The Ecological Impacts of Light Pollution at Night-time a Mechanistic Appraisal

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Abstract—*Artificial light at night and its negative consequences are of great interest in the fields of Ecology, Human Geography Astronomy, and Human Health. Most of the studies to date concentrated on the influences of light pollution has on our ability to view the night sky, on biodiversity, and ecosystems. Though, in recent years, with the use of new technologies sensors, which provide accurate information for determining of night lights at the area, most consideration were given for estimating artificial light at night within the urban areas. In this study, urban night lights within the cities of Nigeria was evaluated by monitoring data from the ground measurements using Sky Quality Meter (SQM-LU-DL) devices. Besides, the SQM was used at the zenith (upward direction) for maximum evaluating of artificial light at the sites. Differences in night sky brightness were found between the observation sites with the brightest values measured in the upward direction (20.14 to 22.00* mag_{sqm} $arcsec^{-2)}$ *as the SQM measurements were influenced by surface albedo, this was due to the reflection of solar radiation during the day by the earth's surface; and the other sources that exposed direct lights from buildings and car lamps, while in some locations the upwards direction represented skyglow. Cluster analysis result has shown that some places are more ecological friendly especially for migrating birds and other nocturnal animals. GIS software was used to group the data according to the data obtained during the monitoring. The result showed tha, the area with a dark color in the map indicated the darkest region of the study area and the bright areas on GIS map image were associated with areas of high use of artificial light and high albedo. This study provides a clear view for the assessing the sky condition and can serve as a tool for locating the suitable place for a zoological garden and even for optical astronomy in the study area.*

Keywords—GIS, SQM, Sky brightness, Light pollution, Cluster analysis.

I. INTRODUCTION

The diurnal cycle of light and dark is among the toughest ecological aspects of life on Earth. Numerous classes in both terrestrial and aquatic animals use the level of ambient light to control their metabolic rate, growth, and behavior. The night sky glow caused by artificial lighting from urban and suburban areas disrupts this natural phenomenon and has been shown to impact the behavior of organisms, even from some distance away from the sources light. It might be assumed that reasons that increase the brightness of the sky amplify the amount of this ''ecological light pollution''. It shows that cloud coverage intensely increases the sky luminance, by a factor of 10.1 (Kyba et al., 2011).

Therefore, among the most alterations that rapidly increase in this natural environment is the variation of the atmospheric light levels in the night environment which produced by an artificial light due to the excessive illumination beyond the levels and scattered by cloud, aerosols, and pollutants in the atmosphere such as suspended particulate of matter. These must take account globally by the researchers of global change. This phenomenon is term as light pollution. Therefore, the invention of street lightings and other electric light everywhere had no doubt that will be altered the natural phenomena of day and night in the ecosystem. This loss of darkness occurring due to the existence of light pollution has become a dangerous effect on several species and habitats. The movements of animals and the physiological cycles will all be disorganized due to the excessive outdoor light emission everywhere (Marin and Jafari, 2007).

According to McKinney et al. (2007); the light pollution will even influence the entire scenario of the ecological balance of the local living environment. Also, it was explained that the estimated birds killed every year in the Northern America were up to millions due to crossing into public windows after attracted by light and trying to navigate by artificial lights instead of natural direction cues such as stars (Whitekeys, M., 2013). Extensive research shows that light illumination in excess near

people's place of living may influence their personal health (Davis et al., 2001; Blask et al., 2005), even though the full physiological impacts of these lighting on human have not been fully established (Stevens, 2006).

A light pollution study is very essential because it serves as a guide on how to prevent the environment we live from severe pollution. The study by Marco et al. (2014) on light pollution in the surrounding of Valencia revealed the effects of light pollution on the wildlife animals, and the ecosystem in general. The result clearly shows that cloud coverage is one of the major factors that increases the sky brightness especially in the saturated zone where the lunar is no longer be seen. This effect is usually affecting the nocturnal wildlife and the entire ecosystem where the presence or absence of the moonlight is welcoming. According to their study, the impacts of clouds on the city is so high; that can be brightened the sky in more than three (3) magnitudes when compared with the first reading before the existence of cloud (Enric Marco et al., 2014).

In conclusion, the problem of light pollution occurs as a result of many anthropogenic factors. These factors include the increasing of street lighting, present changing of the types of lamp uses from high-pressure sodium lamp to white light LEDs, creating and installation of uncontrolled luminaries everywhere as well as the natural phenomena such as clouds, fog, aerosols, etc. may all reinforce the problem of increasing the sky brightness. Therefore, due to the insufficient study of sky brightness or even lack of this study in Nigeria motivated me to carry out this research in this country. This research will use the portable, sensitive and accurate device called Sky Quality Meter (SQM) to measure the sky brightness in the main and populated urban areas to fill the gap in the literature of this field of study.

II. MATERIALS AND METHODS

Study area

The study was conducted in Nigeria, which is located at the longitude of 8° 00′ east of Greenwich meridian and latitude 10° 00′ north of the equator and has elevation ranges from 10 meters to 484 meters. Nigeria surrounded by the Benin Republic in the west, in the eastern Chad and Cameroon, and in the north by the Niger Republic. It lies on the Gulf of the Guinea in the south, and also in the northeast with Lake Chad (United Nations, 2016). However, this study was carried out in fourteen sites in the different geopolitical zone of Nigeria due to their differences in weather, and climate, and other human activities. GIS software Arc map was used by interpolation method to distribute the data spatially for these monitoring sites.

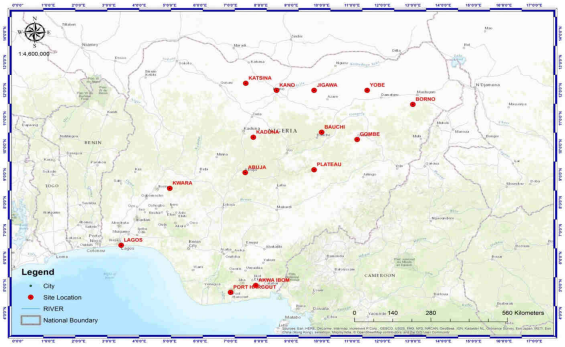

Fig.1: The map of the study area showing the sites where the monitoring took places.

III. DATA COLLECTION

The data monitoring was carried out in November and December 2015; from January to March 2016 using the SQM-LU-DL device as a tool for quantifying the sky brightness of fourteen sites of Nigeria. The activities were conducted in the evening after sunset, for maximum light emission from the surrounding such as public windows, headlamps, street light and others caused by human activities to be assessed. The device was fixed on a tripod stand above the ground of about 1.2 meters and pointed to the zenith. It corresponds with other research carried out in various parts of the world such as the research done by Kyba, et al. (2013) in Berlin, Kocifaj, et al. (2015), Slovakia and Mexico, and by Kim (2012), in Virginia Arizona. The device was linked to the PC by the use of cable for transferring the data directly from the SQM to the PC. However, Global Positioning System was used for assessing the exact locations for the sampling is taking place. The reading of the SQM was logged in every minute for a complete hour at each site; that is 60 reading has been recorded, for an easy perceptible of changes of the sky during the time.

IV. STATISTICAL ANALYSIS

This study used Agglomerative Hierarchical Clustering technique and GIS software Arc Map version 10.1for the data analysis. Hierarchical Agglomerative Clustering Analysis (HACA) via Ward's method was used to cluster out the data according to the values obtained. This method is a good technique for classifying data into groups rendering to the amount of pollution in the research areas (Gaston, K.J., et al., 2015). The HACA is used to find clusters in a given set of data that usually generated to reduce the data set into groups (Duda, R. O., et al., 2012; Cohen, J., et al., 2013). In addition to this, GIS was used to digitized the map of the study area and spatially allocate the resultant data according to their geographic locations.

V. AGGLOMERATIVE HIERARCHICAL TECHNIQUES

Cluster analysis is a method or technique capable of grouping datasets with similar objects. Each group consists of datasets with similar properties among the groups and differ with the other cluster (Kaufman, L., and Rousseeuw, P. J., 2009; Halkidi, M., 2001). HACA is acknowledged as a suitable technique in the fields of sciences and social sciences that inhabit the prominent position in categorizing a group of data sets. Starting from *n* set of data as clusters to a fewer set of clusters less than *n*; up to magnificently reduced to a state where all the *n*-set of cluster will be into one cluster (Caverlee, J., and Liu, L., 2005; Cai, X., 2010; Wang, Y., 2011). It is the method that always look at the similarity of all the datasets and grouping it to their cluster centroid and is defined by

$$Sim(x) = \sum_{n=1}^{\infty} cosine\ (d, \quad c) \ldots (1)$$

Where *d*, is data in a cluster, *X*, and *c* are the cluster centroid of *X*, i.e., the mean of the data sets vectors. And the selection on which pair of clusters to merge is made by determining which pair of clusters will give to the smallest decrease in similarity; where d_1 and d_2 are the given data sets in cluster 1 and cluster 2, respectively express mathematically:

$$\text{The similarities (cluster 1 and cluster 2)} = \frac{\sum cosine\ (d1,d2)}{size\ (cluster\ 1)*size\ (cluster\ 2)} + \cdots (2)$$

VI. INVERSE DISTANCE WEIGHTING (IDW)

There are many application and techniques in modeling data using GIS software. Henceforth, the most exciting one in this research is the used of interpolation method. IDW is among the modest means of interpolation. It is based on estimate and assumption of a given value at the non-point location some distance from a given set of numbers. IDW are usually decreasing with the power of distance (inversely proportional to the weight and distance) (Haque, M. N., et al., 2016; Kazemi, H., et al., 2016) and mathematically represented in equation below:

$$f(r) = \sum_{i=1}^{m} w_i\ z(r_i) = \frac{\sum_{i=1}^{m} w_i\ z(r_i) / |r - r|^p}{\sum_{j=1}^{m} 1/|r - r|^p} \ldots\ldots (3)$$

Where *r*, is the non-point location that leads to an estimator, *p*, is a parameter (normally *p*=2) as in the literature (Alvarado, A., et al., 2016). Consequently, this primary method is standard and easy to implement and is available in the GIS. Therefore, among the limitations of this approach are its practical applications (Alvarado, A., et al., 2016; Fathian, F., et al., 2016); and does not create the local shape implied by data and produces local extreme at the data points.

VII. RESULTS AND DISCUSSIONS

The data generated were analyzed statistically and plotted using the HACA and GIS. The sky brightness data, took from the fields using SQM-LU-DL; the magnitudes per arc second squared (mag/arcsec2), were used as provided by the manufacturers (Unihedron); and various literature such as (Kyba et al., 2013; Luginbuhl et al., 2014).The data sets were measured in November 2015 to March 2016 with Sky Quality Meter (SQM), for the fourteen cities sites of Nigeria. The complete monitoring data set obtained with the relevance information (list of coordinates, dates, and SQM readings) is available upon request. For the comparison, all the measurements of the sky brightness in both locations of the study area were conducted on various occasions. But during the same period (November 2015–March 2014), giving values ranging from 20.14 $Mag._{sqm}$ /arc $sec.^2$ (NELM of 5.6-6.0); showing that all the stars brighter than 5.60 are visible at the zenith) to 22.00 $Mag._{sqm}$ /arc $sec.^2$ (NELM of 6-7). Therefore, this result shows that the sky is on all the sites is very friendly and suitable for the biological activities. It also showing that result from cluster 1 for the HACA method and the darkest color in the GIS map is in clear and unpolluted skies that can be able to see all the stars but depending on the observer.

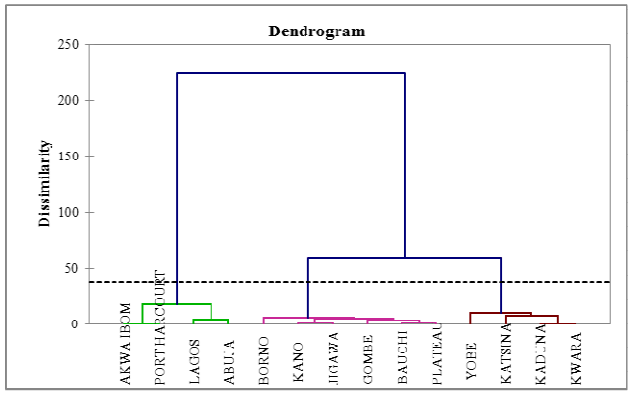

Fig.2: Results conferring to clusters using HACA

Table 1: Shows and explains the groupings (Result by object)

Observations Sites	Class
Kano	1
Katsina	2
Kaduna	2
Jigawa	1
Kwara	2
Akwa Ibom	3
Lagos	3

Borno	1
Gombe	1
Bauchi	1
Yobe	2
Plateau	1
Abuja	3
Port Harcourt	3

In addition to that, the result highlighted the sites with excellent sky quality ranging from 21.661 to 21.995 $Mag._{sqm}$ /arc sec.^{2} These sites with the Reserve Dark Sky are Jigawa, followed by Kano, Bauchi, Borno, Gombe and Katsina which was all found to be in cluster 1 in the HACA cluster, analyses and have the same appearance in colors in the GIS map results (darkest region).

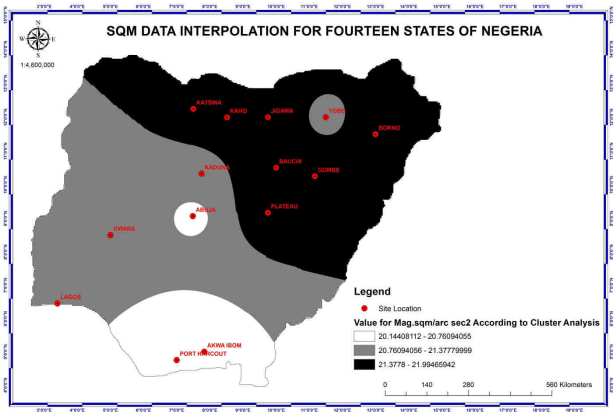

Figure 3: Results according to clusters using GIS

VIII. CONCLUSIONS

The sky brightness of fourteen sites of Nigeria was recorded, and analyzed, and the result illustrated that the sites have high quality regarding darkness. This research was conducted to find the best location for ecological and astronomical activities in those areas. And according to the literature in this field, this is the first assessment of the night sky brightness for the ground field measurement in these sites. The results obtained in this study from both of the monitoring sites revealed dark skies even when compared to other dark sky areas worldwide. Though, due to rapid urbanization in Nigeria, there will be possible adverse effects of artificial light at night on human and animal's health and the entire ecosystems for the site in cluster 3 (i.e. the white color on the GIS map) if care is not be taken. Therefore, the monitoring and assessment of these locations dark skies are of utmost important so that to maintained the sites as dark skies locations. Henceforth, this study will be critical current and future interdisciplinary research including effects on health and the ecosystem.

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