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GEOSTATISTICAL APPLICATION FOR SPATIAL DISTRIBUTION OF WATER SUPPLY FACILITIES TOWARDS ACHIEVING THE UNITED NATIONS' SUSTAINABLE DEVELOPMENT GOALS

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Abstract
Geostatistical tools are considered to be very imperative in achieving the Sustainable Development Goals (SDGs), most especially in the distribution of facilities. Studies on the application of geostatistics such as Average Nearest Neighbour (ANN) in the spatial distribution of sustainable water supply facilities are often very rare. This study, therefore, explores the critical importance of the ANN analytical tool of ArcGIS to examine the spatial distribution of public water supply facilities in Lapai, Nigeria. The ANN sets the null hypothesis that there is no difference between the random distribution and the distribution of public water facilities in the study area, where the z-score and p-value results are both measures of statistical significance which explains whether the null hypothesis should be accepted or rejected. The results obtained indicate a similar spatial distribution pattern for all water facilities in the study area, as they are dispersedly distributed from the global view. The method will allow more proactive decision making in the provision of sustainable public water supply facilities to better the wellbeing of urban dwellers.
Keywords: Geostatistics, Average Nearest Neighbour, Public water facilities, Sustainable Development Goals, Spatial distribution

Introduction
The United Nations (UN) during the September 2015 general assembly attended by head of states and representatives of 193 member states agreed to adopt the 2030 Agenda for Sustainable Development consisting of 17 goals and 169 targets – the Sustainable Development Goals (SDGs) (UN, 2015). The new global sustainable goals require major efforts in conducting and monitoring its progress (Giupponi, Gain, & Farinosi, 2018). Thus, experts from various professions proposes techniques in achieving and monitoring the progress of the SDGs most especially geospatial and geostatistical techniques (Avtar, Aggarwal, Kharrazi, Kumar, & Kurniawan, 2020; Josepha, Gething, Bhatt, & Ayling, 2019; Onwe, Nwankwor, Ahiarakwem, Abraham, & Emberga, 2020). Geospatial technique with the aid of Geographic Information System (GIS) provides 'the right information on the right things and at the right time' where geospatial data, adequate technology, and management systems complement high-quality official statistics (UN, 2015). These techniques need to be available quickly enough to ensure that the data cycle matches the decision cycle (Andres et al., 2017; Choudhury, Maria, & Meggiolaro, 2018; Giupponi & Gain, 2017). For example, UN-Habitat (2016) suggests that if data for the SDGs goals and targets were collected and represented using geospatial and geostatistical data, this would significantly enhance understanding of the spatial determinants of sustainable development, including the urban and rural patterns of progress.
Geostatistical tools such as ANN have a wide range of applications across various sectors. ANN was employed by Aghadadashi (2019) while examining the spatial structure of sedimentary total Polycyclic Aromatic Hydrocarbons (PAHs) and potential eco-risks to explore the suitable lag size. When assessing geographical analysis of the distribution and spread of human rabies in China, Guo et al. (2013) used ANN where it suggests that the number and duration of cluster decreased significantly after 2008. Hazrin et al. (2016) examined the spatial distribution of dengue incidences where it was argued that spatial statistical analyses are important in guiding health agencies, epidemiologists, public health officers, town planners, and relevant authorities in developing efficient controlmeasures and contingency programmes in identifying and prioritizing their efforts in effective dengue control activities.
Using the ANN tool of the spatial statistics toolbox of ArcGIS 10.3, Javari (2016) examined the temporal-spatial distribution of the precipitation station locations. Also, using ArcGIS 10.2, Li et al. (2019) examined rural settlements to identify whether the distribution of the rural settlements is clustered or dispersed in order to achieve village regrouping in the eastern plains of China where ANN is seen as the best technique. Furthermore, Mansour (2016) studied the spatial pattern of the distribution of public

health facilities across Riyadh governorate, Saudi Arabia using ANN where ANN was recommended as one of the best methods in analysing spatial pattern. Studies on spatial distribution of sustainable water supply facilities using ANN geostatistics are often very rare.

The SDG 6, which is on water and sanitation, provides the targets and indicators for monitoring progress towards universal and equitable access to safe and affordable drinking water and to adequate and equitable sanitation and hygiene (WHO, 2016; UN Water, 2018). This goal has attracted several studies and approaches in attempts to enable and accelerate progress towards achieving the goal and its targets (Mycoo, 2018; Ortigara, Kay, & Uhlenbrook, 2018; Park, 2018). For instance, Hall, Ranganathan & Raj Kumar (2017) focuses on how multiple-use water services (MUS) approach to SDG 6 could reinforce a wide range of other SDGs and targets by developing modeling framework. Mycoo (2018) analyses water governance challenges in meeting SDG 6 where it proposes policies, good practices, and tools to confront growing threats to water security and to attain sustainable development. While focusing on education, training, and research and how they could contribute to enabling and accelerating progress towards achieving SDG 6, Ortigara et al. (2018) also addresses countries reports and frameworks.

Most of the past studies were limited to frameworks, policy guidelines, country reports, and good practices while only a few focuses on tools and techniques most especially geospatial techniques in achieving SDG 6 (Cole, Bailey, Cullis, & New, 2018; Vanham et al., 2018). The few that focus on geospatial techniques also ignore geostatistics most especially the Average Nearest Neighbour (ANN) analysis. The ANN has capabilities for examining the distribution pattern of items on space amid its wide application (Aghadadashi et al., 2019). ANN has been applied to analyse health facilities (Mansour, 2016), diseases (Hazrin et al., 2016), precipitation variation (Javari, 2016), village regrouping (Li, Liu, Chen, Li, & Yu, 2019), seismic surveys (Trevisani, Boaga, Agostini, & Galgaro, 2017) and other applications that have to do with clustering among locations (Wilson, 2018). From the previous studies, applications of ANN in assessing the spatial distribution of sustainable water supply facilities are often very rare or ignored. It is on this backdrop that this study explores the critical importance of the ANN analytical tool of ArcGIS to facilitate the spatial distribution pattern of public water supply facilities in Lapai, Nigeria and accelerate progress towards achieving the United Nations' SDGs (specifically SDG 6) in the area.

Methodology of research and materials

Study Area

Lapai is located within latitudes 9°1'40" and 9°4'10" North of the Equator and longitudes 6°32'30" and 6°34'10" East of the Greenwich meridian. Lapai is a medium town and covers an area of 3,730 Km^2 with an estimated population of 12,859, based on the census of 2006 (NPC, 2006). The town is about 56 Km East of Minna, Niger State Capital. Lapai Local Government Area of Niger State is situated in a rural setting, and the major occupation of the people is farming. Few are either employed in white-collarr jobs or involved in private businesses. The locational map of the study area is shown in Fig. 1.

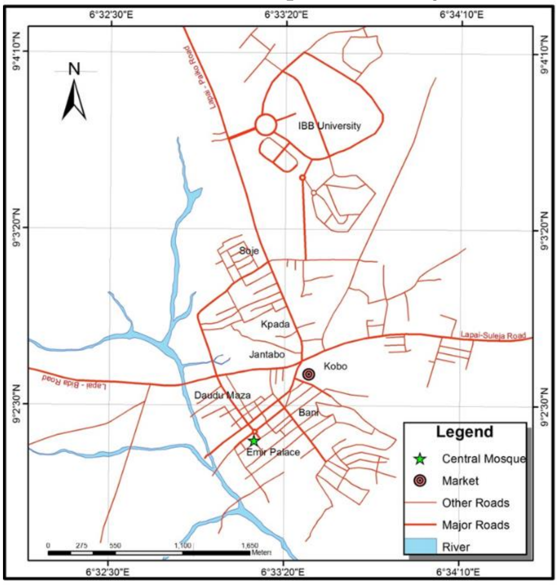

Fig. 1. Lapai Town in Niger State of Nigeria
Source: Ministry of Lands and Housing, Minna (2018)

Data and Materials

The locational position of water supply facilities in terms of X and Y coordinates were taken using hand-held GPS before further analysis, to provide detail information on the nature and condition of the existing facilities. The coordinates were taken in Universal Traverse Mercator (UTM) using handheld GPS (Etrex 10). The total number of public water supply facilities found in the study area was 45 which includes 2 taps, 26 motorised boreholes, 13 hand pump boreholes and 4 wells (see Fig. 2). There are other features on the map, some of which belong to the water agency (Niger State Water Board) which includes the Water Board, main source, and water storage tank. However, data needed for ANN analysis such as the motorised boreholes, hand pump boreholes and wells were collected with the exception of public taps because they were not functional.

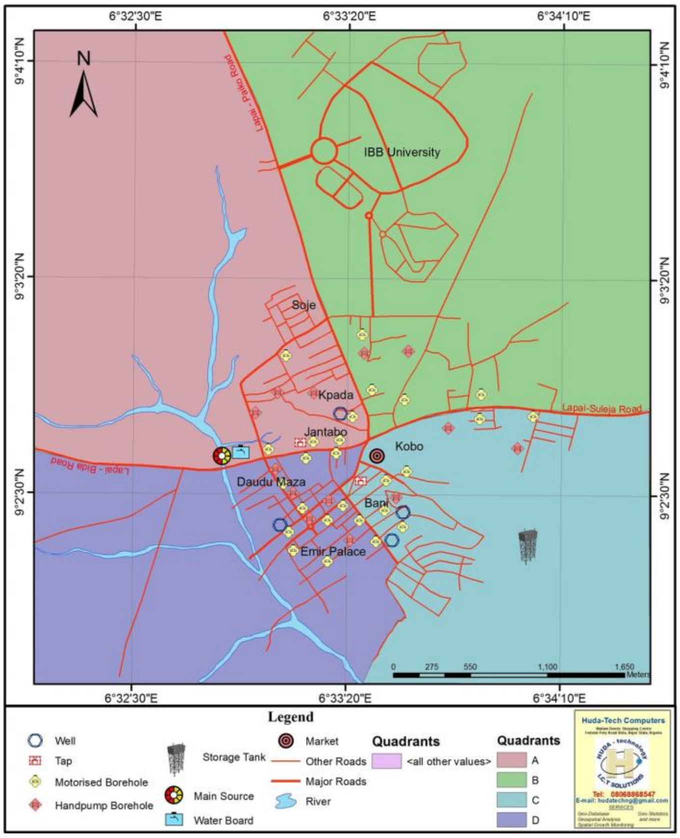

Fig. 2. Lapai Town Showing Location of Public Water Facilities
Source: Authors' fieldwork, 2018

Analysis

ANN Analysis tool was adopted in measuring patern of spatial distribution pattern of water supply facilities in the study area. The ANN ratio is given as (Mitchell, 2005):

$$ANN = \frac{\overline{D}_O}{\overline{D}_E} \quad (1)$$

where $\overline{D}_O$ is the observed mean distance between each feature and its nearest neighbor:

$$\overline{D}_O = \frac{\sum_{i=1}^{n} d_i}{n} \quad (2)$$

and $\overline{D}_E$ is the expected mean distance for the features given in a random pattern:

$$\overline{D}_E = \frac{0.5}{\sqrt{n/A}} \qquad (3)$$

In the above equations, d_i equals the distance between feature i and it's nearest neighbouring feature, n corresponds to the total number of features, and A is the area of a minimum enclosing rectangle around all features, or it's a user-specific Area value.
The ANN z-score for the statistic is calculated as:

$$z = \frac{\overline{D}_O - \overline{D}_E}{SE} \qquad (4)$$

where:

$$SE = \frac{0.26136}{\sqrt{n^2/A}} \qquad (5)$$

The ANN sets the null hypothesis that there is no difference between the random distribution and the distribution of public water facilities in the study area, where the z-score and p-value results are both measures of statistical significance which explains whether the null hypothesis should be accepted or rejected.

Discussions and results

Average Nearest Neighbor Analysis is a method/tool used to explore and explain the spatial distribution of public water supply facilities. The tool sets the null hypothesis that there is no difference between a random distribution and the distribution of public water supply facilities in the study area (see Fig. 3 – 5 and Tables 1 – 3). Although, public tap facilities are not considered in these spatial statistical results due to limited and non-functioning of those facilities.

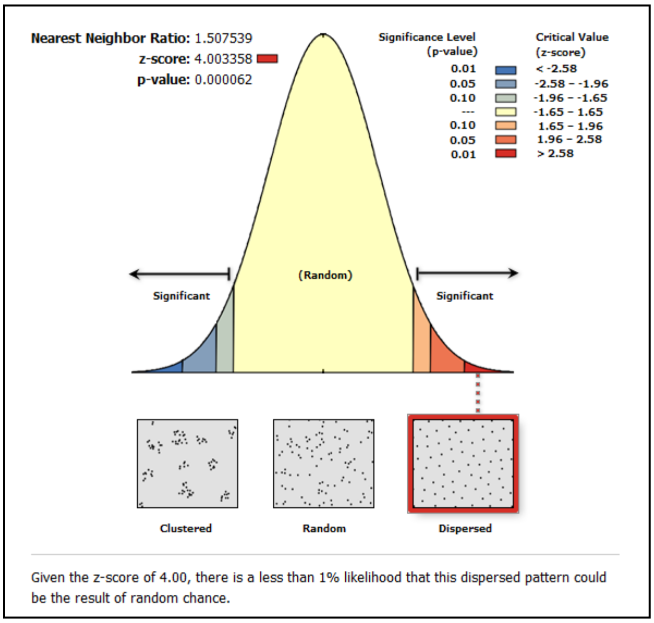

Fig. 3. Spatial Distribution of Public Hand Pump Borehole in Lapai Town
Source: Authors' fieldwork, 2018

Table 1

Average Nearest Neighbor Analysis Summary of Public Hand Pump Borehole in Lapai Town

Observed Mean Distance	**820.541468**
Expected Mean Distance	544.292172
Nearest Neighbor Ratio	1.507539
z-score	4.003358
p-value	0.000062
Input Feature Class	Handpump Borehole
Distance Method	EUCLIDEAN
Study Area	20145269.833852

Source: Authors' fieldwork, 2018

Fig. 3 and Table 1 are the outcomes of the global view spatial cluster test of public hand pump borehole facilities. When examine the p-value of 0.000062 and given the z-score of 4.003358, the pattern does not appear to be significantly different than dispersed. Therefore, reject the null hypothesis that all public hand pump borehole facilities are randomly distributed in a global view. However, by re-examining the public hand pump borehole facilities map in Local View, find out that some of the public hand pump borehole facilities are dispersed in locally limited areas.

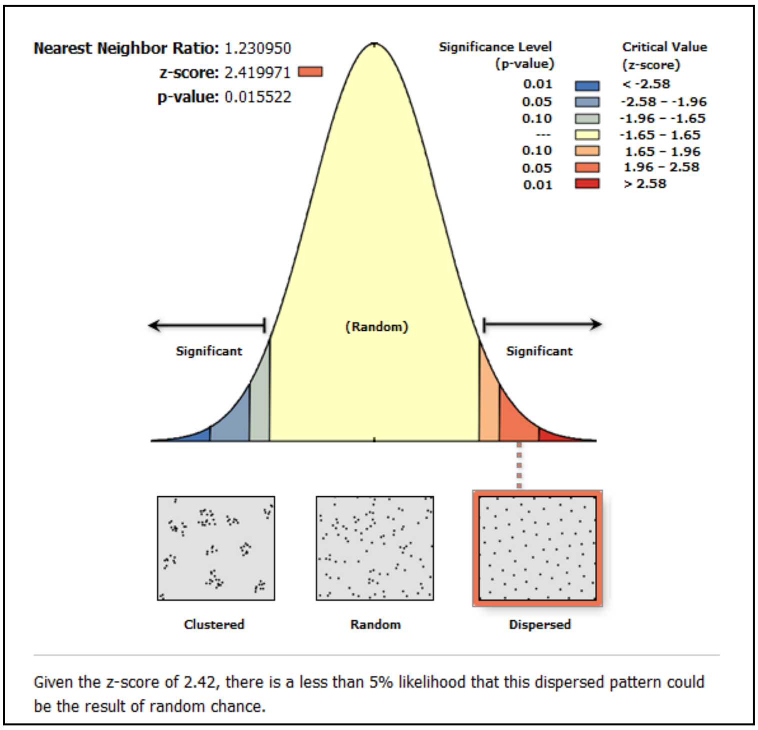

Fig. 4. Spatial Distribution of Public Motorised Borehole in Lapai Town
Source: Authors' fieldwork, 2018

Table 2

Average Nearest Neighbor Analysis Summary of Public Motorised Borehole in Lapai Town

Observed Mean Distance	**505.942337**
Expected Mean Distance	411.017644
Nearest Neighbor Ratio	1.230950
z-score	2.419971
p-value	0.015522
Input Feature Class	Motorised Borehole
Distance Method	EUCLIDEAN
Study Area	20145269.833852

Source: Authors' fieldwork, 2018

Fig. 4 and Table 2 are the outcomes of the global view spatial cluster test of public motorised borehole facilities. When examine the p-value of 0.015522 and given the z-score of 2.419971, the pattern does not appear to be significantly different than dispersed. Therefore, reject the null hypothesis that all public motorised borehole facilities are randomly distributed in a global view. However, by re-examining the public motorised borehole facilities map in Local View, find out that some of the public motorised borehole facilities are dispersed in locally limited areas.

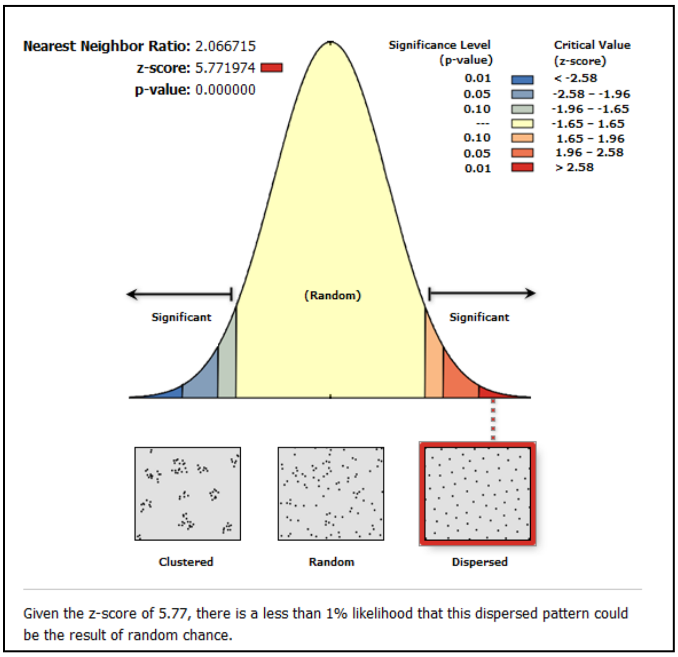

Fig. 5. Spatial Distributions of Public Well Facilities in Lapai Town
Source: Authors' fieldwork, 2018

Table 3

Average Nearest Neighbor Analysis Summary of Public Well Facilities in Lapai Town

Observed Mean Distance	1631.841318
Expected Mean Distance	789.582058
Nearest Neighbor Ratio	2.066715
z-score	5.771974
p-value	0.000000
Input Feature Class	Well
Distance Method	EUCLIDEAN
Study Area	20145269.833852

Source: Authors' fieldwork, 2018

Fig. 5 and Table 3 are the outcomes of the global view spatial cluster test of public well facilities. When examine the p-value of 0.000000 and given the z-score of 5.771974, the pattern does not appear to be significantly different than dispersed. Therefore, reject the null hypothesis that all of public well facilities are randomly distributed in a global view. However, by re-examining the public well facilities map in Local View, yet, there are few public well facilities in the study area and that some of the public well facilities are dispersed in locally limited areas. This is similar to the previous results of hand pump borehole and motorised borehole.

The pattern of all water supply facilities in the study area is dispersedly distributed from analysis of the ANN. This can be better explained with large data most especially of water supply facilities. As explained earlier, it can be argued that ANN is one of the best tools in examining the spatial pattern of urban public water supply facilities and also can aid the achievement of the SDGs most especially 'the water SDG' (i.e., SDG 6). This has been argued earlier by Mansour (2016) and Hazrin et al. (2016) that ANN is the best tool for examining the spatial pattern of both health facilities and disease in terms of urban, rural, and regional basis.

Conclusions and proposals

The study has shown that by adopting ANN geostatistics in examining the spatial distribution pattern of public water supply facilities; it will facilitate the achievement of the SDGs by enhancing; safe, affordable, and sustainable water facilities provision. This study has proven that it can be more beneficial in developing countries, especially African nations in formulating policies, programs, and frameworks. ANN geostatistical application is therefore recommended for SDGs for meeting its SDG 6 target before the year 2030. ANN application can also be extended to other aspects of SDGs to study or analyse the distribution of spatial data and phenomenon that can contribute to the achievement of the goals in all countries particularly in developing countries where the settlement pattern is complex, largely informal and difficult to provide infrastructure and services. Yet, Africa can benefit from this approach in formulating policies, programs, and frameworks at country, state, and settlement levels to achieve the SDGs most especially the SDG 6. The tool will allow more proactive decision making in the provision of sustainable public water supply facilities to better the wellbeing of urban dwellers.

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