International Journal on Advanced Science Engineering Information Technology

Vol.7 (2017) No. 1
ISSN: 2088-5334

Night Sky Brightness Assessment in Nigeria Using Environmetric and GIS Technique

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***Abstract*— High anthropogenic activities are rapidly increasing phenomenon and it is assumed to have global implications. In Nigeria, high anthropogenic activities rapidly increase above the standard of the threshold values especially the lighting sources. This increase due to the vastly growing of industries, residential and commercial uses and other sources such as street lighting in urban and semi-urban areas, which can make the night sky brightness in the area above the threshold set for polluted status. The study measures the night sky brightness at the most densely populated urban centers of Nigeria; to estimate and quantify the level of the night sky brightness from the sites nearby the cities of the planned research study. The research monitored the zenith sky brightness from November 2015 to March 2016 using Sky Quality Meter (SQM). However, typical values ranging from 20.14 to 22.00Mag.sqm /arc sec.2 were measured at different sites of the study area. This data recorded in the field was analyzed using Agglomerative Hierarchical Method via Ward's Methods to cluster our data according to the pollution status of the areas. Result showed three clusters in which class 1 has low pollution; class 2 is moderate while class 3 has the high pollution status. The sites classified in class 3 are more polluted due to the high use of artificial light. However, geographical information system (GIS) software was employed to confirm the results obtained from environ-metric technique and concluded that this result is confirmed to be the same. Hence, it illustrated that sites in cluster 1 have an excellent dark location that can be used to build optical observatory stations and other astronomical observations due to their dark sky.**

***Keywords*— sky brightness; sky quality meter; light pollution; cluster analysis; environmetric technique; GIS**

I. INTRODUCTION

Study of sky brightness is an essential topic in the field of astronomy, especially for optical astronomical observations that need very clear and dark sky conditions [1]. Nevertheless, sky brightness rapidly increases due to higher anthropogenic activities. These anthropogenic activities such as the increase of artificial light at night to brighten our night time have a negative impact in the field of astronomy. Hence, the concern of this research is the adverse effects that light pollution has in the destruction of the natural sky brightness name "light pollution" or sometimes called "light trespass" "glare" or "over lighting" [2], as shown in Fig. 1.

In the astronomical field of study, light pollution is defined as any mortification of the capacity to view the sky during the night due to scattering of artificial lights in the atmosphere [3]. Light pollution can also refer to any negative effects that alter the natural phenomena and light patterns both temporal and spectral with direct impact on fauna and flora as well as human health. The estimation and quantification of sky brightness within cities of Nigeria using a very portable and a sensible device called SQM-LU-DL, which is the latest model of SQM-LU is an advancing field of research. This type of research has an extensive significance for astronomers [2], [4], [5]. This estimation and quantification of sky brightness have considerable advantages, especially for locating and building of observatory stations [2]. Nigeria has many open places within and near the urban environment which can serve for this purpose.

The research will use SQM device to monitor the sky brightness in the densest sites of Nigeria. Recent studies were carried out to quantify night time in many cities in the world using different instruments such as space-borne that are used to collect data at each spatial scale, which also using the Defence Meteorological Satellite Program. Light detection and ranging (LiDAR) system which is another approach to understand the light pollution pattern using a precise evaluation of the land cover and the surface.

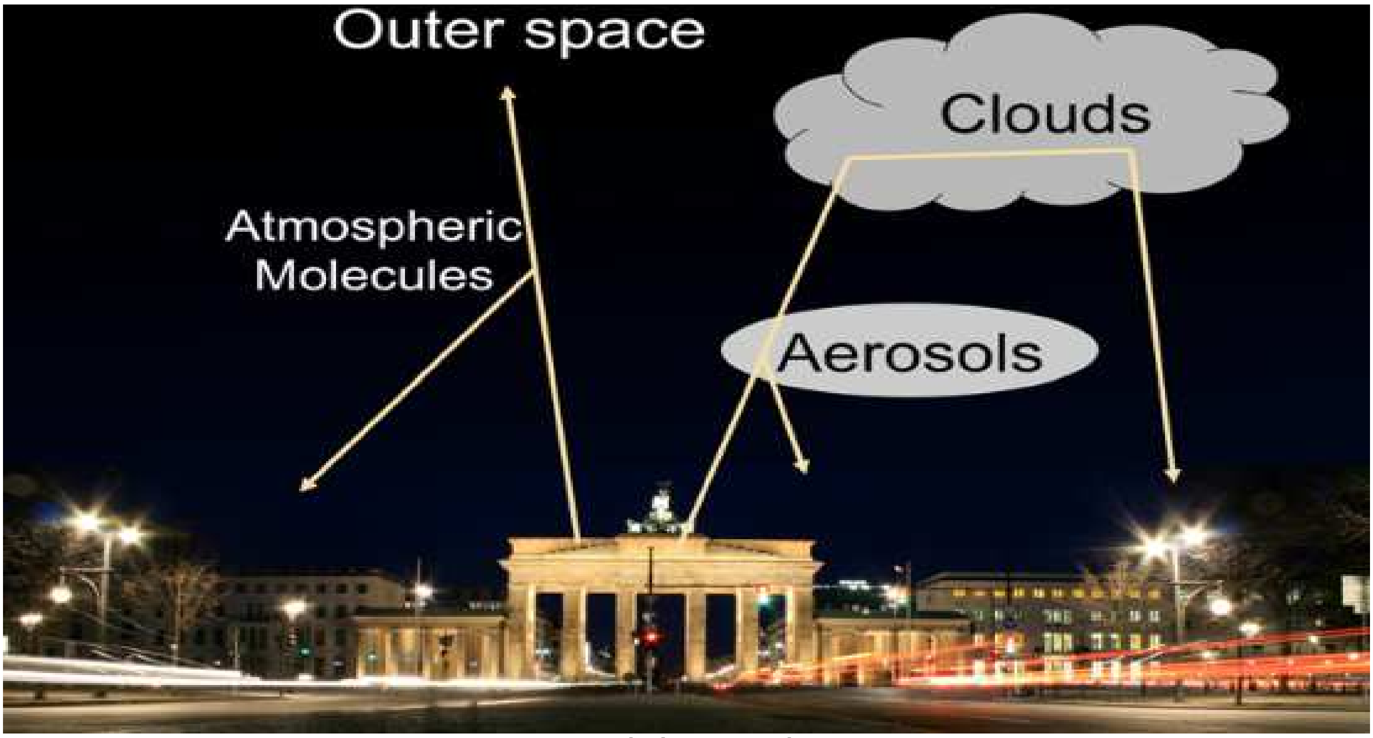

Fig. 1 Skyglow occurs in the city

Another method is by the use of ground field measurement employing spectral light meters and ground-based digital images.

This study used the SQM pointed to the zenith angle as this corresponds to other studies carried out in different parts of the world. A study carried out by [2] in Berlin used two cameras mounted on an aerial platform to evaluate the urban upward light distribution in two directions. Another research was conducted in Slovakia and Mexico using DSLR Cameras with a different slot, to measure the ratio of the zenith radiance proportionate to the horizontal irradiance [6]. Also in Virginia, Arizona, another research was carried out by using two light meters simultaneously in which one measured the upward direction and the other one measured the downward direction, so as to measure the direct light from the fixed position.

However, the aim of this research is to find better places for locating/building of the observatory station for the astronomical activities in the study area. This can be carried out using the data obtained from ground measurements by the use of a photosensitive device called Sky Quality Meter (SQM-LU-DL) Model. This instrument is capable of measuring direct light, scattered as well as reflected light [7]. Hence, to the best of the author's knowledge, there is no any of such study done in Nigeria. Therefore, it is a great and important privilege carrying out this research in this study area so that it will be helpful to astronomers.

II. Material and Method

A. Study Area

The study was carried out in Nigeria, which is a country in the West African region with a geographical coordinate of $8^{\circ} 00'$ East of Greenwich Meridian and $10^{\circ} 00'$ north of the Equator with an elevation between 10 meters to 484 meters.

The study was carried out in Nigeria, which is a country in the West African region with a geographical coordinate of $8^{\circ} 00'$ East of Greenwich Meridian and $10^{\circ} 00'$ north of the Equator with an elevation between 10 meters to 484 meters. It is bordered by the Benin Republic in the West, in the East by Chad and Cameroon and in the North of Niger Republic. Its coast lies on the Gulf of Guinea in the South and also in the Northeast with Lake Chad. Abuja is the capital city of Nigeria and is also the predominant among the rest of the states regarding municipality. Nigeria has a total population of 185,618,975 million as of 2016, based on the latest United Nations estimates in its thirty-six states plus federal capital territory (FCT) Abuja. Nigeria has many open areas located near the cities. It also builds up with residential, commercial and industrial sections due to its high population.

For this research, 14 main cities of Nigeria including FCT Abuja were used as field sites. This is due to differences in their geographical locations, temperatures [25], [26] whether and climate, residential, industrial as well as their commercial usages. GIS software, Arc Map version 10.1 was used to spatially distribute the data from these 14 states where the monitoring took place as illustrated in Fig. 2.

B. Data Collection

The study used SQM-LU-DL to measure the sky brightness in these 14 cities of Nigeria in the months of November and December 2015; and January, February and March 2016. During the data collection, the device was mounted on a tripod stand at least 1.2 meters above the ground to avoid any disruption of the sensor by either shadow or any external agents.

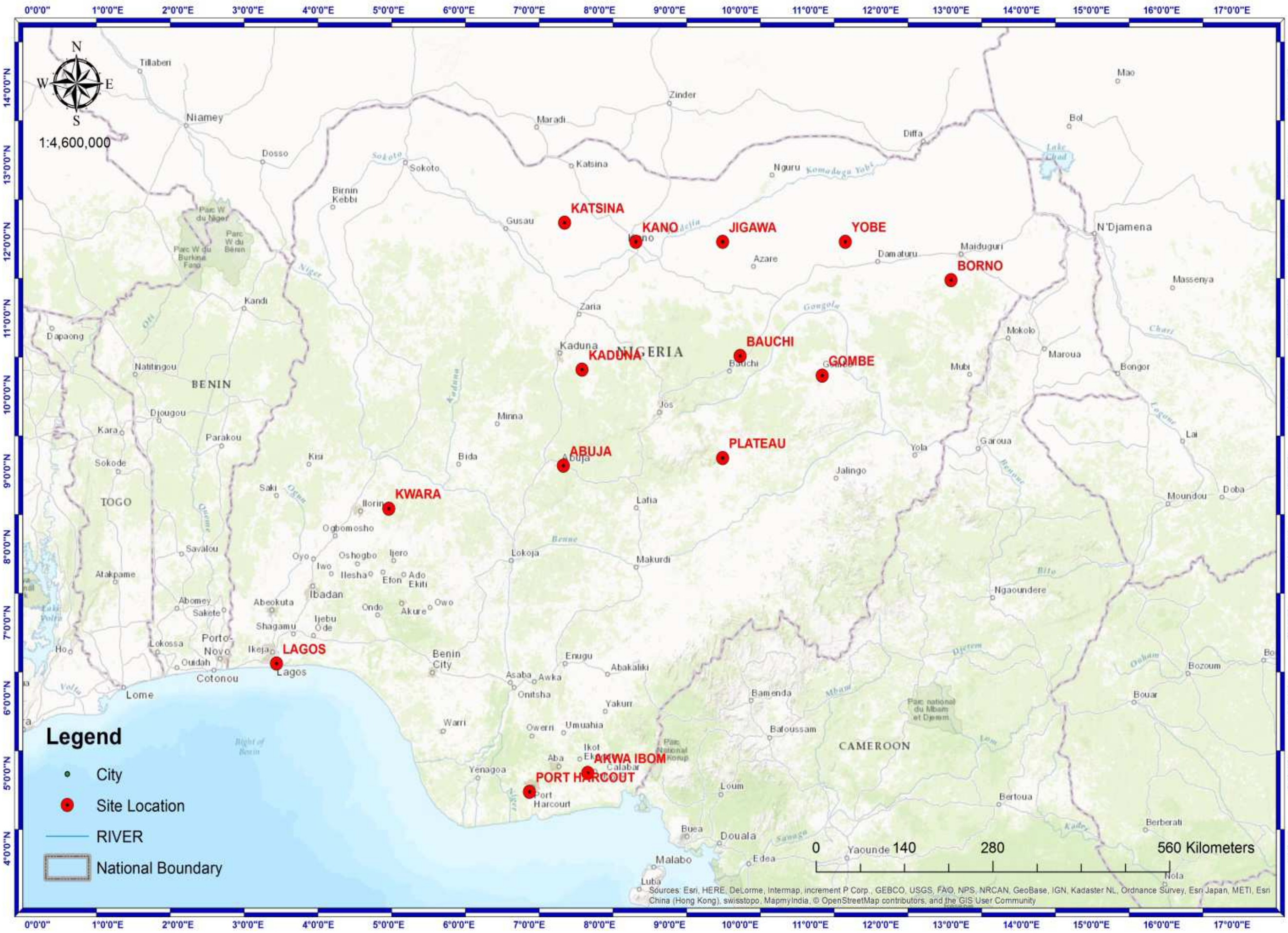

Fig. 2 Fourteen sites selected in Nigeria [1]

However, it was fixed in one position in which the device pointed vertically to the zenith angle (at 90˚) to the horizontal axis at a fixed position Fig. 3. Therefore, the position is being fixed. The device was connected directly to the PC so that the data will be stored automatically and display SQM reading as shown in Fig. 4. We also used GPS to find the exact locations where the sampling is taking place. The reading of the SQM was recorded in every 1 minute for an hour at each site.

Fig. 3 Setting of the SQM device for ground measurements of sky brightness in the study area

That is 60 reading was recorded so that we can notice the changes of the sky in every minute during the hour.

However, this data collection was conducted in the evening, 1-2 hours after sunset. This period was chosen because of the high activities using artificial light at this time.

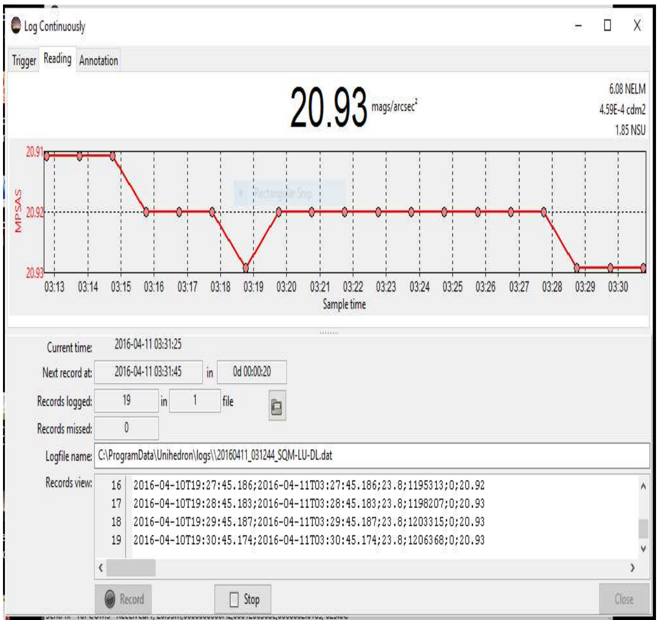

Fig. 4 Data logger during the data collection at the site

By doing this, maximum light emitted from all the surrounding sources such as open windows (public windows), car lamps and other vehicle lamps, street lights and the rest caused by human activities was recorded.

C. Statistical Analysis

This research used XLSTAT 2014 05.03 and GIS software Arc Map version 10.1 to analyze the monitored data. Agglomerative hierarchical clustering method (HACA) via Ward's method was used. This method is used to classify a given data into groups according to the amount of pollution accumulated in the research areas [8]. However, this method was used to construct the hierarchy from each set of data by progressively merging clusters and present the result in the form of a dendrogram, by categorizing the result into groups and their proximity [9], [10]. In addition to this, GIS was employed to digitize the map of the study area and spatially distribute the monitored data according to their geographical locations.

D. Agglomerative Hierarchical Techniques

Cluster analysis is defined as the classification of data sets into groups with similar objects. Each group consists of objects (datasets) with similar properties between the groups and differ from the other group [11], [12]. The Agglomerative Hierarchical Clustering method is recognized as a suitable method in the fields of the sciences and social sciences that occupy the prominent position in classifying objects or a group of data sets [13]. Starting from n set of data as clusters to a fewer set of clusters less than n, until it successfully reaches a point where all these n set of the clusters will be all in one cluster [14], [15]. The study used different set values of data. These sets of data will be difficult to analyze and explain in a straightforward and accurate way. To find the solution of these problems we have to use agglomerative hierarchical techniques for clustering the data sets. Intra-Cluster Similarity Technique is a method that groups the data sets into groups of related properties. This hierarchical method looks at the similarity of all the documents in a cluster to their cluster centroid and is defined by

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

where d is a document in a cluster, X, and c are the centroid of cluster X, i.e., the mean of the data sets vectors. The choice on which pair of clusters to merge is made by deciding, which pair of clusters will give to the smallest decrease in similarity. The similarity of a cluster can be defined as follows: where d1 and d2 are the given data sets in cluster 1 and cluster 2 respectively.

The similarities (cluster 1 and cluster 2) equal to

$$\frac{\sum cosine\ (d1, d2)}{size\ (cluster\ 1) + size\ (cluster\ 2)} + \cdots \tag{2}$$

Furthermore, agglomerative hierarchal clustering will often put data sets of the same class in the same cluster, even at the earliest stages of the clustering process. Because of the way that hierarchical clustering works, we recommended that Agglomerative Hierarchical Clustering is often portrayed as "better" environ-metric technique and widely known for classification of data sets according to the similarity of the neighboring values. Many studies discuss and explain that agglomerative hierarchical clustering is a superior technique, although other methods can perform same classification or better. For example, a PCA can also be used to execute the same work for agglomerative hierarchical clustering techniques [16].

E. Geographical Information System (GIS)

GIS is a system organized as a combination of software and hardware that is designed to work and is capable of capturing and recording information (data), storing and checking, manipulating and analyzing that information retrieved and displaying it accordingly and are spatially referenced to the Earth [17]. There are many techniques in modeling data using GIS tools. The most interesting one in this research is the use of interpolation method. Interpolation is the phenomenon that can be done using various methods and in different ways, but depends on the types of data the research is dealing with. Interpolation methods are used to estimate the values obtained each location. The field measurements required conversion into a continuous space before the mapping and spatial analysis to take place. And this can be done using an interpolation method. The most common techniques for interpolation in GIS are Kriging, Inverse Distance Weighting (IDW), Point TIN, Spline and the rest [18], [19].

However, for this research, Inverse Distance Weighting (IDW) was employed to interpolate our datasets according to the geographical location. This method is essential as it has many advantages over the others, especially when the data is not dealing with peaks or mountainous areas [19]. Some of the advantages of this IDW are it is capable of estimating extreme changes in terrain, it can interpolate a dense evenly point and can either increase or decrease the sample points so that it will influence the cell values. Furthermore, a point interpolation is also used to create a point station from data sets of sample measurements where each point represents a location where the monitored data has been measured. Interpolation was used to predict the values between these input points [20], [21]

F. Inverse Distance Weighting (IDW)

IDW is among the simplest methods of interpolation. It is based on approximation and the assumption of a given value at the unsampled points within several distances or from a given set of numbers. Weights usually decrease with the power of distance (inversely proportional to the weight and distance) [22], [23]. It is related by the following equation where *r*, is an unsampled location that leads to an estimator as

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

And *p* is a parameter (normally *p* = 2) as in many literatures [20]. However, this basic method is common and easy to implement and is available in almost any GIS. Nevertheless, among the shortcomings of this method are limiting its practical applications and it does not create the local shape implied by the data and produces local extreme at the data points.

III. Results and Discussion

The result obtained from the datasets (as we have 14 sets of data) using agglomerative hierarchical analysis via ward's method were submerged into 3 clusters C_1, C_2 and C_3 according to the nearest values obtained during the sampling. Fig. 5 and Fig. 6 illustrate this whereas Table 1 clearly explains the clusters.

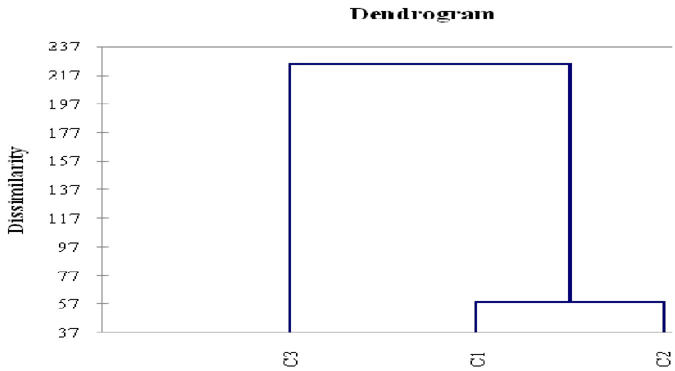

Fig. 5 Cluster analysis categorizing the sky brightness values measured in all the fourteen cities into three groups

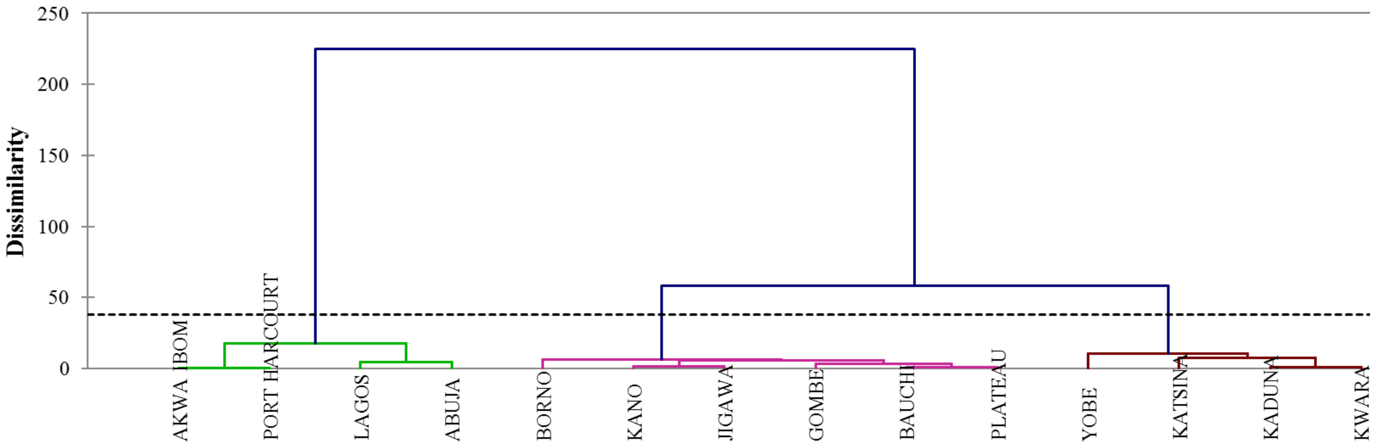

Fig. 6 Dendrogram shows a different cluster of sampling sites classifying the states where SQM reading took place according to the level of sky brightness

TABLE I
The Categories of Clusters (Result by Object)

Observations	Class
Kano	1
Katsina	2
Kaduna	2
Jigawa	1
Kwara	2
AkwaIbom	3
Lagos	3
Borno	1
Gombe	1
Bauchi	1
Yobe	2
Plateau	1
Abuja	3
Port Harcourt	3

Therefore, by comparing the brightness levels as measured by the SQM in all the fourteen states of Nigeria in five consecutive months (November and December 2015 and January, February and March 2016), we found that it is statistically significant, and the differences between the readings were due to the differences in the urbanization and the activities carried out at different sites. And also directions and dates at which the data were collected are other factors that can cause the differences. As the clusters given above, C_1 group, including Kano, Jigawa, Gombe, Bauchi, Borno and Plateau States, was classified as the group with the least pollution (the darkest region). While the C_2 group which included Yobe, Katsina, Kaduna, and Kwara was classified as the moderate (darker region); the C_3 group was the one with high light pollution which consisted of AkwaIbom, Abuja, Lagos and Port Harcourt (brighter area). Hence, we can conclude that there is a significant difference between subsequent measurements of each group since the cluster categorized it. If there is no difference, the results will not show any clusters. However, we can predict that the third group is brighter than the remaining groups because all the states within the C_3 group have high anthropogenic activities.

Though, there was no research of this type carried out in this study area as those discovered used SQM devices pointing towards the upward direction (zenith). The results obtained only correspond to some previous studies using SQM devices pointing them mostly upwards for evaluating night sky brightness in different parts of the world as [24]. This result was also in the range of the world accepted values (16 to 24 mag./arc sec^2). Therefore, to confirm the result, GIS was used to spatially distribute the monitoring data into the digitized map of the study area. The result was illustrated in the same way as in agglomerative hierarchical clustering above, in which the sites that were in the same cluster in the analyses above still have the same color in the map. This indicated that they belong to the same categories (high, moderate and low). The darker color in the map refers to the area with least pollution status (darkest region) and the area with white color indicates the brightest area (with high anthropogenic influence on sky brightness). Therefore, the brighter the place is on the map, the higher its pollution and the brighter the night sky is (Fig. 7).

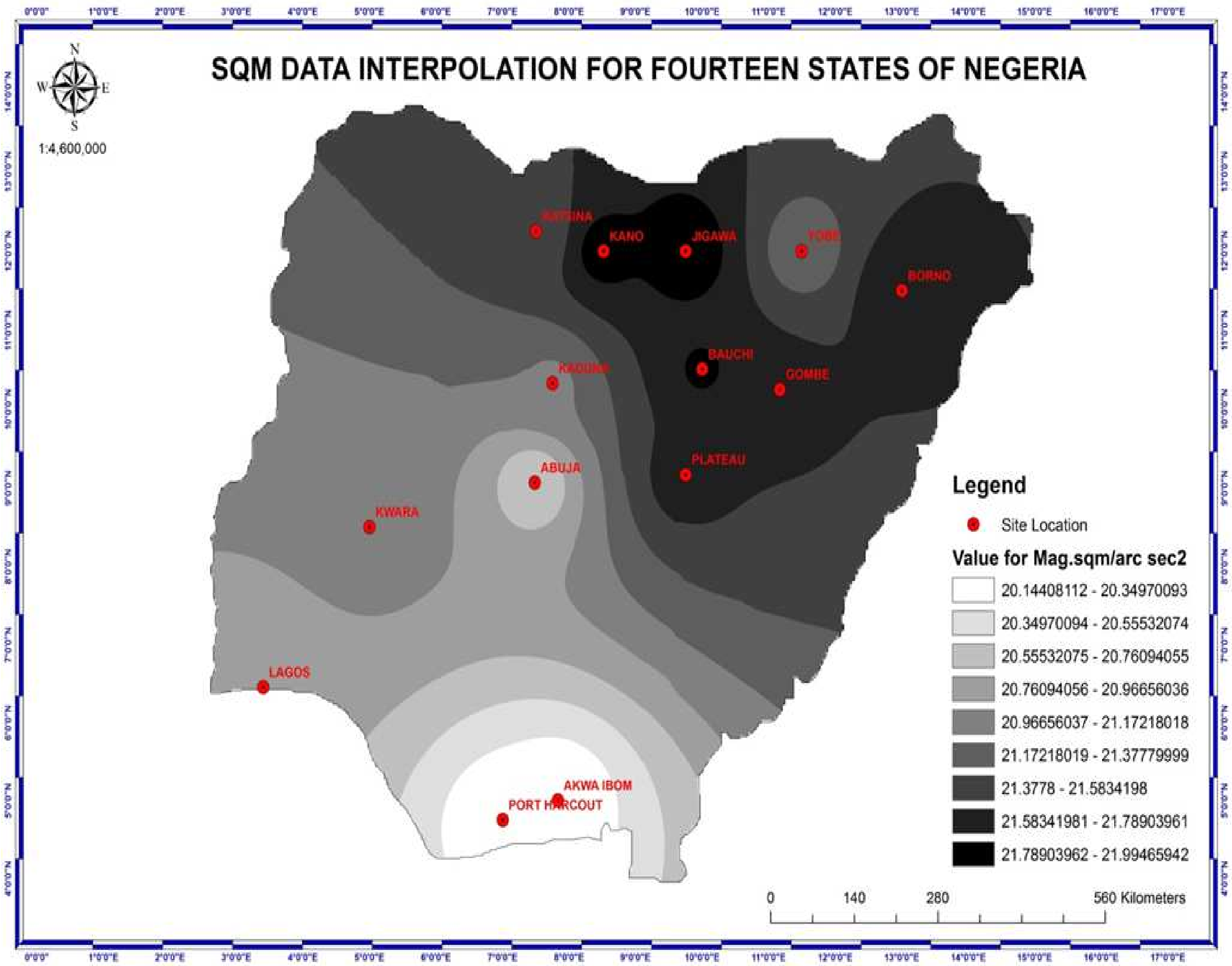

Fig. 7 The maps of the study area showing the spatial distribution of the night sky brightness

IV. Conclusion

The study highlights and suggests better places for locating/building of an astronomical observatory in the study area as sites in cluster 1. The research also employed a new method of estimation and quantification of artificial sky brightness at the local scale using a portable and a sensitive device for ground field measurement called SQM with a particular model of SQM-LU-DL. During this research, we found that there are differences in night sky brightness as measured by the SQM in different cities of Nigeria. We pointed the SQM device to the zenith (upward direction) as corresponded to the previous literature carried out using SQM for sky brightness study and artificial light measurement by other researchers in various cities of the world. We chose the main attractive cities of Nigeria because urban areas have the significant contribution or have become the main source of global light pollution due to industrialization, commercialization and high population density.

Therefore, there is the need to estimate and quantify artificial light pollution in our local scale for our various cities. This will help us to improve our environment by controlling our artificial sources of light pollution and other anthropogenic emissions so as to regulate the effects of light pollution on natural sky brightness. However, the research concluded that the cluster 1 is the best site to build an optical observatory and Jigawa and Kano are the darkest location in Nigeria in term of sky brightness. We suggest for future research, quantifying and evaluating artificial sky brightness using other instruments and devices such as light meters, EROS-B, satellite and the rest. This estimation and quantification of sky brightness may have paramount importance for astronomers.

Acknowledgment

The authors would like to thank Dr. Abdu Yunusa, Head of Physics Department Northwest University, Kano-Nigeria for his technical advice; also to Prof. Dr. Ekhwan Toriman, Deputy Vice-Chancellor Research and Innovation, Universiti Sultan Zainal Abidin for his technical support. A profound gratitude goes to Prof. Garba Babaji for the tireless support given to us and the English editor in person of Lawan-Sabo Ibrahim. Lastly, to my junior brothers Abdullahi Garba

Abdullahi, Buhari Idris Nuhu who accompanied us to the field work during data collection.

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