STUDY OF URBAN GROWTH DYNAMICS USING GHSL AND NIGHT TIME LIGHT DATA

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KEY WORDS

Defense Meteorological Satellite Program, Operational Linescan System, Urban growth, Vegetation Adjusted Nighttime light Urban Index.

ABSTRACT

The study aims to understand the urban growth dynamics of class 1 cities of Uttarakhand using Global Human Settlement Layer (GHSL) data and Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS) data. The DMSP/OLS data is corrected for saturation using urban indices namely Human Settlement Index (HSI) and Vegetation Adjusted Nighttime light Urban Index (VANUI). The GHSL data and corrected DMSP/OLS data were then compared and correlated to find out the interdependency of these two datasets. The GHSL data was analyzed for two decades, to find out the growth character of different class 1 cities of Uttarakhand , and the results were correlated with the night light data. The growth pattern of the cities showed least growth in the urban centers and increasing growth towards the city peripheral regions, which depicted densification of the cities and the increasing sprawl. The urban sprawl phenomena was negatively correlated with the nightlight data, which showed high intensity of light in the cities and lessening intensity towards the periphery regions . The study demonstrated the usefulness of GHSL and DMSP/OLS datasets in analyzing the urban growth dynamics of the city. The interlinking of both datasets helped to recognize the urban growth character as well as its spatial attributes.

1. INTRODUCTION

The understanding of the character of urban growth is vital for the effective planning and development of the urban areas. The use of newly available Global Human Settlement Layer (GHSL) data can be quite useful in urban growth studies due to its free availability and also the detailed grids providing data on the built-up, population and settlement models. Simultaneously the night time lights (NTL) data acquired by Operational Linescan System abroad the Defense Meteorological Satellite (DMSP/OLS) can also be used to identify the habituated regions (Corbane et al. 2016).

The present research aims to analyse the urban growth dynamics of class 1 cities of Uttarakhand, using GHSL and DMSP/OLS night time datasets. The aim is achieved with the help of following research objectives:

1. To study applicability of urban indices for removing OLS data saturation.
2. To evaluate the correlation between GHSL and saturation corrected OLS datasets.
3. To analyse urban growth dynamics based on GHSL and saturation corrected OLS datasets.

2. GLOBAL HUMAN SETTLEMENT LAYER (GHSL)

GHSL concept was introduced by the JRC in the years 2010-2011 with the aim of providing improved, ready-to-use or pre-calculated baseline data reporting about the human presence on the globe in support to crisis management applications. GHSL provides a consistent time series of high-resolution data on built-up areas covering forty years. This in turn allowed the testing at the global level of the degree of urbanization, a new, people-based definition of cities and settlements. It practically demonstrates how new open data and innovative data processing technologies may support novel global awareness on urbanization trends and dynamics. GHSL consists of three main information components hierarchically placed at three different levels of abstraction: Global Human Settlement built-up areas (GHS-BU), the GHS population grids (GHS-POP) and the GHS urban/rural classification model (GHS-SMOD) (Freire et al. 2016).

The GHS-BU grids are produced from Landsat imagery collections (epochs: 1975, 1990, 2000 and 2013-2014). GHSL technology relies on automatic analysis of satellite imagery to produce unprecedented fine scale maps quantifying built-up structures in terms of their location and density. The image processing technology exploits structure (texture, morphology, and pattern) as key information, outputting a texture-derived "built-up presence index". The distribution of built-up areas is expressed as their proportion (ratio) of occupied footprint in each cell. GHS-BUILT is aggregated from its native output resolution (38 m) to 250 m and 1000 m, in World Mollweide projection.

3. DEFENSE METEOROLOGICAL SATELLITE PROGRAMME OPERATIONAL LINESCAN SYSTEM

The OLS is an oscillating scan radiometer with two broad spectral bands: the Visible Near-Infrared (VNIR, 580~910 nm Full Width at Half Maximum (FWHM)) and Thermal Infrared (TIR, 1030~1290 nm FWHM). The current OLS system has been operated by the USA Air Force DMSP since 1976. Night time images are collected using the VNIR band, which is intensified by a photomultiplier tube to detect low level of radiance emission. There are two spatial resolutions of night time images: "fine" resolution data have a nominal spatial resolution of 0.56 km, while "smooth" data have a nominal spatial resolution of 2.7 km with 5 × 5 block averaging. Given the sensitivity of the sensor at night, DMSP/OLS data can be used as a proxy for built up area. The availability of freely downloadable, annual stable night light data at a moderate spatial resolution of 1 km has enabled researchers to study urban dynamics at global, national, and regional level. Although the advantages of night time DMSP/OLS data are commonly recognized, several disadvantages in using this data have also been identified, namely:

1. Relatively low spatial resolution 2. Absence of on board calibration 3. Lack of inter-satellite calibration 4. Lack of records of in-flight gain changes 4. Limited 6-bit quantization of digital numbers 6. Light saturation in highly populated urban centers because of the standard operation at the high gain setting 7. The blooming effect (i.e., overestimation of lit area) due to the coarse spatial resolution of data and reflectance of light from adjacent areas (e.g., water bodies).

The ability of NTL data to characterize inter and intra urban variation is limited due to the well-documented issue of saturation of data values, especially in urban cores (Elvidge et al. 2007). If the saturation of NTL data values can be corrected or reduced, it could greatly improve the utility of these data for inter- and intra-urban applications. Since the archival DMSP/OLS NTL record spans twenty years from its start in 1992, a simple method to reduce the saturation could yield significant benefits for time series studies of intra-urban form, structure, and energy use globally (Zhang et al. 2013). For reducing the effect of saturation, urban Indices were developed by combing the night light data with MODIS NDVI data, with the assumption of low NDVI values for built up spaces with illumination values. In the present study two urban indices were used for OLS data correction, viz., HSI and VANUI.

4. HUMAN SETTLEMENT INDEX (HSI)

Vegetation indexes like NDVI (which represent the vegetation abundance) are negatively correlated with the impervious surfaces and can be used for estimation of built-up areas. Since, NDVI and OLS data are complementary to each other, in the sense, that in a pixel where the fraction of built-up area is higher, there will be less vegetation cover which will result in high DN values in OLS data but corresponding low values in NDVI and vice versa. Hence, by combining both OLS and NDVI data sets, a HSI is developed to estimate the fraction of built-up area on per pixel basis (Lu et al. 2008, Maithani 2010). The strong negative relationship between the vegetation indices and the built-up surface, is utilised in defining HSI (equation 1). A higher HSI value represents a higher fraction of built-up area in a pixel and vice versa.

$$HSI = [(1-NDVI_{max}) + OLS_{nor}] / [(1-OLS_{nor}) + NDVI_{max} + (OLS_{nor} * NDVI_{max})] \text{ ---- } (1)$$

where,

$$OLS_{nor} = (OLS - OLS_{min}) / (OLS_{max} - OLSmin)$$

OLS_{min} and OLS_{max} are the minimum and maximum values in the night-time OLS image,

$$NDVI_{max} = MAX (NDVI_1, NDVI_2, \ldots, NDVI_{12})$$

where,

$NDVI_1$, $NDVI_2$, …, $NDVI_{12}$ are the 12 monthly MODIS NDVI images acquired in a particular year.

5. VEGETATION ADJUSTED NTL URBAN INDEX (VANUI)

The Vegetation Adjusted NTL Urban Index (VANUI) also combines MODIS NDVI with NTL and reduces the effects of the NTL saturation in urban areas (Zhang et al. 2013). VANUI is also based on the fact that vegetation and urban surfaces are inversely correlated. VANUI is developed as a robust spectral index which uses a vegetation signal to reduce NTL saturation and to increase inter and intra urban variability in night time luminosity values (equation 2)

$VANUI = (1- NDVI_{mean}) * NTL$ ---- (2)

where,

$NDVI_{mean} = MEAN (NDVI_1 , NDVI_2,,…., NDVI_{12})$

where,

$NDVI_1$, $NDVI_2$, …, $NDVI_{12}$ are the 12 monthly MODIS NDVI images acquired in a particular year.

The index is intuitive, simple to implement, and enables rapid characterization of inter and intra urban variability in night time luminosity. Assessments of VANUI (Zhang et al. 2013) shows that it significantly reduces NTL saturation and increases variation of data values in urban core area and can be used for studying the urban structure, energy use, and thus carbon emissions. VANUI was applied to a number of studies in order to test its capability and to reduce the saturation of the night light. The capability of VANUI to reduce the saturation of light in the cities of USA, China, India, Brazil, Japan were analysed by Zhang et al. 2013. The study confirms that VANUI reduces NTL saturation, increases inter and intra urban variability of NTL values, and is a useful index to characterize urban areas.

6. STUDY AREA AND DATA BASE GENERATION

The study of urban growth dynamics is carried out in the state of Uttarakhand with major focus on the class 1 cities viz., Dehradun, Haridwar, Roorkee, Haldwani, Kashipur and Rudrapur (Figure 1).

6.1 Data sources used

6.1.1 GHSL data: In present study, GHSL data of the years 1992, 2000 and 2014 were used. The data consists of built-up density, population grids and the settlement model for the study area, at 1 km spatial resolution. The built up density grid represents the built-up intensity in the area. The population grid represents the population in the area, and its density. The settlement model represents the type of settlement in the area according to the population density.

6.1.2 DMSP/OLS data: OLS data of three years 1992, 2000 and 2012 were used for the study. The light areas in the image represents the settlement regions and the darker the cells, the lesser the habitation.

6.1.3 Intercalibration of OLS data : The OLS data suffers from intercalibration problems due to the differences occurring in the satellites, which results in same ground radiance being represented by different DN values or different ground radiance being represented by same DN values. Due to this absence of on-board calibration, the DMSP/OLS stable NTL annual composites product derived from multiple sensors (F12–F18) and different years (1992–2013) are not comparable directly. Elvidge et al. 2009 worked on OLS data intercalibration parameters, which were used in the present study.
The OLS data is calibrated using the following equation : $NTL_{adjust} = a + b * NTL + c*NTL^2$

where,

NTL_{adjust} is the calibrated night light image DN value, NTL is the original value, a, b and c are the coefficients derived from the second-order regression model .

7. ANALYSIS AND RESULTS

7.1 Correlation of HSI and VANUI with OLS data

The HSI and VANUI outputs were correlated with the OLS data in order to find out the correctness of the applied index in the study area. The correlation between the two indices and the OLS data is shown in Table 1. The correlation between the indices and the OLS data clearly depicts that the HSI is not appropriate for study in the present context. There is a very less correlation between the two datasets showing the loss of the character of the data. On the other hand, VANUI index showed a high correlation with the OLS dataset, thus portraying the high usability of the index in the area and also its success in reducing the saturation effect.

7.2. Correlation between GHSL and NTL datasets

GHSL data is a product of satellite imageries depending on the spectral signatures of various objects. NTL data works in a totally different method and the information captured also varies in nature. The correlation between both the datasets hence need to be verified before making further conclusions on the interdependency of the data. The dependency of the datasets was compared using scatterplot. The positive correlation between GHSL and NTL data shows that there is a good interdependence of built-up and night light (Figure 2)

7.3 Monitoring the NTL variation with urban growth

The NTL data can be used to assess the built-up change and the urban growth of an area. The NTL intensity changes with the built area and it can be helpful in identifying the socio-economic conditions of the growth areas. The variations of the NTL intensity help to identify the growth areas. The high density areas will have a higher light intensity and the low density zones a lower light intensity. The built-up change from the year 1992-2000 depicts the urban growth and comparing it with NTL 2000 data, the growth areas can be verified as sprawl areas or densification zones. Hence, there should be a negative relation between VANUI and urban growth during 1992-2000 period. The comparisons between both the data sets are carried out using visual analysis and correlation methods. The correlation calculation, showed a negative correlation (**-0.5548)** between both the datasets, thus depicting the utility of NTL to showcase the settlement conditions.

7.4 Monitoring Built-up area growth

The GHSL maps of the years 1992, 2000 and 2014 were compared to find the built-up area growth in the study area. The urban growth was divided into three classes namely,

a. Class 1 consisted of cells with low change in the built-up value

b. Class 2 consisted of cells with medium change in the built-up value

c. Class 3 consisted of cells with high change in built-up value.

The built-up growth map was generated for the period 1992-2000 and 2000-2014. The results showed a large amount of cells in the Class 3, followed by Class 2 and then Class1. (Figures 3a and 3b).The analysis of the spatial distribution of the of the three classes revealed that the Class 1 growth cells are located mainly within the existing built-up areas, where are the Class 2 and Class 3 cells are situated in the city fringe. Thus it can be inferred that the urban areas in the region is experiencing a rapid outward spread. There is slow densification of existing built up areas, as depicted by the Class 1 cells.

8. CONCLUSION

The study evaluates urban indices used for removing the saturation in DMSP/OLS datasets. Human Settlement Index (HSI) and Vegetation Adjusted Night time light Urban Index (VANUI) were calculated using the DMSP/OLS and NDVI dataset. A correlation analysis of HIS and VANUI with GHSL data showed that VANUI was a better index compared to the HSI. The different grids of the GHSL data were analysed to find out the growth character of the class 1 studies in Uttarakhand and the results were correlated with the NTL data. The growth pattern of the cities was also evaluated using the temporal GHSL datasets. The results showed least growth in the existing urban areas and increasing growth towards the peripheral regions, depicting increased urban sprawl. The growth rate was negatively correlated with the NTL data, showing high intensity of light in the cities and lower intensity towards the peripheral areas. Thus, the two datasets together served as a data provider and also as validator. The NTL data was helpful in verifying the correctness of the GHSL data derived results.

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Table 1: Correlation of HSI and VANUI with OLS data

	OLS data 2000	**OLS data 2012**
HSI 2000	0.19329	-
HSI 2012	-	0.25226
VANUI 2000	0.98006	-
VANUI 2012	-	0.97785

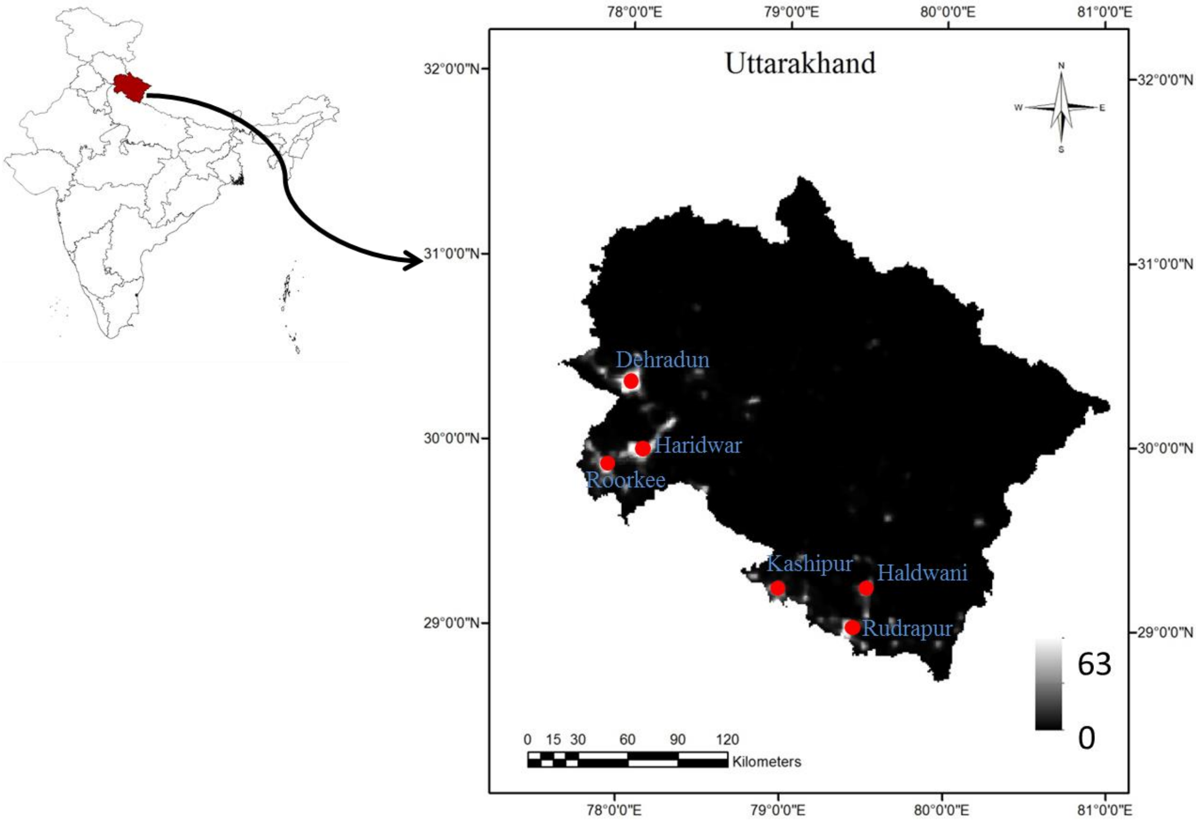


Figure 1: Study area (Uttarakhand state and location of six class 1 cities in the state)

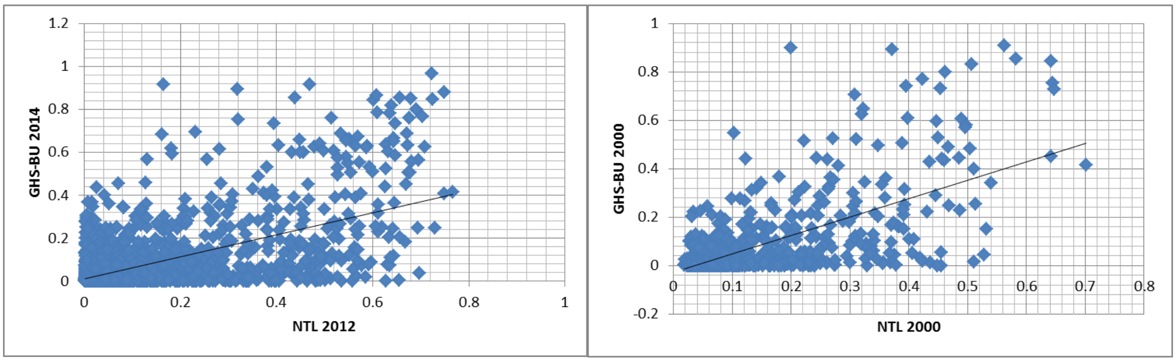
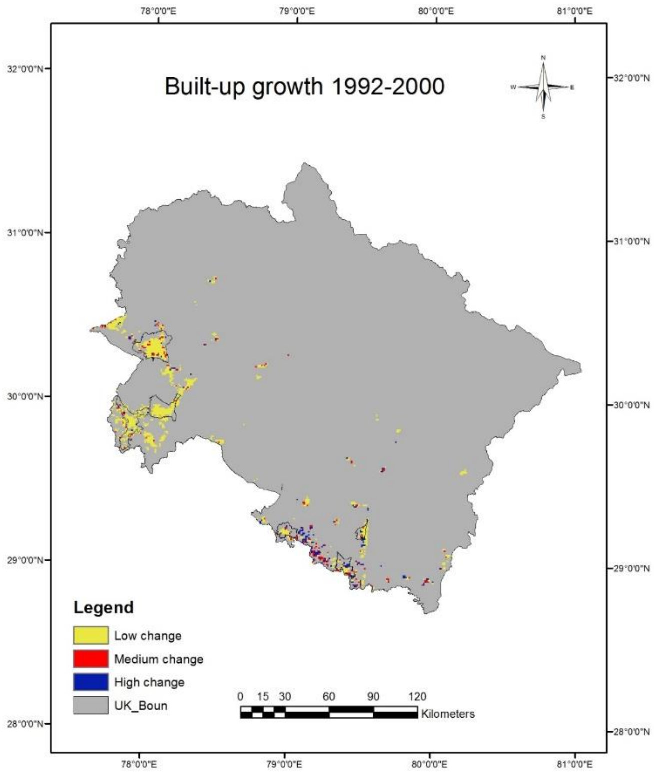
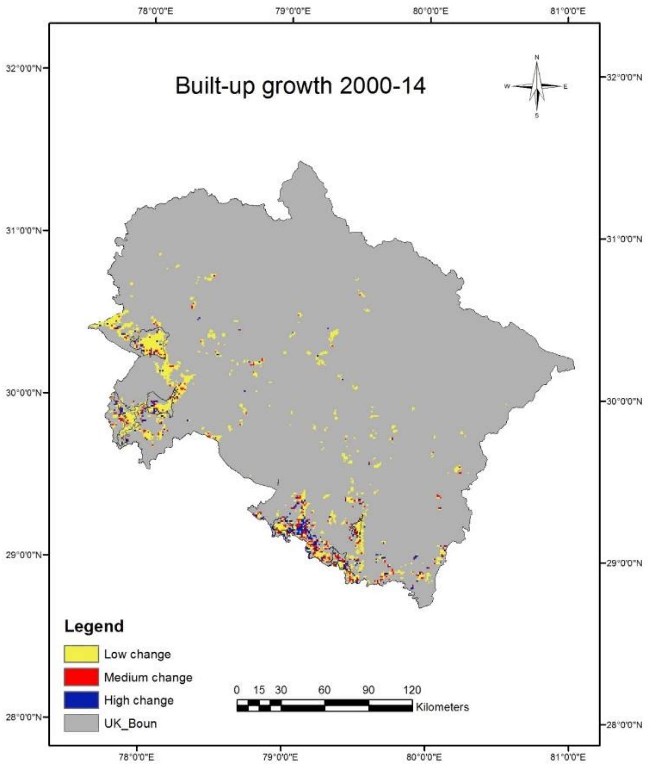


Figure 2: Correlation between GHSL and NTL datasets



(3a)



(3b)

Figure (3a) GHSL derived urban growth for period 1992-2000 (3b) GHSL derived urban growth for period 2000-2014.