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Assessment of light pollution in Bojnord city using remote sensing data

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ABSTRACT

Aims: The first aim of this study was to estimating the percentage of land area that was affected by various levels of light pollution and secondary aim is to assess the light pollution growth.
Materials and Methods: This study describes a methodology for modeling light pollution in Bojnord city, using geographical information systems and remote sensing technology. The Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) and Landsat TM^5 images in 1991, 1999, 2005 and 2012 were used. The DMSP-OLS images were classified to six categories from null to very high. The Landsat images were applied in order to calculate the urban area and extraction urban border in 4 years.
Results: The results were showed that the light pollution area (km^2) in very high category has increased 10.34, 2.73 and 15.94 km^2 of the entire study area from 1991-1998, 1998-2005 and 2005-2012, respectively. While, in that periods of time, the null category area (km^2) declined 23.19, 21.97 and 100.36 km^2, respectively. In 2005 and 2012 about 92.8% and 86% of the total study area has been in the Null class. There was a direct association between urbanization, spatial development of urban areas and light pollution growth.
Conclusions: One of the main reason for light pollution growth is declaring this region as capital city in 2005 and consequently, urban development and population emigration to capital.

Key words: Bojnord, Defense Meteorological Satellite Program-Operational Linescan System geographical information systems, light pollution, urbanization

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INTRODUCTION

With increasing the world population, urbanization and globalization, the demand for artificial lighting has been increased. Variation of natural light level and unwanted aspects of artificial lighting that mainly are produced by poor lighing design lead to light pollution.[1] Light pollution is known as one of the important increasing factor of environmental degredation. This kind of pollution is spreading vastly and developing continuously in all over the world.[2]

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According to the International Dark-Sky Association, light pollution consists of the sky glow, glare, light trespass, light clutter and wasting energy.[3] The sources of light pollution are numerous, as is evident in the industrial, residential, advertising, shopping, security and transporting and recreational centers (e.g., sporting stadiums). Despite the great need for night-time lighting, light pollution would be a serious problem for mankind and his environment and can cause long-term health problems in humans and living organism.[4]

Medical researchers find out the negative effects of unnecessary light on the human health.[5] This affects are included increased headache incidence, worker fatigue, medically defined stress, increase in anxiety and low melatonin production.[6] It has been proven that little melatonin levels is related to increased cancer risks.[7] Melatonin is an essential hormone in circadian rhythms and sleep. The melatonin variation in night shifts, raises the incidence of some types of tumors.[8,9] The melatonin is known as a regulator circadian rhythms in all vital organisms.[9]

Melatonin regulation in plants and animals depend on the cycle of light and dark.[10,11] The impact of artificial light on environment include structural-related mortality due to disorientation and effects on the light-sensitive cycles of many species.[2,12,13] Generates significant costs in Light pollution including negative effects on health, wildlife, astronomy and wasting energy.[14] The Light pollution costs in the U.S. was nearly 7 billion dollars annually. Light pollution due to poor lighting design wastes energy and increase the carbon dioxide emissions and global warming.[12]

A study done by Chalkias *et al*. submitted that night light emissions that originate mainly from large urban areas are among the main elements of environmental pollution.[13] As regards, around 50% of the world's population lives in cities.[15] Bojnord city which located in the north-east of Iran has been declared as a capital city of South Khorasan province in 2005. In recent years, this area has been encountered the physical extension in the urban areas and population growth. Therefore, it is necessary to detect the light pollution in these areas as essential prerequisites and main tools to urban planners and designers.

The various methods exist to detect the light pollution in great scale, spatially in around urban areas using the satellite images. Now-a-days, the remote sensing (RS) images has been distinguished as the latest information on earth in which geographical information systems (GIS) plays an important role in linkage and analysis of such spatial data such as environmental planning and resource management.[16] Over the last decades, many researchers have assessed light pollution in various methods. Falchi and Cinzano for the first time applied the Defense Meteorological Satellite Program (DMSP) satellite imaging to compute maps of artificial and total sky brightness in large areas.[17] Chalkias *et al*. have modeled light pollution for the outskirts of urban areas by integrating GIS and RS techniques and produced visibility analysis maps.[13] Pierantonio Cinzano, expressed that the light pollutions growth in Veneto plain was about 10% annually.[18]

In this study, a methodology for modeling light pollution and estimating the level of light pollution in urban areas of Birjand, using novel technologies include GIS software and RS was developed. The DMSP and Landsat images in four different years (1991-2012) used to identify areas that are affected by light pollution. The main objective of this study was to showing the percentage of land area that was affected by different levels of light pollution and to assess the light pollution growth.

MATERIALS AND METHODS

The study area

The current study was done in Bojnord city, provincial capital of South Khorasan, in the South-east of Iran and approximately between 37°31' and 33°20' northern longitude and 54°08' and 59°39' eastern latitude [Figure 1]. This city changed quickly due to urbanization and rapid population growth, especially after becoming the capital of province.

Data source

In order to detecting the light pollution, the satellite images from the DMSP and Operational Linescan System (OLS) were used. The data made by the DMSP-OLS are composites of cloud-free visible band observations.[19] DMSP satellites are in low altitude (830 km) sun/synchronous polar orbits with an orbital period of 101 min. The night-time visible lights data were obtained from the US Air Force DMSP-OLS digital data set developed by the US National Oceanic and Atmospheric Administration's National Geophysical Data Centre.[20,21]

Four sets of DMSP images belonging to1991, 1999, 2005 and 2012 were used. The images are freely available on the DMSP Archive (http://www.ngdc.noaa.gov/dmsp/dmsp). Also

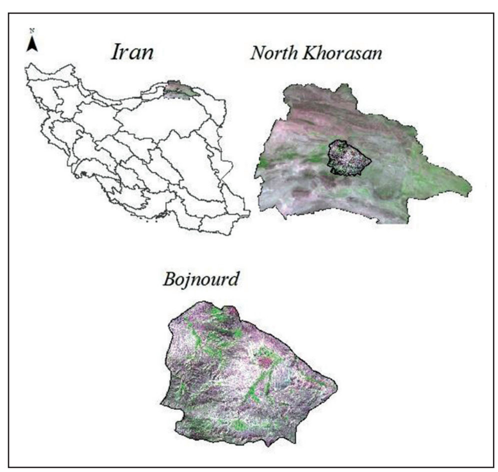


Figure 1: The study area

three sets of Landsat TM images belonging to 1992, 2005 and 2012 were used. The images are freely accessible from the Landsat archive on the United States Geological Survey (USGS) (http://earthexplorer.usgs.gov/).

The Landsat TM[5] images have also been used to determine the urban area (km^2) and extract the urban borders. The Landsat TM images achieved from www.usgs.gov.in, for four dataset on 1991, 1998, 2005 and 2012 with nearly 0% cloud cover over the region.

Methodology

Preparing light pollution maps

The Arc GIS 10 software performed for processing the satellite images. At first, all images were clipped into the study area then geometric corrections were done to UTM projection, WGS 84 datum zone 40 north. Whereas, the best technique to monitor the light pollution changes is direct measurements of night sky background.[22] The images were reclassified (grouping ranges of values into single values) to 6 categories. In satellite image, each pixel has an intensity value that represented by a digital number and the pixel location in an image (row and column numbers). The intensity value represents the calculated physical quantity like the solar radiance in a given wavelength band reflected from the earth, emitted infrared radiation or backscattered radar intensity. This value is generally the average value for the entire ground area covered by the pixel.[23] In the images, the pixels value is related to the sources of pollution and demonstrate that how much light upward of the earth. Since different spectral values have various effects on light pollution of their environments. The visible pixels of DMSP-OLS images are relative values ranged 0-63.[13] The number 0 shows the Null areas and the number 63 shows the areas with very high pollution. The DMSP-OLS images were classified to six category from null to very high light pollution, null; 0, very low; 1-12, low; 13-24, moderate; 25-37, high; 38-49 and very high; 50-63. Finally the light pollution maps were extracted [Figure 2]. The other numerical results were transmitted to Excel 2010 software to calculate the area (km^2) in each class [Tables 1 and 2].

Calculating urban area and extraction urban border

In order to calculate the urban area and extraction urban border in 4 years, all processing have been performed by GIS 10 software. Pre-processing steps was included the extraction of the study region and performing False-color images. The urban boarder in 4 years of the study's images were distinguished and digitized. Afterwards, the areas (km^2) were calculated separately for each year. At the end, the urban boundary maps in each year were overlaid with light pollution map with the same year [Figures 3-6]. These Figures show the merged maps that derived from the classified DMSP images and urban border with the similar year between 1991 and 2012. In this study, Arc GIS 10 and excel 2010 software were used.

RESULTS

The current study has been done in 4 years, 1991, 1998, 2005 and 2012. In 2005, Bojnord city was declared as a capital of South Khorasan province. The years' period in before and after 2005 was compared. All process for assessing light pollution has been prepared by GIS software. The classification of light pollution maps were extracted from DMSP images. Figures 3-6 show the light pollution maps that are overlaid with urban boundaries in each year.

The area (km^2) affected by various classes of light pollution have been shown in Table 1. Table 2 illustrates the Bojnord city area (km^2) extracted by Landsat satellite in each year.

According to Table 1, with the passing of the time, the light pollution area (km^2) in very high class raised during1991-2012. The very high class represents the area where the maximum light have been recorded by satellite. In 1991, 1998, 2005 and 2012, the area in this class were 4.45%, 5.9%, 7.2% and 14% of the study area, respectively. As can be clearly seen, the considerable growth in the light pollution area in this class was between 2005 and 2012 with approximately 15.4 km^2.

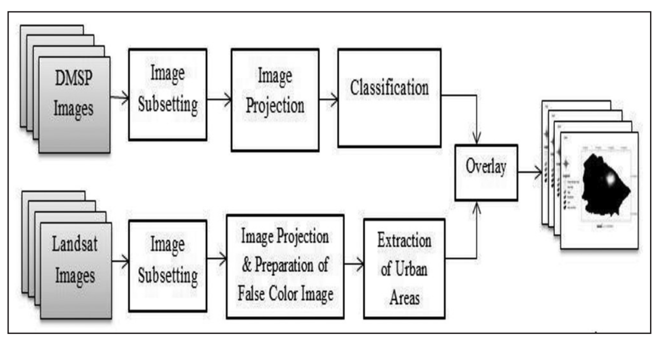


Figure 2: Flow-chart of the methodology

Table 1: The areas affected by light pollution (km^2)

Class name	1991		1998		2005		2012	
	km^2	%	km^2	%	km^2	%	km^2	%
Very low/null	1586.96	95.55	1563.77	94.1	1541.8	92.8	1441.44	86
Low	31.24	2	37.32	2.3	45.47	2.7	100.09	6.3
Moderate	10.84	0.65	15.1	0.9	23.82	1.5	42.39	3
High	14.15	0.8	16.66	1	19.03	1.2	30.26	2
Very high	17.22	1	27.56	1.7	30.29	1.8	46.23	2.7
Total	1660.41	100	1660.41	100	1660.41	100	1660.41	100

The results showed that the very high light pollution's category has increased 10.34, 2.73 and 15.94 km^2 of the entire study area from 1991-1998, 1998-2005 and 2005-2012, respectively. One of the main reason for this growth is declaring this region as capital city and consequently, urban development and population emigration to capital.

The Null class demonstrates the areas that light pollution is zero or there is no light pollution. This class is showed on the maps with black color. The surveys found that the null class covered the villages and wastelands. According to Table 1, the null class was 1586.96 (km^2) in 1992 that has diminished to 1441.44 (km^2) in 2012. In these periods of times, the areas (km^2) of null class were decreased, whereas the light pollution areas (km^2) were increased in Low, Moderate, High and Very high classes. There was a substantial diminish in Null areas. In 1991, 1998 and 2005 the null regions areas were 95.55, 94.1 and 92.8 percent of the total study area, respectively. In 2005 and 2012 about 92.8% and 86% of the total study area has been in the Null class. The low class has the greatest area (km^2) between all light pollution classes. The classified images of light pollution in each year showed that light was chiefly saturated (over exposed) and consequently had the highest value. In the urban area, it becomes readily apparent that the urban boundaries and the light pollution footprint approximately match.

Table 2: Bojnourd area (km^2) in each years of the study

Year	Urban/human-made environment (km^2)
1991	7
1998	8.5
2005	16.45
2012	27

Graph 1 shows the increasingly levels of light pollution areas (km^2) and urban/human-made environment (km^2) separately in 4 years of the study. Light pollution is an important and avoidable consequence of poor lighting design, or poor installation and maintenance, therefore the results of this study is essential prerequisites and main tools to urban planners.

DISCUSSION

In this study, the novel technologies include RS and GIS were used to assess the light pollution in Bojnord city in four different years. Base on the figures, there was a direct association between urbanization, spatial development of urban areas and light pollution growth. This graph indicated a rising trend in urban area and light pollution classes; Low, Moderate, high and Very high, especially after 2005. Based on these results and Table 2, it is clear that the physical growth of this city, urbanization and population growth rate have

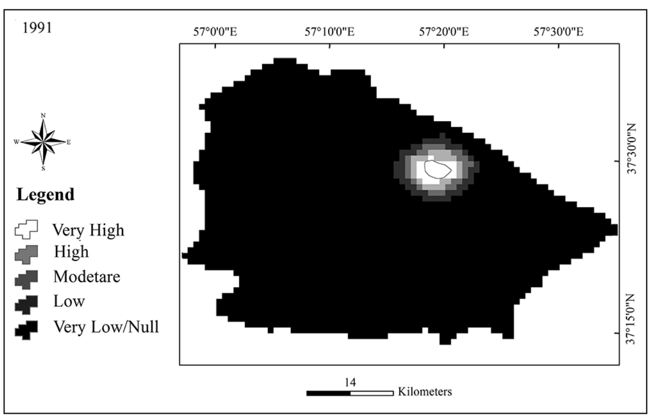


Figure 3: Light pollution map in 1991

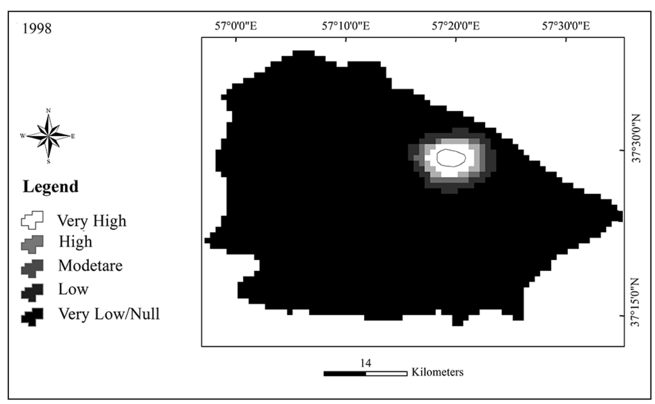


Figure 4: Light pollution map in 1998

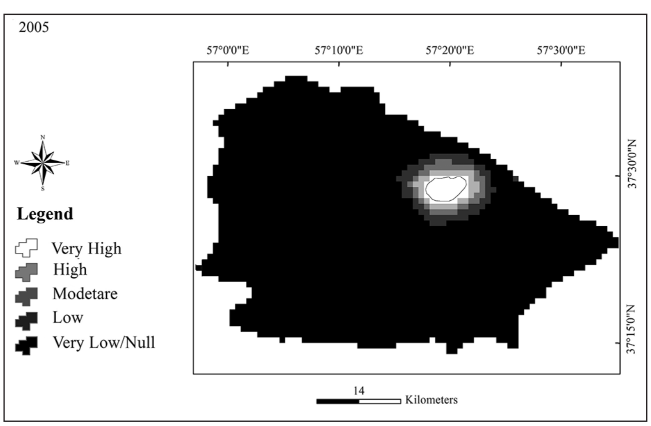


Figure 5: Light pollution map in 2005

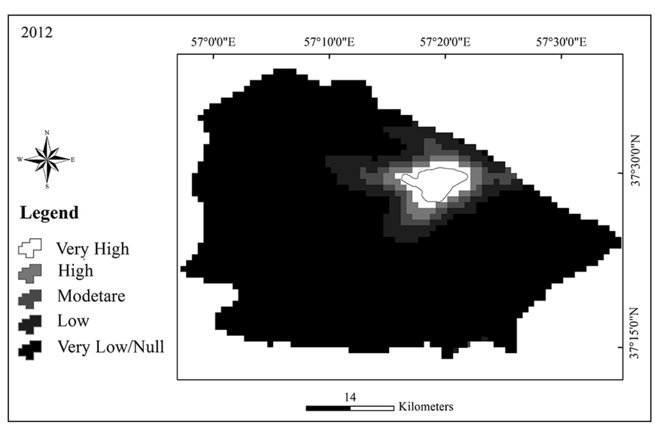
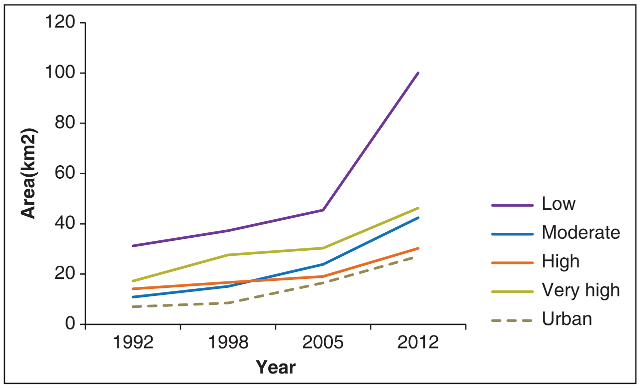


Figure 6: Light pollution map in 2012



Graph 1: Light pollution and urban area (km^2) changes around 1991-2012

been one of the reasons for increasing of light pollution with passing of time.

The results were showed the uncontrolled growth of light pollution in this city. In 1991, about 4.5% of the whole city area was affected by very high class of light pollution, while in 2012 the light pollution has increased to 14%. In similar results, Chalkias *et al*. studied on Athens' region and found out that about 10% of the whole area were affected with light pollution and there was a significant increase in light pollution during the last 10 years.[13] The study of Cinzano *et al*. revealed that in 66 nations, the artificially brightened were 10%.[19] Pierantonio Cinzano illustrated that the light pollutions growth in Veneto plain was about 10% annually.[18]

In this study due to year's increment, the light pollution areas (km^2) increased. The result was similar to Cinzano *et al*. study, they revealed an yearly growth in light pollution in Europe[25] and A study carried out in North American countries by Gallaway *et al*. has shown that about 16.97 and 8.08% of the land area had a night sky glow, respectively, approximately 2-4 times higher than the natural level and their results showed that there was statistically significant relationship between light pollution levels, that increase the population rate and light pollution.[12] Sky glow occurs when light escaping upwards from a city is scattered back to the ground, through interactions with atmospheric components.[26]

In the all extracted light pollution maps the urban border was overlaid. The maps point out that the very high class of light pollution entirely covers the urban areas and human settlements. While, the urban area was smaller than the areas surface affected with light pollution and does not completely correspond to very high class, due to the sky glow, sky glow is one type of light pollution that appears around urban areas at night time by bright halo.[4] Similar to our findings, Rodrigues in 2012 reported that urban border is not covered by the light pollution border, he pointed out that the reason was sky glow.[26]

According to the hidden effects of light pollution on the environment and especially humans health, special attention must be paid by officials and city planners to reduce and prevent the light pollution effects by increasing the public knowledge, education for proper usage of artificial light, reducing the artificial light usage, employing the urban management policies by policy makers, managers and planners for reducing this type of pollution in the city, such as; replacing the standard light with poor quality light, passing lows to use standard lights by public and private companies, study to evaluate the current urban lighting and redesign them if necessary. Proper light usage with standard angle of the lights on the ground, turning off non-essential lights. In 1986 Florida passed a restrictions law to protect the sea turtles from regulate beach front lighting, due to this low, there was 25% decrease in beach lighting since 1996.[27]

In this study, one of the most important limitations was low resolution of DMSP images; it is recommended for future studies to achieve an accurate results with advanced precision should be used higher-resolution images and shorter time intervals. Another limitation were the lack of accurate data in previous years such as urban population, the lack of Meta data by images Provider web site including the taking pictures times such month and day. Choosing DMSP and Landsat images in Equal periods of times with seven years interval to reveal the changes in light pollution growth due to urbanization, was the study strength.

CONCLUSIONS

Light pollution is an important and avoidable consequence of poor lighting design, or poor installation and maintenance. The current study was done in Bojnord city, the capital of South Khorasan province in the north-east of Iran. The main objective was to assessing the light pollution during for 1991, 1998, 2005 and 2012 by capabilities of novel tecniqies. This study revealed that the integration of RS and GIS capabilities have been played an important role for mapping and assessing light pollution in the study area. Undoubtedly, applying these technologies is useful to accurate economic estimation of vast changes. The results would be helpful to determine the high risk areas for policy makers and urban planners to diminish and prevent the light pollution. The results clearly showed that in the last decades there has been a quick increase in the Light pollution, thus, Light pollution will become a trouble in the future in this city.

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