Monitoring Urbanization Dynamics in Cyprus using Time-Series DMSP/OLS Nightlight Imagery

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Abstract

Urbanization is a major source of concern for the island of Cyprus for more than a century. In this paper, the Defense Meteorological Satellite Program Operational Linescan System (DMSP/OLS) night lights data, being recorded for more than two decades on an annual basis, are used as a primary source to quantify urbanization trends and patterns. The data were first inter-calibrated using a parallel regressions method to form a comparable time-series of images, and the degree of urbanization was subsequently estimated using the Sum of Lights (SOL) index. Accuracy assessment was based on the correlation between intercalibrated and socioeconomic data, namely population and gross domestic product (GDP). The results indicate that night lights can be a reliable source of information when used for capturing urbanization trends. In the case of Cyprus, the results illustrate that urbanization followed an upward population trend during the period 1992-2013, exemplified as a steadily increasing growth rate, particularly during the last decade. Three major centers of activity were identified in the Northern territories of Cyprus, which appear to be enhanced over time, while suburban areas absorb the majority of activities as a result of the high degree of saturation within urban centers. Lastly, Pearson correlation coefficient values imply a strongly positive linkage between urbanization and auxiliary socioeconomic data.

Keywords: Urbanization, nighttime lights, DMSP/OLS, SOL

1 Introduction

Population growth, along with the current globalization trend and rapid technological advances of recent decades, has been among the main causes of ongoing urbanization worldwide. As United Nations' latest report on urbanization prospects reveals, 10 years have passed since urban population surpassed rural population. Approximately 66% of the global population will be urban by 2050, causing the gradual extinction of rural space. Rural to urban migration forces us to take actions for mitigating urbanization effects, such as air and water pollution, greenhouse gas emissions (Johnson, 2001) or soil sealing (Stathakis, 2015). Thus, a big part of the research on global changes has been devoted to studying and monitoring urbanization along with its impacts in natural ecosystems (Elvidge, et al., 1997). As human activities are not evenly distributed in space, urban centers and suburban areas absorb the vast majority of urbanization pressures. In combination with the lack of proper planning, cities tend to spread, and growth takes the form of a phenomenon generally known as "urban sprawl (or diffusion)" (Bruegmann, 2005).

Cyprus is lagging behind the current trend of sustainable urban development and the compact city model, mainly due to two reasons. The first one is directly connected with the impacts of Turkish invasion in 1974, causing the migration of almost the half population of the island mostly towards the urban centers of the southern areas (Attalides, 1981). The second reason has to do with the tertiarisation of employment, as Cyprus's economy changed over time to become highly dependent on the services sector, the infrastructures of which are generally located within urban extents. For urban and regional planning to take effect, we should face cities as living organisms that are rapidly changing (Batty, 2013). Thus, in order to attain a full understanding of how their complex structures evolves, a constant monitoring of urban growth and urbanization dynamics is needed (White, et al., 2015).

The exploitation of satellite-derived data has proven to be particularly useful in delimiting urban boundaries (Abed & Kaysi, 2003). The main advantage of using remote sensing data is that they are not limited to any kind of spatial boundaries. However, when it comes to urbanization, traditional classification techniques using optical data cannot adequately capture the dynamics of such a phenomenon. Nightlight datasets in contrast, have been extensively used in urbanization studies as they can provide a consistent measure of human activity (Mellander, et al., 2015). Energy consumption related to human activities can be detected via this kind of sensors, and can be utilized to characterize urbanization trends and patterns.

Operational Linescan Systems of the Defence Meteorological Satellite Program (DMSP/OLS) in particular, had been spanning earth during night-time since 1960, thus being the most reliable source of nighttime light (NTL) data (Kramer, 2002). OLS's ability to detect relatively weak sources of lights (up to 10^{-9} $watts/cm2$/sr) on earth's surface, has led to the development of a variety of applications using derived data (Elvidge, et al., 2009a; Ma, et al., 2012).

The purpose of this study is twofold. First, to record and analyse urbanization in Cyprus, both in space and time, through the extraction of relative pattern and trend information using DMSP/OLS NTL time series. Second, to examine the relationship between urbanization and socioeconomic characteristics of Cyprus, namely population and Gross Domestic Product (GDP). The main novelty of the current study is that no other recorded studies of this kind exist in the literature for the area of Cyprus.

2 Data and Methods

The total area of Cyprus (9.251 sq. m.) was taken into account in this study. Cyprus is located in the Eastern Basin of the Mediterranean Sea. According to the Statistical Service of Cyprus, its population in 2011 was 840.407, excluding the population of Northern Cyprus. Cyprus is divided into six districts at the LAU 1 level.

The partition of the country after the Turkish invasion and the fact that no statistical data are available for the territory of Northern Cyprus, as well as the tertiarisation of economy call for external solutions to tackle the impacts caused by the rapidly urbanized cities of the country. It should be also stressed that the particular datasets and methods used for monitoring the spatio-temporal patterns of urbanization in Cyprus have never been used in the past to study such phenomenon in the area.

2.1 Data Sources and Processing

Six different satellites equipped with OLS sensors were spanning the Earth over 22 years (1992-2013) between 8:30 and 9:30 p.m. local time to record data with a swath of 3000 km and in a range of 0.5 – 0.9 μm VNIR (Elvidge, et al., 1997; Hsu, et al., 2015). Stable lights, emerged after DMSP-OLS Nighttime Lights Time Series data post processing to "clean" average visibility digital number values from ephemeral events such as fires, were used as primary data in this study. In addition, initial recorded data were resampled to reach the spatial resolution of 1 km and background noise was replaced with zero values, so as data values range between 1 to 63 (Elvidge, et al., 2014). It should be noted, however, that DN values in this dataset represent annual average digital values recorded by the visible band of the OLS sensor, and not a single capture. More precisely, 34 cloud-free annual composites of Version 4 of DMSP-OLS Nighttime Lights Time Series were downloaded via NOAA's National Centers for Environmental Information (NCEI), formerly the National Geophysical Data Center (NGDC), and available at https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html (Huang, et al., 2014). Data were also re-projected from WGS84 to the CGRS93 Local Transverse Mercator 1993 map projection.

Integrating datasets from different satellites can be a challenging task. The lack of on-board calibration from DMSP-OLS sensors does not allow for direct comparison of the derived composites. Moreover, sensor calibration prior to the flight does not account for radiometric discrepancies between different sensors (Elvidge, et al., 2014), while atmospheric conditions, image capture time and sensor band range differ as well. A post-flight intercalibration method to form comparable data sets has to be employed (Liu, et al., 2012).

2.2 Intercalibration

A variety of methods have been developed for DMSP-OLS NTL data inter-calibration. Most often, a regression model is established to correct initial NTL data for inconsistencies while reducing as much as possible the data variation between different years (Stathakis, 2016). Thresholding is also applied after intercalibration to maintain initial DN value range. Moreover, the average DN value for years in which more than one composites were available was retained, resulting into an "average satellite year" (Bustos, et al., 2015), excluding unstable pixels where a zero (0) value was assigned.

The most widespread method for stable NTL annual composite inter-calibration, is the "invariant region" method developed by Elvidge, et al. (2009a, 2009b). The above method includes choosing a stable area, in terms of illumination (Invariant Region) and a Base Year to form the reference composite, used to correct the remaining annual composites. Then, second-order polynomial regression models are constructed for each year using the coefficients derived from reference composite statistical processing.

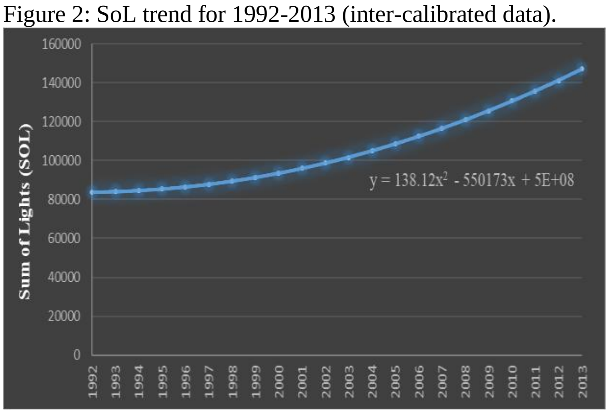
In this study, a novel approach developed by Stathakis (2016), namely "Parallel Regressions", was applied. The basic concept of this method is to use the general trend to reduce the error of the least reliable annual composites due to high-degree variations. According to Stathakis (2016), initial time-series of DN values are stored in a vector beginning from the first pixel onwards. Then, the Elvidge (2014) regression model is applied replacing the independent value with that vector. Starting with the first pixel onwards, inter-calibrated values of time-series composites are estimated for each pixel of every image. By the end of the process, a new time-series of annual composites is constructed. Even though the "Parallel Regressions" method can be highly demanding in terms of computing power, it can overcome the main drawbacks of the "Invariant Region" method, of having to choose an invariant region and a base year, thus producing a smoother time-series. Moreover, the increase of the degrees of freedom (DF) provides additional statistical significance to the model.

2.3 SOL Urbanization Index

Despite EU efforts to develop a definition for urbanization in order to be integrated in a common international scale (Dijkstra & Poelman, 2014), urbanization is a complex phenomenon and thus not easily quantifiable. In this study, we use the Sum of Lights (SoL) index as an urbanization metric, based on the general assumption that nightlights are a direct measure of urbanization. This assumption is based on the fact that SoL and both population and GDP, which constitute the main driving forces of urbanization, are highly correlated (Ghosh, et al., 2013).

In simple terms, SoL is the sum of pixel values of the NTL image in a particular area. Despite its simplicity, relative studies have proven that SoL can be a reliable indicator of urbanization trends. When depicted on a map, the spatial patterns of urbanization can also be revealed. Elvidge, et al. (2014) have also used SoL to evaluate the NTL data intercalibration process. Figure 2 below, shows a clear trend of SoL index for NTL inter-calibrated time series between 1992-2013 for Cyprus. As noted in Stathakis (2016), the main hypothesis is that urbanization constitutes a gradually growing process, thus its degree, ceteris paribus, should be growing over time. The exponential curve of SoL index shown in Figure 2 satisfies the above hypothesis.

Figure 2: SoL trend for 1992-2013 (inter-calibrated data).

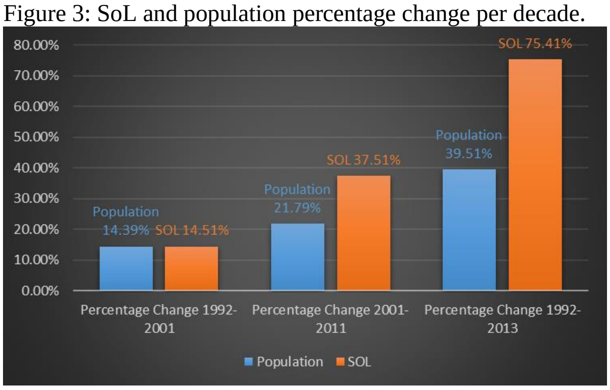


3.2 Urbanization in Cyprus

The SoL index in Cyprus has more than doubled in a decade (Figure 3). A new era of economic growth and development was about to start after 2000, despite 37% of the island's area being under Turkish occupation. Cyprus accession to the European Union in 2004 and the Eurozone in 2008 boosted Cyprus GDP, while population was increasing as well.

To avoid inconsistencies when comparing areas of different size, the SoL density index (Figure 4) was calculated for both Northern and Southern areas. In contrast to Southern areas,

Figure 3: SoL and population percentage change per decade.



Source: Cyprus Statistical Service.

Table 1: Regression models for inter-calibration assessment.

	Sum of Lights (y)		Sum of Lights Density (y)	Sum of Lights Per Capita (y)
Population	r = 0,992***	-	-	-
Population Density	-	-	r = 0,992***	-
GDP (ppp)	-	r = 0,970***	-	-
GDP p.c. (ppp)	-	-	-	r = 0,929***

Pearson Correlation Coefficient (r)
*Statistical Significance: ***p-value<0,01 **p-value<0,05 *p-value<0,1*

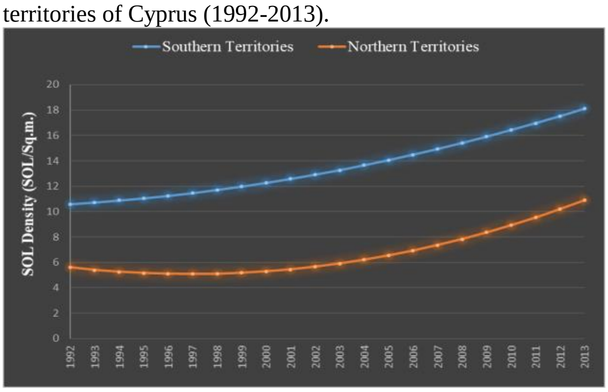
3 Results

3.1 Validation

Inter-calibration accuracy was assessed in two steps. First, the general trend of SoL index was evaluated. The lack of abnormal variations in SoL trend indicates that the data inter-calibration process followed leads to reliable results. Second, the SoL correlation with both population and GDP was used to assess the overall reliability of the inter-calibration method.

The Pearson correlation coefficient (r) corresponding to polynomial regression models was then used as a metric for quantifying the correlation between variables (Table 1). Time-series analysis was conducted using Ordinary Least Squares (OLS). Normalized variables of Population and GDP were also put to the test, resulting to a high degree of correlation with SoL. Both stages of inter-calibration assessment converge to the conclusion that "Parallel Regressions" method can reliably be used to calibrate DMSP/OLS time-series data, thus allowing the use of SoL index as an urbanization metric.

Figure 4: SoL Density trend for Southern and Northern territories of Cyprus (1992-2013).



urbanization in Northern territories of Cyprus was not rising all along. The SoL density index was declining during the first decade of study, while attaining a tremendous increase in the second decade.

Figure 5: Average DN values for Southern Areas of Cyprus per decade.

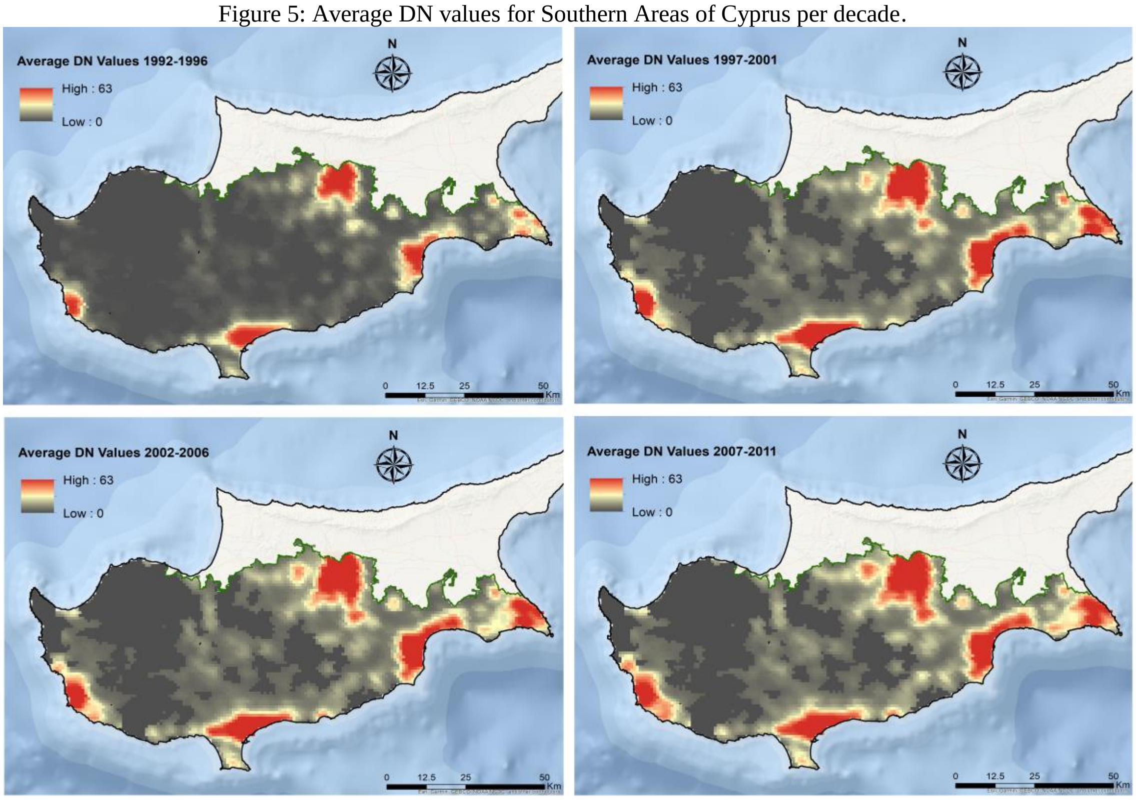


Figure 6: Average DN values for Northern Areas of Cyprus per decade.

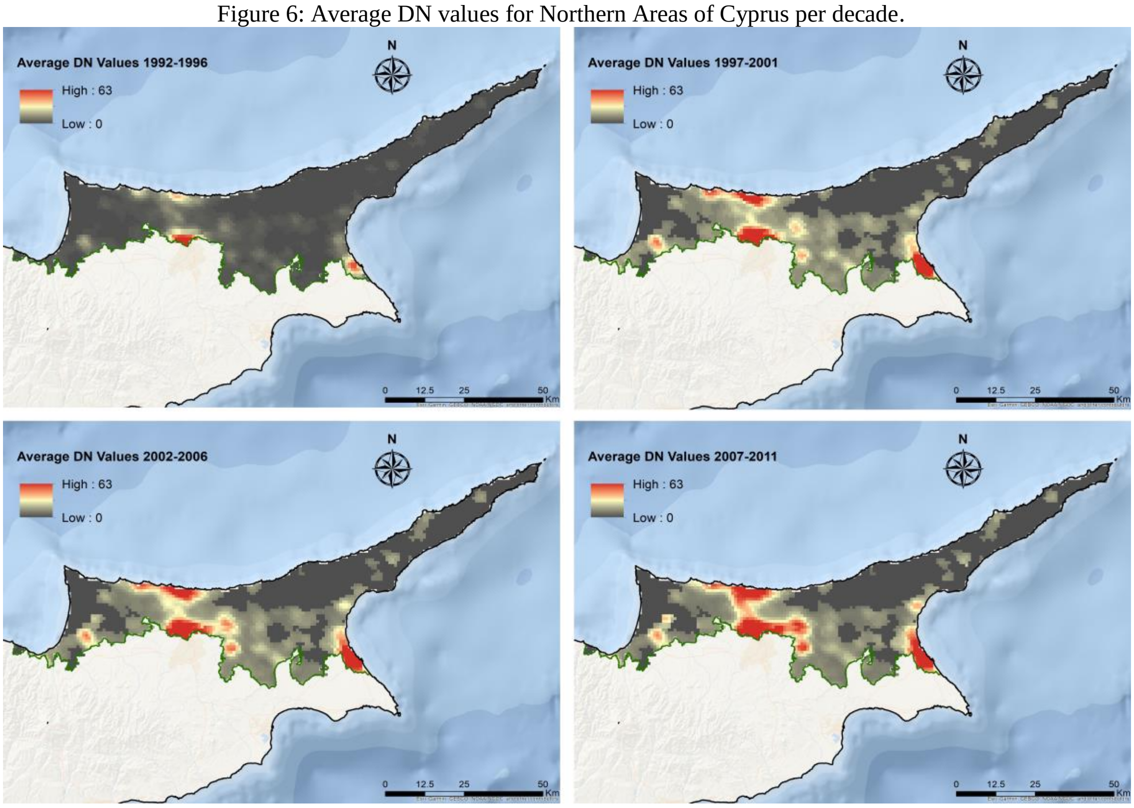
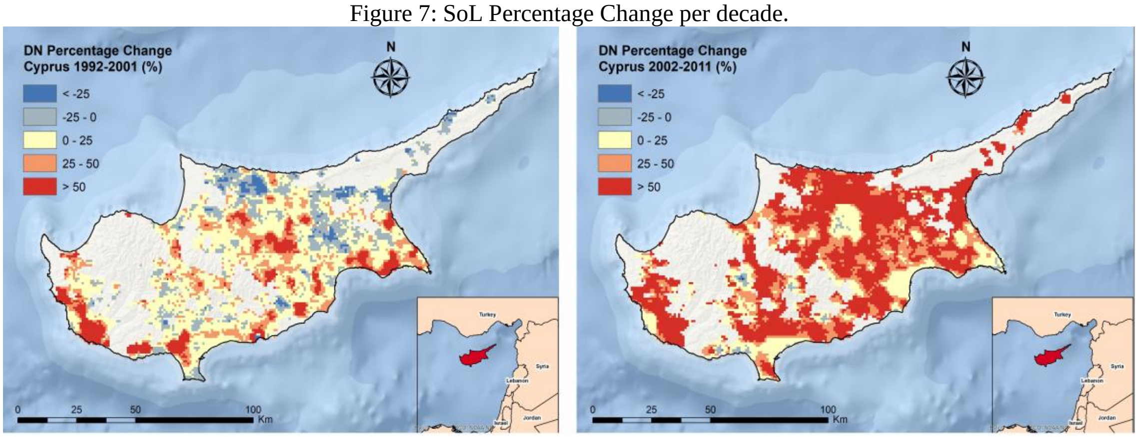


Figure 7: SoL Percentage Change per decade.



Nevertheless, the latest statistical clues for Southern territories indicate a decrease both in population and GDP, thus normally we expect the curve of SoL index to start declining after the period of study.

The spatial distribution and intensity of nightlights are depicted in Figures 5 and 6, revealing the overall urbanization patterns. As expected, the urban centres of Nicosia and Limassol have absorbed the vast majority of human activities in Southern territories, while activity in Larnaca and Paphos seems to be scattered along the coastline. Seasonality of Famagusta has led to the development of multiple clusters of activity during the summer season, as the most populated tourist area of the island.

Although in not a high degree, urbanization affected Northern territories as well. In particular, the urban centre of Keryneia located in the northern part of Cyprus has attracted various types of human activities, especially those connected with tourism. The Northern areas of Nicosia and Famagusta cities are getting more attention over time as well, while the rest of the areas have remained in undeveloped state. In both cases, the most significant variations in nightlights are observed during 1997-2001.

The percentage change of DN values (Figure 7) can provide a more transparent and comparative picture of the phenomenon. City centers seem to become saturated after 2001 and we can assume that urban growth is taking the form of sprawl (or diffusion) in most areas due to lack of proper planning and decision making. We should also note the comparative change of nightlights in occupied areas between the two decades. Especially after 2000, the number of settlers from Turkey in Cyprus has significantly increased, enhancing the local growth prospects. Tertiarisation of economy has also led to a huge stream of internal migration from rural areas, mainly from Troodos, towards the peri-urban areas.

4 Conclusions and Further Research

Based on the results of this study, urbanization presented a relatively equal distribution among urban centers in Cyprus, alluding to a polycentric urban growth model. However, the rapid changes on the island did not allow for proper planning, leading to the development of urban sprawl phenomena for some of the suburban areas, mainly across the main road axes. Due to urban center saturation, development around Nicosia should be carefully planned onwards and measures to mitigate the consequences of diffusion effects should be taken.

Despite the assumptions made, DMSP/OLS NTL data, even though they are not directly correlated with urbanization, can provide a consistent measure of its dynamics, thus can be considered as a reliable source of information for this kind of studies. The inter-calibration method proposed by Stathakis (2016) and applied for the first time, proved to give better results compared to widely used existing methods.

The time-series created (1992-2013) is long enough to provide useful conclusions regarding urbanization, including information emerging as a result of historical and other events. However, additional data availability both before and after the study period would lead to safer and more meaningful results. If available, data before 1992 would help obtaining a clearer picture of the impacts of Turkish invasion, as big demographic changes due to integral migrations had definitely contributed to the urbanization phenomenon in Cyprus. On the other side, there are no available DMSP/OLS NTL data after 2013, a year onwards from which Cyprus was hit by an economic crisis that changed both GDP and population dynamics.

Moreover, SoL and SoL density indices offer reliable means to quantify urbanization as proved in the current analysis. General trends and spatial patterns of urbanization have been revealed. Monitoring urbanization dynamics through interpreting the above mentioned results can provide planners and decision makers a powerful tool, helping them to form the proper policies for evaluation and future planning.

Finally, the potential fusion of DMSP/OLS NTL data with Visible Infrared Imaging Radiometer Suite (VIIRS) data, in combination with the latest available statistical information will provide a very promising avenue for extracting useful information regarding the latest urbanization trends and dynamics in Cyprus.

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