Dimensioning Environmental Indicators: A Principal Component Analysis of Auchi Region, Edo State

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Abstract

The environment is a multidimensional system and its components are interrelated and fuzzy. The environment is of concern to humans because of its growing deterioration which has prompted the need to improve its quality. Hence environmental quality assessment has become a means of determining quality. The study is on dimensioning the 66 variables that affect the quality of Auchi Region. Principal component Analysis was used to select the underlying factor structure of the variables. The result is an 8-factor solution of housing, erosion, distance, solid waste, natural environment, flooding, land use and erosion effects that explain 46.26 per cent of the variance in environmental quality of Auchi Region. The technique is recommended as an effective means of dimensioning the complex system of environment in less developed countries where data input is difficult to obtain.

Keywords: Environmental Indicators, Principal Components, Dimensionality, Auchi

INTRODUCTION

Environment has become a major focus of research in the 21st century because of increasing problems affecting humans. The environment is multidimensional and it is not easily amenable to a comprehensive handling (Adriaanse, 1993; Bartone, Bemstein, Leitmann & Eigon 1994). Many researchers have approached it narrowly from their own disciplinary background. However the environment is a great container and a web of interrelationships. These relationships must be accounted for, if any meaningful investigation of the environment is to be embarked upon. Many phenomena in the habitat of man do have environmental implications and impacts. These underscore the need for us to be interested in environmental concerns.

The starting point of the study of environment is what to distil as the constituents of environment. The environment is multidimensional as approached by many scholars taking toll on the air, water, and ground quality, pollution, biosphere and the cultural elements and built developments (Cunningham and Saigo, 2001; Khatun, 2007). The intricate nature of the environment is such that the seemingly endless list of elements does not exist in isolated bits, but rather are closely knitted together in a web. The complex nature of the environment has fostered researchers to seek interest in modelling environmental components in the form of indicators. These indicators are hung on themes like water, air, biotic, economic development and built environment. These indicators are, however, not comprehensive and scientific enough to capture the essence of the environment they are modelling. After the Rio Earth Conference Brazil, various international organisations, national governments, and institutions have evolved different environmental quality indicators to study the environment (Chang-ching, Quinn, Dufournould, Harrington, Rogers and Lohani 1998). One theme that runs through the indicators derived by the United Nations Environmental Programme (UNEP), World Bank and Dutch Government (Chang-Ching *et al*, 1998) is that the indicators have been hampered by the complexity of the environment system regarding what to measure and how to measure them. Since the environment is multidimensional and complex, dimensioning it requires simplification and data reduction. A good statistical technique of achieving this is principal component analysis (PCA). The present study aims at dimensioning the indicators of the environmental quality of Auchi Region in Edo State. The theoretical search started with the review of literature on the built environment of a region. Sixty-six variables that described the environment of Auchi Region were chosen for the purpose and these are pretty too many and fuzzy for dimensioning the environment of Auchi Region.

The study sought to reduce these sixty-six variables into a few dimensions that can indicate the quality of environment of Auchi Region. Thus, the study will answer these questions: How many variables can be used to dimension the quality of Auchi Region? How is principal component analysis used to dimension the environmental quality of Auchi Region? It is hoped that these would help policy makers to reach decisions on environment measurement.

The Study Area

The location for the investigation is Auchi Region. Taking Auchi as the locus, and a radius of about 10.5km, the area spans about 346.361km^2. The area has western boundary with Owan East and Akoko-Edo LGAs, an eastern boundary with Etsako Central and in the southern area it is bounded by Esan West, Esan Central and Esan North-east. The area has some few urban centres in Auchi and Jattu. Ughiole, South- Ibie and Jattu are coalescing with Auchi to form one continuous urban form.

Methodology

The concept of environmental quality is multidimensional and has been carried out by many assessors using different approaches. In this study interview survey was used in recording the responses of participants because it afforded the opportunity of trained interviewers to clarify some issues to the respondents. The following steps were followed:

Sampling

The study area is the Auchi Region. Although the Town Planning Authorities use a radius of 5.5 km from a point in Warrake Road, Auchi as its declared planning area based on schedule iv of the defunct Bendel State of Nigeria Gazette No. 67 vol. 26 of December 1989, this application is inadequate for this study. Reason being that commuting distance covered in terms of interaction between residents of Auchi and its neighbours far exceeds this. A distance of 10.5 kilometres was chosen based on the commuting distance covered by workers of Auchi Polytechnic, Auchi from their residences.

From available estimates based on the National Population Censuses of 1991 and 2006 and the arithmetic projection carried out to 2011 the population of the region is 232, 126 persons. However, the study population is based on the population of the 24 sampled settlements which is 216,468 persons. A sampling fraction of 0.005 was used to determine the sample size for the survey. This gives a sample size of 1082 respondents. A sample size calculator gives 384 as the precise sample size for a population of 216,468 at an accuracy of error margin of 5 per cent and at 95 per cent confidence level (Van Ambury cited in Mitchell & Jolley, 2007. This is far less than the chosen sample size of 1082 persons. The study population was chosen based on the spatial distribution of population among the settlements and the PCA technique as applied in the study.

There are 38 settlements within the radius of 10.5 Km that form Auchi Region. These settlements are the large population centres of Auchi, Jattu, Iyakpi and 35 villages. The three urban nodes are of relatively large population concentrations compared to other settlements in the region. The disparity in the size of population between the large and the small settlements necessitated the splitting of the three large settlements for comparability of their sizes (see Table 1). Auchi was split into six units (Igbei, Akpekpe, Aibotse, Usogun, Iyekhei and GRA); Jattu into two (Old and New); and Iyakpi into two (Old and New). Thus Auchi, Jattu and Iyakpi were divided into ten spatial units. The following settlements were combined into seven pairs (Ikabigo/Idato, Ibienafe/Ugieda, Iyerekhu/Ughiekhai, Ayua/Elele, Buneka/Ebese, Afashio/Afowa and Uluoke/Ogbido. The pairing is based on their contiguity. The remaining eight settlements, each on its own, stood as a spatial unit. Altogether there are 24 spatial sampling units that were used for the survey.

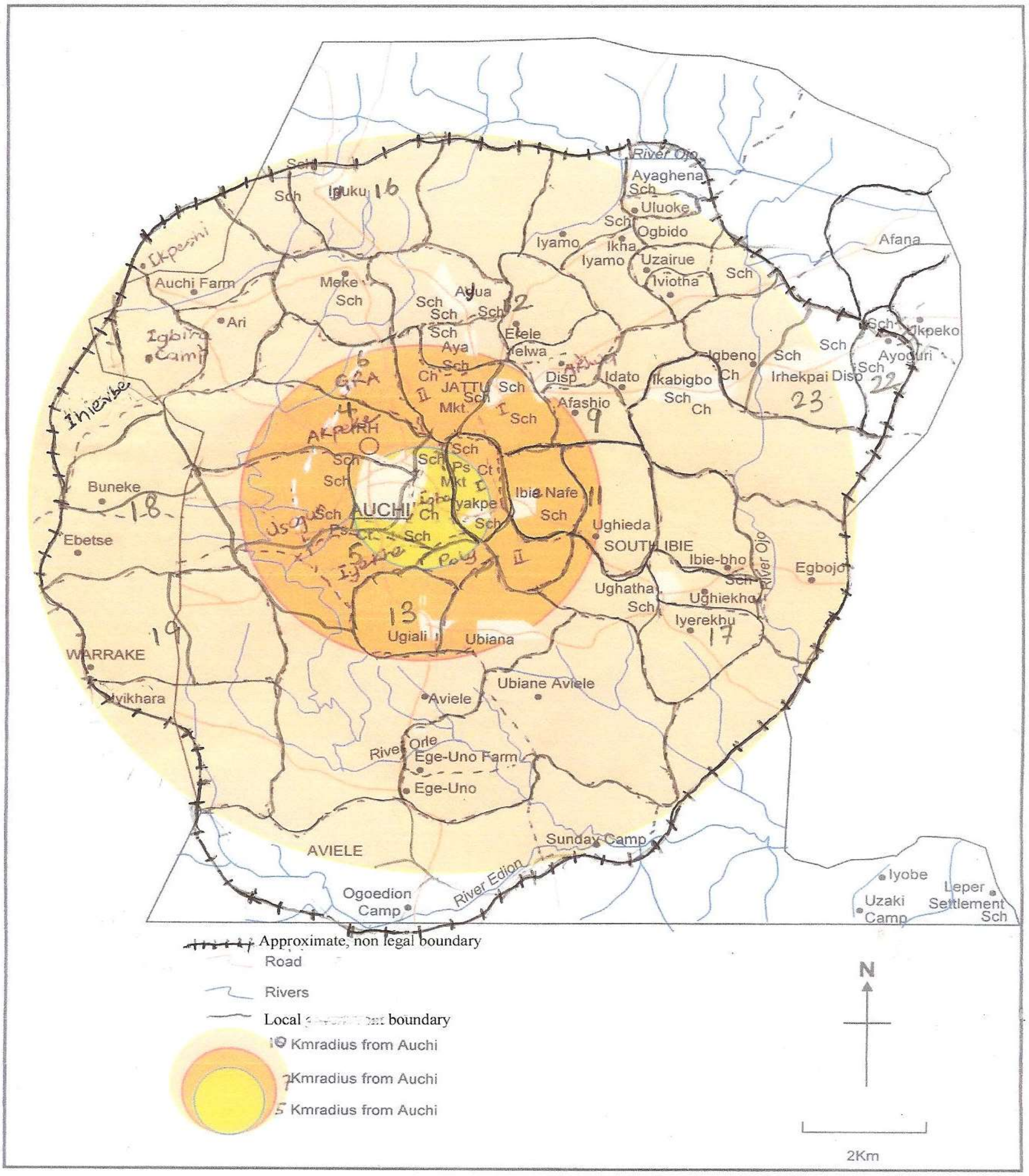

Figure 1: A sketch of Auchi, the study area.

The distribution of the sampled respondents for the interview survey is shown in Table 1. . The survey carried out in the region shows a response rate of 81.89 per cent (i.e. 886 respondents were interviewed across the 24 spatial sampling units). The distribution of those interviewed in the 24 spatial sampling units is shown in Table1.

The respondents for the survey were the heads of households. A household is regarded as persons that live together, eat together and share the same apartment. The selection of the respondents was based on a random systematic sampling. In the larger sampling units, a household head was interviewed at every 5th house from randomly selected streets; and in the smaller sampling units an interval of every 2nd house was used. Wherever these requirements were not met in the smaller sampling units, any available household head was interviewed in a house.

Table 1 Sample units of the study area

Zone	Settlement/Quarters	Population Size	Sample Size	
			Initial	Administered
Auchi – A	1. Igbei	9,240	46.2	39
Urban core	2. Aibotse	12,320	61.5	57
	3. Usogun	21,560	107	81
	4. Akpekpe	18,480	92	81
	5. Iyekhe	15,400	77	61
	6. GRA	6,161	30	25
		83,161		
Intermediate – B	7. Jattu (1-Old)	16,725	83	65
	8. Jattu (11 – New)	11,151	56	42
	9. Afashio/Afowa	8,384	42	34
	10. Ikabigbo/Idato	4,602	23	20
	11. Ibienafe/ugieda	5,184	26	31
	12. Ayua/Elele	6,735	34	29
	13. Ugioli	5,791	29	25
	14. Iyakpi (1 – Old)	5,984	30	26
	15. Iyakpi (11 – New)	7,978	40	28
		72,534		
Periphery – C	16. Iyuku	7,568	38.8	42
	17. Iyerekhu/Ughiekhai	3,978	20	19
	18. Buneka/Ebese(Ivbiaro)	7,994	40	31
	19. Warrake	11,784	59	41
	20. Ihievbe	8,636	43	27
	21. Uluoke/Ogbido	3,597	18	15
	22. Ayogwiri	7,366	37	29
	23. Irhekpai	3,320	18	14
	24. Ikpeshi	6,530	33	24
		60,773		
Total		**216,468**	**1082**	**886**

Interview Schedule

A major instrument that was used in gathering data in the study is the questionnaire. The interview schedule was structured into sections reflecting the variables and the attributes of urban environmental quality.

Execution of the interview survey

The interviewers were 24 Higher National Diploma students in Urban and Regional Planning Department of Auchi Polytechnic, Auchi. Each of these students covered a spatial sampling unit. Four students from the Post-Higher National Diploma Programme in Urban and Regional Planning of Auchi Polytechnic, Auchi were chosen to supervise the field activities of the interviewers. Each supervisor was in charge of 6 interviewers. The supervisors and the interviewers for the survey were selected based on their knowledge of the study area and the theme for the study. Apart from interviewing the respondents, the interviers were also to observe objectively certain phenomena in the field, such as distances by using pacing. A pace was set at an average distance of 0.5 metre.

Data Analysis

A principal components analysis was carried out to provide understanding on the underlying factor structure that accounts for the variance in the physical environmental quality of Auchi Region. The PCA used 886 cases and 66 items or variables based on SPSS version 16. The following steps were followed in the PCA analysis to unfold the major dimensions environmental quality could be explained.

(a) Assessment of the Suitability of the Data for Analysis

Two main issues are generally considered in determining the suitability of data set for factor analysis. These are the sample size and the strength of relationship among the variables or items. While there is disagreement among authors concerning how large a sample should be, the recommendation generally is that a large sample is better (Pallant, 2011). The correlation coefficients among the variables in small samples are less reliable than as in large samples. Tabachnick and Fidell (2007) reviewed this and suggested that it is 'comforting to have at least 300 cases for factor analysis' (p.613). In the study a sample of 886 was used.

In terms of the strength of the intercorrelations among the 66 variables that were selected for the principal components analysis, SPSS generated data to assess their factorability based on Kaiser-Meyer-Olkin Measure (KMO) and Bartlett's Test of Sphericity. These tests applied the cut-off of .3 coefficients as suggested by Tabachnick and Fidell (2007). The measure of sampling adequacy for the MKO is .6 or above and the Bartlett's Test of Sphericity value was significant at .05 or smaller. In the study the KMO value is .861 and Bartlett's test is significant (p =.001). Therefore factor analysis is appropriate. In the correlation matrix, correlation coefficients of .3 and above are very many.

(b) Factor Extraction

This involves determining the smallest number of factors that can be used to best represent the interrelationships among the set of variables (Pallant, 2011). There are many ways this can be done. The approach that is applied here is the principal components analysis (PCA). The PCA helped in finding a simple solution with as few factors and tried to explain as much variance in the original data set. This decision was reached through Kaiser's criterion, scree test and parallel analysis.

Kaiser's Criterion. Using Kaiser's criterion, we are considering components that have eigenvalue of 1 or more. To determine how many components met this criterion, this is read in the Total Variance Explained Table (see Table 3). Browse down the initial eigenvalues. This reveals 17 components, which explain a total of 62.22 per cent of the variance.

Scree Test. Another approach used in the literature in determining the number of components to retain is Catell's Scree test. This involves the SPSS package plotting a graph of the components of the PCA (see Figure 2 Catell's Scree test). The elbow of this plot which signifies a change in direction determines the cut-off for retaining the eigenvalues before the horizontal change in direction. In the investigation, the inspection of the plot reveals 12 components. The Scree test depends on an eye judgment of the researcher which may tend not to be accurate. Both the Scree test and KMO test are often criticized for yielding too many components that are not adequate for retention in PCA analysis.

Parallel Analysis. An additional approach which many social science literature feel that addresses the issue of components better than any of the approaches discussed above is the Horn's parallel analysis (Horn 1965 in Pallant, 2011). According to Pallant (2011) 'Parallel analysis involves comparing the size of the eigenvalues with those obtained from a randomly generated data set of the same size.'(p.184). In this approach you need to down load a zip file from the Internet (Parallel analysis zip) onto one's computer. Unzip this onto the hard drive and click on the file Montecarlopa.exe. This software was developed by Walkins (2000). The program requested for three pieces of information: the number of variables you are analysing (in this case 66); the number of cases in the sample (in this case 886); and the number of replications (specify 100) then click on calculate. The program yielded the output in a table (see Table 2). The next step is to systematically compare the first eigenvalues you obtained in SPSS with the corresponding values from the random results generated by Parallel analysis (Pallant, 2011). This is compiled in Table 2.

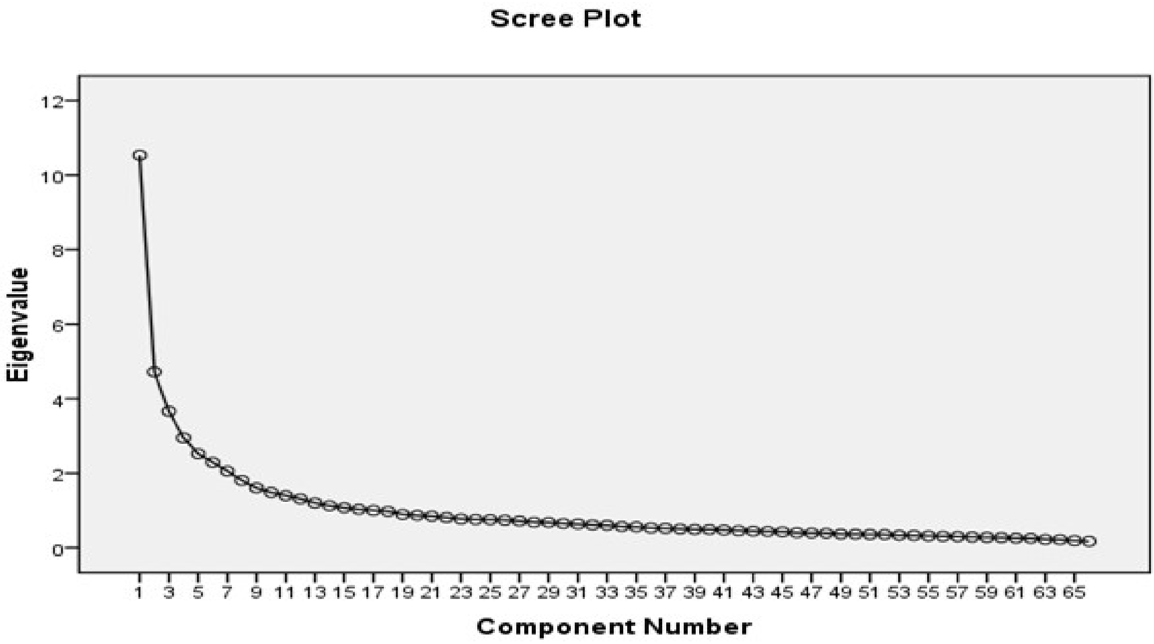

Figure 2: Catell's Scree test

Table 2: Comparison of Eigenvalues from PCA and Criterion Values from parallel analysis

PC	Actual Eigenvalues from PCA	Criterion value from parallel analysis	Decision
1	10.533	1.5773	accept
2	4.720	1.5342	accept
3	3.661	1.4981	accept
4	2.948	1.4664	accept
5	2.522	1.4422	accept
6	2.291	1.4158	accept
7	2.055	1.3927	accept
8	1.805	1.3726	accept
9	1.605	1.3527	accept
10	1.481	1.3324	accept
11	1.398	1.3137	accept
12	1.310	1.2939	accept
13	1.200	1.2760	reject
14	1.124	1.2587	reject
15	1.072	1.2419	reject
16	1.031	1.2265	reject

If the value is larger than the criterion value from parallel analysis, you retain this factor; if it is less you reject it. Based on this approach we retain 12 components which confirmed the result of the scree plot.

Table 3: Total Variance Explained (Abridged)

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
PC	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	10.533	15.960	15.960	10.533	15.960	15.960	6.442
2	4.720	7.151	23.111	4.720	7.151	23.111	4.860
3	3.661	5.547	28.658	3.661	5.547	28.658	5.984
4	2.948	4.466	33.124	2.948	4.466	33.124	2.910
5	2.522	3.821	36.945	2.522	3.821	36.945	4.211
6	2.291	3.471	40.416	2.291	3.471	40.416	4.595
7	2.055	3.114	43.530	2.055	3.114	43.530	3.266
8	1.805	2.734	46.264	1.805	2.734	46.264	4.898
9	1.605	2.431	48.695				
10	1.481	2.244	50.940				
11	1.398	2.118	53.058				
12	1.310	1.984	55.042				
13	1.200	1.818	56.861				
14	1.124	1.703	58.564				
15	1.072	1.624	60.188				
16	1.031	1.561	61.749				
17	1.001	1.517	63.266				
18	.975	1.477	64.743				
19	.894	1.354	66.097				
20	.868	1.316	67.413				
…							
61	.258	.391	98.403				
62	.252	.382	98.786				
63	.223	.338	99.124				
64	.216	.328	99.451				
65	.190	.288	99.739				
66	.172	.261	100.000				

Extraction Method: Principal Component Analysis. a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Table 4: Component Matrix[a] (Abridged)

	Component							
	1	2	3	4	5	6	7	8
Attraction of House in terms of Landscape features	.697	-.023	-.041	.098	.095	-.030	.079	-.077
General Condition of Housing Unit	.651	-.079	-.138	.110	.022	.057	.143	-.183
Satisfaction with the Level of Street Cleanliness	.635	.074	.113	.067	.010	.036	-.213	-.057
Attraction of House in terms of Aesthetics	.628	-.128	-.193	.066	.032	-.172	.132	.105
Satisfaction with Natural Environment	.623	.082	.114	.059	.041	.141	-.036	.087

Heathiness of Area in Terms of Common Diseases	.595	.001	.049	.181	.106	-.056	-.305	-.011
Pollution of Air in terms of Stench	.560	-.275	.153	.049	-.065	-.156	-.333	.005
…								
Degree of Noise in Neighbourhood	.371	-.182	.107	-.086	.397	.263	-.174	.381
Permanence of Street Flood	.318	-.177	.218	.333	-.364	.224	.054	.355
Seriousness of Erosion	.434	.047	.062	.145	-.330	.526	.102	.051
Present of Erosion	.408	.014	.073	.147	-.352	.456	.108	.019
Width of Gully	.016	-.172	-.049	.147	-.100	.056	.298	.203

Extraction Method: Principal Component Analysis. a. 8 components extracted.

Table 5: Pattern Matrix[a] (Abridged)

	Component							
	1	2	3	4	5	6	7	8
Distance of House to building at the Left	.792	.041	-.022	-.180	.013	.008	.107	.171
Distance of House to Middle of Street	.782	.046	-.007	-.051	-.047	.002	.058	.052
Distance of House to Building at the Right	.733	-.012	-.022	-.191	-.006	.120	.139	.141
Per centage of Openspace in Building Plot	.565	-.143	-.121	-.173	.185	-.092	-.027	-.137
Pollution of Air in terms of Stench	.549	-.120	.008	.225	.187	.115	.103	-.182
…								
Heathiness of Area in Terms of Common Diseases	.271	.103	-.042	.244	.244	.112	.142	-.348
Width of Gully	-.085	.038	-.217	.013	-.050	.255	.021	.335
Quality of Water	.042	.176	.114	-.029	.147	.075	.307	-.317

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 28 iterations.

(c) *Factor Rotation and Interpretation*

The PCA extracted 17 factors based on eigenvalue of one, using KMO which is the default option of SPSS (see Table 3). In order to interpret the pattern of loadings in a clearer manner, there is need to rotate the 12 components arrived at through the compromised decision of scree plot and parallel analysis (see Table 2). There are two main approaches to rotation, resulting in either orthogonal (uncorrelated) or oblique (correlated) factor solutions. Within the two broad categories of rotational approach there are a number of different techniques provided in SPSS.

The initial rotation was based on 12 components and this did not have a discernable pattern matrix showing dimensions of loadings. In subsequent reruns it was discovered that an 8-factor structure provided the optimal factor solution. The result of the fixed 8-factor solution is shown in Table 5).

RESULTS AND DISCUSSION

The 8-factor solution gives a total variance explained of 46.26 per cent. The individual components contributions are: component 1 providing 15.96 per cent; component 2 is 7.15 per cent; component 3 is 5.55 per cent; component 4 is 4.47 per cent; component 5 is 3.82 per cent; component 6 is 3.47; component 7 is 3.11 per cent; and component 8 is 2.73 per cent (see Table 3). The interpretations of the eight components are based on variable loadings correlation of .3 (Tabanick & Fidel, 2007) for 5 components with high loadings and .2 for three components with low factor loadings (Pallant, 2011). The interpretation of these factors is based on the pattern matrix rather than on the structure matrix because the pattern matrix is pragmatic and easier to interpret. According to Tabachnick and Fidell (2007), "The difference between high and low loadings is more apparent in the pattern matrix than in the structure matrix." The labels given to the components are:

Component 1: housing; component 2: erosion; component 3: distance (weak); component 4: solid wastes (weak); component 5: natural environment; component 6: flood; component 7: land use; and component 8: erosion effect (weak). Thus the eight components formed the underlying dimensions that can be used in explaining the variance in environmental quality of Auchi Region.

Dimensions of Environmental Quality

The principal components analysis shows that the variables of environmental quality of Auchi Region can be subsumed in eight dimensions. These dimensions determine largely the spatial variability in the environmental quality of Auchi Region. There is, therefore, a compelling need to explain how the dimensioned variables are linked with the quality of the environment. This link is traceable to the factor loadings of the dimensioned components. These components are orthogonal with the highest correlation between any components less than 0.162 (see Components Correlation Matrix, Table 4). The loadings are found in the Pattern Matrix (Table 5). Next, the dimensioned factors are considered one after another.

1. *Principal component* 1: Housing was clearly identified as principal component 1 in the study. The variables that highly load into housing are set-backs, open space in buildings, size of plots, facilities in homes etc. These variables have been identified in many studies as the major attributes that constitute housing as seen in Ozo (1987). The shelter component is not the only attribute of housing. And in the study the quality of this attribute fared generally above average in the region. For example, the average condition for the dwelling units in the region is 3.4. This value is above the average quality score. This has also confirmed previous studies in regard of the quality of the shelter components in urban areas in Nigeria in which structural elements of roofs, walling materials are generally satisfactory.
2. *Principal component 2*: Erosion contributed 7.15 per cent of the variance explained. The variables that are highly loaded into this dimensioned factor or component are informal communal erosion measures, formal erosion control measures, informal individual control measures, etc. These loadings show that erosion is a potent factor in explaining the variability of Auchi Region. Previous studies on Auchi Town and the neighbouring settlements point to the environmental degradation caused by erosion (Sada & Omuta, 1979).
3. *Component 3:* The variables that load on this relate to distance. The total variance explained by this component or factor is 5.5 per cent. The variable loadings which are weak are related to the distance between Auchi Town and the other settlements of the region. The hypothesis that was tested on this confirmed the weak correlation between environmental quality and distance of settlements moving away from the urban core of Auchi Region (Onaiwu, 2013). This does not confirm the ecological models that postulate that quality of urban environment increases from the core to the periphery.
4. *Component 4:* The pattern of correlation matrix identified in component 4 is solid waste. The variables that identify this pattern are weak and relate mainly to pest infestation, healthiness of the environment in terms of common diseases, etc. This component is weak because the variability in the solid waste conditions in the settlements of Auchi Region is low. The level of environmental sanitation is generally low among the settlements. The analysis of variance carried out shows weak effect sizes for the various conditions of solid waste management (Onaiwu, 2013).
5. *Component 5:* Component 5 is identified as the natural environment. The variance explained by this component amounts to 3.82 per cent. The variables that load on this are: vegetation condition, greenery, surfacing material in unbuilt plots, etc. The presence of vegetation in the three zones varies;

and the peripheral zone was identified as the most vegetated part of the region. Vegetation plays an important role in checking the devastating effects of erosion and flooding. Many studies have shown the potency of vegetation in doing this (Igbozurike, 1993).

6. *Component 6:* The pattern matrix in Table 5 identified flooding as a dimensioned component or factor. The variable loadings on this component are: flood seriousness, permanency of flood, condition of road, width of gullies, etc. The conditions of flooding vary from one zone to the other in the region. Flooding is a serious problem in the core and intermediate zones. This has been identified in many studies as an environmental degrader of the quality of urban environment (Nwafor, 2006)

7. *Component 7:* Component 7 is identified as land use. The factor loadings into this account for 3.11 per cent of the explained variance. Land use compatibility affects the quality of urban environment. Another aspect of land use that affects the quality of the settlements in the region relates to density. Many of the building developments exceeded the prescribed densities in development control.

8. *Component 8*: This identified erosion effects of gullies. This component is mainly localized especially in few portions of the core and intermediate zones of the region.

The eight components discussed show the dimensions the environmental quality of the emerging urban region of Auchi could be managed to enhance its quality. In most urban settlements in Nigeria the identified dimensions in which the urban environmental quality hangs are worth considering in enhancing their quality. Thus, if any appreciable progress is to be made in improving urban environmental quality in Nigeria, there is the need to focus on few major indicators of quality because of the scarcity of resources to address every problem at the same time.

CONCLUSION AND RECOMMENDATIONS

Principal component analysis is a statistical technique that can be used for effective dimensionality of the environmental quality indicators, especially in less developed countries where data input is a problem in environmental investigations. Residents of such countries are asked to perceive certain environmental variables that affect where they live. The dimensioning of such variables into a few uncorrelated variables for environmental assessment can help in improving the quality of environment.

The 8-factor principal components solution that revealed the issues that affect the sensitivity of the environmental quality of Auchi Region are coterminous with what investigators obtained in the past in assessing its quality (Omuta, 2002; Ohiaegbunem 2006; Al Hasan *et al*., 2009).

The PCA went further in the assessment because it used the dimensions that were used in limited, isolated forms in previous studies in a more objective and holistic form to model the environmental quality of Auchi Region. This is a better way of representing the multidimensional nature of the environment. The use of the 886 respondents and 66 variables in arriving at an 8-factor structure makes the PCA to reduce its traditional deformity of lack of statistical inferences on the population based on the particular sample analysed. Thus policy makers in less developed countries can use the PCA as a starting point in describing and objectively reaching decisions on their environment.

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