hamidi et al., 2015), the availability of data makes it a competitive option, especially for developing countries that
lack metrics and census data from the field. According to Bhatta et al. (2010), RS dominates sprawl monitoring.

Although numerous valuable methods are available for monitoring urban sprawl (Barnes et al., 2001; Bhatta et al., 2010; Ewing et al., 2003; Galster et al., 2001; Hamidi et al., 2015; Torrens, 2008), most are inefficient at and impractical for investigating sprawl in developing countries. In many cases, the complexity of the proposed methodology and the dependency on high-resolution census and statistical data restricts its usability by developing countries. For these reasons, when creating and suggesting a measurement framework, researchers should consider the capacities of both developed and developing countries.

This study asserts that a robust and logical method for sprawl monitoring should meet the following criteria. The method should

(a) be multidimensional, covering at least the primary characteristics of sprawl;
(b) distinguish exurban (low-density) from urban (high-density) development;
(c) consider both quantitative and qualitative characteristics; and
(d) be easy to perform, applicable under any circumstance, and independent of high-resolution census or statistical data.

To achieve these objectives, the proposed sprawl monitoring method, which integrates time-series data with RS and GIS, employed the four characteristics detailed earlier in this article.

**Methodology**

In this study, the Famagusta region of Northern Cyprus served as a case study for exploring a new combined method of monitoring urban sprawl. The core of the applied method is structured according to time-series data (2001, 2006, 2011, and 2016) integrated with RS and GIS technologies to monitor the transformation of the designated sprawl characteristics. The following characteristics of sprawl were considered: growth rates, built density, spatial geometry, and accessibility. The required data were gathered from satellites and available census and statistical data. The methodology (Figure 1) includes three main parts. In the first part, the current situation of the Famagusta region is addressed. In the second part, the geometric boundary of the Famagusta region is defined, and the time-series satellite scenes are classified. In the third part, the predefined, four dimensions of sprawl are analyzed.

**Study Area**

The Famagusta region is located at 35°07′30″N 33°56′30″E on the east coast of Cyprus (Figure 2). The population of the Famagusta region of Northern Cyprus was 69,741 (de-jure, Table 1) in 2011 (State Planning Organization, 2013). The Famagusta region is governed as three subregions: Famagusta, Lysi, and Lefkoniko. Each subregion includes urban, exurban,
and rural areas (see Ravetz et al., 2013), but the boundaries of these areas are undefinable due to the lack of an official temporal map. Overall, the region has had an eventful history, especially following the Cyprus conflict. By 1974, the most dynamic neighborhood of Varosha was vacated due to decisions made by the United Nations. In 1986, the existing Higher Technological Institute transformed into Eastern Mediterranean University (EMU; Önal et al., 1999). EMU directly increased the population and housing demand in the Famagusta region (Oktay, 2005; Oktay & Marans, 2010). Moreover, by 2004, the enactment of the UN peace plan (Annan, 2004) had significantly boosted construction in Northern Cyprus, which was driven by domestic and foreign demand had significantly boosted construction in Northern Cyprus driven by domestic and foreign demand (Fuladlu, 2020; Yorucu & Keleş, 2007). According to the Yorucu and Keleş (2007),

The Plan assigns environmental policy primarily to the federal government, but there is significant state role in such areas as land zoning, building permits and land registration. The federal and constituent states are expected to cooperate, coordinate and harmonise their policies and legislation, through cooperation agreements, common standards and regular consultations.

Following these events and despite the Annan plan’s stipulations, the lack of a regional master plan and weak construction regulations resulted in sprawling development (Fuladlu, 2020; Hoşkara et al., 2009; Önal et al., 1999). Sprawl is observed primarily along the main arteries leading from Famagusta toward Nicosia (capital city) and toward Agios Sergios and Trikomo along the coastline.

Famagusta is a university city and hosts more than 17,000 students and academic staff from various countries. The lack of a master plan was still valid for the Famagusta region at the time of this study; therefore, landowners and construction companies essentially control construction. The construction activities in Famagusta largely reflect the student population and its potential growth.
### Remote Sensing and Geographic Information Systems

**Dataset.** The Famagusta region’s geometric boundary was obtained from the Famagusta municipality as a GIS-ready shapefile. This shapefile includes the boundaries of the urban, exurban, and rural areas. The total area of the study, according to the shapefile, is 896.72 km². The uninhabited neighborhood of Varosha (6.30 km²) was removed from the Famagusta region’s geometric boundary. Since this is a regional-scale study, the Landsat level 1 product with medium spatial resolution data can respond to the methodology (Lu et al., 2004; Lu & Weng, 2007). The time-series data scenes (Table 2) were mainly chosen from the summer months since summer scenes have minimal cloud coverage, maximum stability of meteorological conditions, and improved distinction between the forested, agricultural, and urban areas (Carlson & Arthur, 2000). Another selection criterion for the data scenes related to the availability of census and statistics data.

**Pre-processing.** The Landsat scenes path 176 and rows 35 and 36 (each 183 km by 170 km) are sufficient to cover the Famagusta region (Figure 2). The scenes were converted to a unique scene using seamless mosaic tools. To avoid image distortion, all datasets were projected to WGS1984 UTM Zone 36 North. The multisource data integration made geometric correction mandatory (Lu et al., 2004; Lu & Weng, 2007). This process used image-to-image registration (Richards & Jia, 1999, p. 57), and mosaics were resampled according to the 2016 mosaic. Fundamentally, the amount of Root Mean Square Error (RMSE) for pixel distortion should be less than 0.5 pixels for all pairs of scenes 30 m in size. The amount of RMSE was acceptable according to Mas (1999) study (Table 2).

Many scholars believe that atmospheric correction is not necessary for single-scene classification since the image is being classified on a relative scale (Lin et al., 2015; Song et al., 2001; Tso & Mather, 2001, p. 11). However, atmospheric correction was mandatory for the current study because multiple scenes were used for the classification (Lu et al., 2004; Lu & Weng, 2007; Tso & Mather, 2001, p. 11). The image-based, dark-object subtraction model was used for the atmospheric correction (Chavez, 1996; Song et al., 2001). The required constant for the radiometric calibration and atmospheric coefficients were extracted from Chander et al. (2009).

**Classification process.** In line with the aims of this research, instead of a detailed LULC classification, the classes were chosen according to Anderson et al. (1976). The classes are (a) built land—includes any structure such as buildings, communication and transportation utilities, and infrastructure; (b) vegetated land—includes any green covers such as forest, pasture, plants, or garden; and (c) open land—includes any remaining covers such as rangeland, wetland, and barren land. Accordingly, the required parameters for the classifications were collected for the predefined classes. Meanwhile, the process experimentally trained data for the classes mentioned above. The data training was made from the high-resolution raster and the field survey. Accordingly, 383 Regions Of Interest (ROI) were trained and these covered 36,550 pixels.

The Artificial Neural Network (ANN) was chosen for classification. This method was founded on a multilayer perceptron that includes three layers: input, hidden, and output. The classification process was formed mainly based on the back-propagation algorithm. To execute the algorithm, required parameters were collected from the user-defined training data. The value of the training data was gathered from the input layer. The received input layers had to be multispectral and possess a value for each pixel. By starting the classification process, all of the pixels were delivered to the neurons in the input layer. In the following stage, each pixel was evaluated using a back-propagation algorithm and based on the pixel weights stored on the hidden layer. The hidden layer was used to generate a predicted value for each neuron on the output layer (Jensen, 1996, pp. 421–423; Mather & Koch, 2011, pp. 250–252; Richards & Jia, 1999, pp. 232–235; Tso & Mather, 2001, pp. 77–79). The ANN classification process was accomplished by using the ROI and one hidden layer; the result is shown in Figure 3.

### Table 2. Landsat Metadata.

| Path/row | ID          | Collection        | Acquired date | Cloud cover | Spectral set of bands | Cell size | RMSE          |
|----------|-------------|--------------------|---------------|-------------|-----------------------|-----------|---------------|
| 176/36   | LE7176362001222MTI00 | ETM+ SLC-on       | August 10, 2001 | 0%          | 1 2 3 4 5 7           | 30 m      | 0.278656 (72 Points) |
| 176/35   | LC81760352016224LGN00 | ETM+ SLC-on       | August 10, 2001 | 0%          | 1 2 3 4 5 7           | 30 m      | 0.108580 (82 Points) |
| 176/36   | LT51760362011210MOR01 | ETM GLS2005      | June 5, 2006   | 0%          | 1 2 3 4 5 7           | 30 m      | 0.019239 (78 Points) |
| 176/35   | LE71760352006156ASN00 | ETM GLS2005      | June 5, 2006   | 0%          | 1 2 3 4 5 7           | 30 m      | 0.108580 (82 Points) |
| 176/36   | L8 OLITIRS | August 11, 2016   | 1%             | 2 3 4 5 6 7 | Reference Mosaic      |           |               |
| 176/35   | LC81760352016224LGN00 | ETM GLS2005      | June 11, 2016  | 1%          | 2 3 4 5 6 7           | 30 m      | Reference Mosaic |
| 176/36   | LC81760352016224LGN00 | ETM GLS2005      | June 11, 2016  | 1%          | 2 3 4 5 6 7           | 30 m      | Reference Mosaic |

Note. RMSE = Root Mean Square Error.
Classification assessment. There has been no agreement among researchers on the accuracy of the assessment methods; however, many studies used a confusion (error) matrix for the accuracy assessment (Congalton, 1991; Congalton & Plourde, 2002, p. 352; Foody, 2002; Lu & Weng, 2007). Besides the assessment methods, the sampling design is another issue that significantly affected the assessment (Congalton & Plourde, 2002, pp. 356–357; Foody, 2002; Lu & Weng, 2007). Foody (2002) argued that simple random sampling could work if the sample size adequately considers all classes. Congalton and Plourde (2002, p. 357) stressed the sample size should be 50 to 100 for each class type. The current study distributed 520 random sample points over the Famagusta region using GIS. To develop the random sample attribute table, the location of each sample was exported and a value assigned from the high-resolution raster and field survey. The designed random sample was subsequently compared with each classification, and the following matrix was developed (Table 3).

Sprawl Dimensions

Although the required time-series classification was developed by RS and GIS, the classification only partially helped to monitor the sprawl characteristics. Therefore, the limited statistical and census data for the Famagusta region was used to fill the gaps.

Growth rate. Lack of development regulation, together with the absence of master plans, are catalysts of sprawl in cases of developing countries. Therefore, the growth rate in the case of the Famagusta region is considered an important characteristic for urban sprawl monitoring. The growth rate can be calculated for any specified place based on its initial and current population. For Northern Cyprus, there are only 3 years (1996, 2006, and 2011) of reliable census data available after the Cyprus conflict (State Planning Organization, 1999, 2007, 2013). This population data partially matched the classification data; therefore, population census data became a basis for projecting the missing years (2001 and 2016). Regression curve estimation was used to estimate the population for 2001 and 2016. According to the outcomes, the logarithmic model (Equation 1) concerning R-square and significance exhibited maximum conformity (Table 4).

\[ f(x_i) = (a \times \ln(x_i)) + d, \]

where \( x_i \) is the variable of time, \( a \) is the estimated parameter, and \( d \) is the estimated constant.

Since the modern state that governs the Famagusta region has never been recognized by any country except Turkey, there are no other resources, such as administrative records or reports of international organizations, to compare to the estimated population. For this reason, the Root Mean Squared Logarithmic Error (RMSLE) was used (Equation 2) as a technique to identify the potential difference between the values predicted by the estimation model and the actual values. The RMSLE was employed to prevent underestimates and overestimates (Table 4).

\[ RMSLE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\log(p_i + 1) - \log(a_i + 1))^2}, \]

where \( n \) is the number of observations, \( p \) is the estimated value, and \( a \) is the actual value.

Based on the estimated parameters, the missing population figures were projected. Consequently, the annual rate of population growth (Equation 3) was calculated as follows:

\[ r = \frac{\log\left(\frac{P_n}{P_i}\right)}{n \times \log(e)} \times 100, \]

where \( r \) is the annual rate of population growth, \( P_i \) is the population in the current census, \( n \) is the number of years between censuses, and \( e \) is the base of natural log (with a value of approximately 2.71828...).

Built density. Built density is another crucial indicator of urban sprawl. Built density was calculated based on the ratio
between the built-up area and the total area of the specific zone. The main criteria for built density measurements are the residential units and the number of buildings in the built-up areas (Downs, 1999; Ewing, 1997; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Gillham, 2007, pp. 290–291; Torrens, 2008). The built-up area was retrieved from the classification section and density was calculated concerning the built-up land ratio (Tables 1 and 5). The results are shared in Figure 4.

### Spatial geometry

The spatial geometry of the Famagusta region was interpreted based on configuration and composition. At the regional scale, with the use of classification (Figure 3), the detected developments are mainly discontinuous and leapfrog. Whereas configuration at the local scale could be classified as the following major types: (a) linear development, which developed with respect to the main arteries and coastline, and (b) polycentric development around activity hubs, exurban settlements, and the historic city center. Both types of development lose their density in a gradual way based on distance from the focal element. According to the observations, the composition of the new development is mainly residential, and absent of other land uses or evident landmarks.

### Accessibility

The number of registered motor vehicles was used as a parameter for monitoring accessibility. The number of registered motor vehicles in Northern Cyprus was retrieved from the

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**Table 3. Confusion Matrix for Accuracy Assessment of Classification Process.**

| Time series | Classes | Vegetated land | Open land | Built land | Total | Producers | User | Kappa coefficient (K) |
|-------------|---------|----------------|-----------|------------|-------|-----------|------|----------------------|
| 2001        | Unclassified | 1 | 0 | 0 | 1 | — | — | — |
|             | Vegetated land | 48 | 8 | 0 | 56 | 90.57 | 85.71 | 0.7406 |
|             | Open land | 4 | 400 | 29 | 433 | 97.56 | 92.38 | |
|             | Built land | 0 | 2 | 28 | 30 | 49.12 | 93.33 | |
|             | Total | 53 | 410 | 57 | 520 | 91.5385 | |
| 2006        | Unclassified | 1 | 0 | 0 | 1 | — | — | — |
|             | Vegetated land | 50 | 14 | 1 | 65 | 94.34 | 76.92 | |
|             | Open land | 2 | 391 | 19 | 412 | 95.37 | 94.90 | |
|             | Built land | 0 | 5 | 37 | 42 | 64.91 | 88.10 | |
|             | Total | 53 | 410 | 57 | 520 | 91.9231 | 0.77164 |
| 2011        | Unclassified | 1 | 0 | 0 | 1 | — | — | — |
|             | Vegetated land | 51 | 14 | 1 | 66 | 96.23 | 77.27 | |
|             | Open land | 1 | 392 | 13 | 406 | 95.61 | 96.55 | |
|             | Built land | 0 | 4 | 43 | 47 | 75.44 | 91.49 | |
|             | Total | 53 | 410 | 57 | 520 | 93.4615 | 0.8192 |
| 2016        | Unclassified | 1 | 0 | 0 | 1 | — | — | — |
|             | Vegetated land | 48 | 13 | 3 | 64 | 90.57 | 75.00 | |
|             | Open land | 4 | 395 | 14 | 413 | 96.34 | 95.64 | |
|             | Built land | 0 | 2 | 40 | 42 | 70.18 | 95.24 | |
|             | Total | 53 | 410 | 57 | 520 | 92.8846 | 0.7981 |

**Table 4. Logarithmic Projection Model and Parameter/Constant Estimates.**

| Logarithmic equation | Model summary | Parameter estimates |
|----------------------|---------------|---------------------|
|                      | $R^2$ | $F$ | $df_1$ | $df_2$ | Sig. | Constant | A | RMSLE |
| Famagusta population | .999 | 624.303 | 1 | 1 | .025 | -20370524.162 | 2684756.658 | 0.00040 |
| Lysi population | .908 | 9.839 | 1 | 1 | .966 | -1217871.211 | 161843.727 | 0.00004 |
| Lefkoniko population | .913 | 10.462 | 1 | 1 | .913 | -313011.970 | 41967.956 | 0.00016 |
| Northern Cyprus motor vehicle (2016) | .972 | 553.367 | 1 | 16 | .000 | -163190596.200 | 21487859.358 | 0.01825 |

Note. RMSLE = Root Mean Squared Logarithmic Error.
published statistical yearbook (State Planning Organization, 2005, 2011, 2016). Since the registered motor vehicles were not classified according to the regions, the number of motor vehicles registered for the Famagusta region was estimated according to the population of the Famagusta region. According to a 2012 government decision to remove unregistered motor vehicles from government statistics, the number of motor vehicles was projected for 2016 with the logarithmic model (Equation 1). The required parameters and constants from Table 4 were applied and the results are shown in Table 6.

### Results and Discussion

The Famagusta region populations increased with a 2.18% mean annual growth and a total change of 38.69% over the last 15 years (Table 1 and Figure 4). Thus, population increased for the Famagusta subregion 53.62%, the Lysi subregion 9.77%, and Lefkoniko subregion 5.22% from 2001 till 2016. The rapid population growth significantly affected growth of the built-up area (Table 5) with built-up area increasing with a 9.67% mean annual growth rate and a total change of 326.69% for the same period. Therefore, built development increased for the Famagusta subregion 248.58%, the Lysi subregion 431.93%, and Lefkoniko subregion 490.84% from 2001 till 2016. A closer look at the subregion alterations reveals that Lysi and Lefkoniko development growth was nearly two times larger than the Famagusta development growth and Lysi and Lefkoniko population growth was nearly eight times lower than Famagusta population growth.

Rapid population growth is an instigator of sprawl since the growing population must reside somewhere. Lack of planning regulations in the Famagusta region led to increased Lysi and Lefkoniko subregions development growth. Moreover, Lysi and Lefkoniko subregions development has more affordable land prices compared with land in the Famagusta subregion. New development has sprawled to the Lysi and Lefkoniko subregions areas of the Famagusta region. The inconsistency between population and development growth significantly affects the population density. The overall population density of the Famagusta region (67.50 %) decreased over the past 15 years, with the Famagusta subregion −55.93%, the Lysi subregion −79.36%, and Lefkoniko subregion 82.19%. Accordingly, the population density decreased from 7,770 per km² total in 2001 to 2,526 per km² total in 2016 (Figure 4). The spatial geometry of development was affected in the absence of regulation as well. Although development sprawled toward suburbia, the configuration was shaped by factors such as land prices and proximity to the main arteries, the coastline, and the hubs.

The spatial geometry of development for the Famagusta region is linear and polycentric (Figure 3). Development along the Mediterranean coastline toward Agios Sergios and

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### Table 5. The Area of Built Lands for Each Subregion Based on Figure 3.

| Time series | Famagusta subregion built land | Lysi subregion built land | Lefkoniko subregion built land |
|------------|--------------------------------|---------------------------|--------------------------------|
|            | Area (m²)                       | Annual growth rate (%)    | Density (Km²)                  |
| 2001       | 4,466,700                      | 0.01686                   | 1,629,000                      |
| 2006       | 6,766,200                      | 0.02555                   | 2,276,100                      |
| 2011       | 9,559,800                      | 0.03609                   | 3,546,000                      |
| 2016       | 15,570,000                     | 0.05879                   | 8,665,200                      |
|            | Total built land area (m²)     |                           | Total built land area (m²)     |
| 2001       | 4,466,700                      | 1,629,000                  | 7,176,600                      |
| 2006       | 6,766,200                      | 2,276,100                  | 10,697,400                     |
| 2011       | 9,559,800                      | 3,546,000                  | 15,771,600                     |
| 2016       | 15,570,000                     | 8,665,200                  | 30,621,600                     |

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![Figure 4.](image-url) The population, built density, and population density of the Famagusta region.
Trikomo is linear development. Likewise, development along both sides of the main arteries toward Lysi, Lefkoniko, and Nicosia is linear, while development around hubs, such as village cores, the university, and other well-known real estate sites, is polycentric. Due to the absence of other land uses in the composition of new development, on one hand, and the decline of the build area to population ratio, on the other hand, automobile dependency increased in the Famagusta region. The number of registered motor vehicles increased by 118.35% over the last 15 years. Relatedly, the Famagusta region deals with a lack of public transportation, which likely adds to automobile dependency. Furthermore, the decline of the build area to population ratio and lack of mixed land uses has more impacts (Schimek, 1996) because low-density and single-use development also increase automobile dependency (Fuladlu, 2020).

**Conclusion**

Rapid population growth and the lack of regulation result in sprawling development in exurban areas. Urban sprawl is a multidimensional phenomenon that negatively affects the sustainability of urban development. There remains no standard definition for sprawl nor its dimensions, impacts, and drivers. Sprawl’s definitions vary from place to place, such that North American sprawl characteristics do not match those of Northern and Western Europe or the Mediterranean European cities. Likewise, the monitoring of urban sprawl is deeply discussed by researchers, and various studies and methods have been developed and applied. Some sprawl-monitoring methods are based on principle components, relevant metrics, or certain tools like RS and GIS. For the most part, these were developed considering the conditions of developed countries where high-resolution census and statistical data are available. Moreover, the majority of available methods were structured in complex ways that make them difficult to apply in cases of developing countries. This study used a time-series approach to consider the four characteristics of sprawl in the Famagusta region.

According to the results of the study, rapid population growth led to a construction boom over the past 15 years. The absence of a master plan fostered an uncontrolled development pattern that eventually resulted in sprawl. The configuration of the sprawl in Famagusta was polycentric and linear with single-use composition. The polycentric development formed around the rural villages and activity hubs, whereas the linear development occurred along the main transportation arteries and along the Mediterranean coastlines. The population growth was dominant in the urban areas while the construction boom responded to cheap land prices in suburbia and the urban periphery. Relatedly, the population density in suburbia significantly decreased compared with that of the urban area because of the abundant construction. Although built density increased, single-use composition in the Famagusta region facilitated automobile dependency, which further enabled sprawl once most of the population had a car. In addition, the lack of public transportation served as a catalyst, exacerbating automobile dependency.

The proposed method is a practical method for responding to sprawl as an urban planning problem. This study was conducted based on the belief that monitoring urban sprawl is a preliminary step toward minimization of its negative impacts. Moreover, this study’s proposed method affirms that monitoring of sprawl is possible for developing countries despite their lack of sufficient census and statistical data to perform other types of sprawl analysis. Finally, future studies should also consider the environmental concerns and sociocultural aspects related to the extremely scattered development patterns of sprawl in the Famagusta region and other developing and developed places.

**Availability of Data and Materials**

All data generated or analyzed during this research are included in this article.

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