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Cropland Suitability Analysis

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Abstract: The wider cognizance of the significance of spatial elements considered in decision-making process, be it agricultural or other forms of land uses, has made Spatial Multi Criteria Analysis to receive greater placement as a tool in decision making. In this study, Land Suitability Assessment using Analytic Network Process, was conducted in Igabi, Kaduna State, Nigeria. The sequence commenced by subdividing the study area into 9 zones and used for all the evaluations, since a block of land is most likely to have uniform characteristics. A GIS technique called Locational Suitability Assessment also referred to as Site Selection, was conducted to produce Compatible Cropping Area (CCA). This is the suitable cropping area in terms of terrain and compatibility with other Land Uses, after extracting all constraints. Then the CCA was subjected to Land Suitability and Capability Analysis (LSCA) i.e. the soil biochemical and physical characteristics of each zone. The parameters requested were the prescription of Food and Agricultural organization. Using the LSCA and climatic factors, pairwise comparison technique was conducted on experts with formal knowledge in agriculture related sciences to determine the most suitable crops for each of the zones. The results revealed that onion is the most suitable to be grown in all the zones except zones G, H and I, where it became the second most suitable after cassava. However, cassava is only prioritized in these three (3) zones. This is the same with potato, which is placed as the third prioritized crop in the G, H and I zones. Peanut is also among the most suitable crops in all the zones. All the four (4) crops identified as prioritized crops in one zone or the other i.e. onions, cassava, potato and peanut are tubar crops. Conversely, yam which is also a tubar crop does not fall within the prioritized crops. Other crops identified as next prioritized crops in the A, B, C, D, E and F zones include millet, sorghum and cowpea. The expert's opinion of the 4 experts, were compared to one another using inferential and discriptive statistics. It was obtained that there is no significant difference among the expert's opinions.

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Introduction

The wider cognizance of the significance of spatial elements considered in decision-making process, be it agricultural or other forms of land uses, has made Spatial Multi Criteria Analysis (SMCA) to receive greater placement as a tool in decision making. Due to the acknowledgment of the essential consideration of more criteria in order to achieve results closer to actuality, ANP has overtaken the predominant approaches of the early generation of the SMCA (Ferratti, 2011; Schaller et al., 2014). Most land decisions involve consideration of a wide range of incommensurable and conflicting criteria. ANP is gaining wider use due to simplicity of procedure resulting from advancing technologies (Huang et al., 2011; Velasquez and Hester 2013; Schaller et al., 2014).

One of the major limitations of SMCA is the 'black box' style of analyzing spatial problems (Fisher, 2009; Ferretti, 2012). This has been resolved in ANP. The limitation of decomposing decision-making problem into hierarchical order in Analytic Hierarchy Process (AHP), which refutes the reality of life in many cases (Zhang and Wang, 2011) has been overcome with ANP. Even though it has limitations, AHP has been used for a number of studies with grater benefits over other SMCA methods like Hernández et al. (2013). ANP can better be applied, since it has been seen to have better advantages over AHP (Chen and Yang 2011; Demirel et al., 2012; Montenegro et al., 2014). The ability to relate all the elements in the ANP network in several conceivable manner (Reig et al., 2010), avails it the possibility to integrate numerous elements that are to be analyzed, thus solving the tedious problem of comprehensive land decision making.

Mathematical and psycho-cognitive roots are combined in ANP method to analyze multifaceted structure within a strict mathematical structure in connection to an explicit network (Targetti et al., 2014). The tedious computation involved in ANP, by creating super-matrices and normalization has been addressed by the development of software packages like Super-Decision. Flexibility of ANP has enabled it integrations with other methods in many application fields such as ANP and Fuzzy (Cheng and Tao, 2010; Chen and Yang 2011; Montenegro et al., 2014). ANP has been used in environmental capacity evaluation of agricultural land use (Pourkhabbaz et al., 2014). Introduced by Saaty (1999) and used several times such as Tegou et al. (2010); Saaty and Vargas (2013) as well as several others. ANP uses network of clusters containing elements. The first activity is the definition of the network structure, by creating the elements inform of control criteria, sub-criteria and the alternatives to be evaluated. In crop or Land suitability assessment, the ANP processes make use of experts' opinion referred to as the Experts with Formal Knowledge (EFK). The conventional approach is using edaphic and climatic factors to determine the suitable crops to be grown in an area using the judgment of crop scientist or agronomists, whom are the EFKs.

Methodology

The adopted approach for this study follows one of the usual processes of land suitability using ANP or even AHP such as Mustafa et al. (2011). However, some modifications were adapted from other literatures like Pedroza and Lopez (2012). Where any of analytic processes (ANP or AHP) is used for ALUP, the sequence commences by a GIS technique called Locational Suitability Assessment (LOSA) to produce Compatible Cropping Area (CCA). LOSA, also referred to as Site Selection, is the suitable cropping area in terms of terrain and compatibility with other Land Uses, after extracting all constraints. Then the CCA is subjected to Land Suitability and Capability Analysis (LSCA).

The LSCA and the climatic factors were assessed and used to generate thematic map layers, then pairwise comparison matrix (PCM) is used to interview experts with formal knowledge (EFK) in agriculture related sciences to determine the most suitable crops for each of the thematic layers. The weightages obtained from the process is used as input for spatial interpolation such as weighted linear combination (WLC) to prioritize the multi suitability maps. In this study, these processes were modified by adopting subdivision of the study area into zones instead of thematic layers. The CCA and the LSCA were conducted for each of the zones. The study area was subdivided into zones (Figure 1) so as to be used for all the evaluations. The purpose of adopting the subdivided zones is consistent with Rilwan (2007) who asserted that a block of land is most likely to have uniform characteristics.

In a nutshell, the processes of the ANP with EFKs include; producing CCA for each zone, conducting the LSCA, conducting pairwise comparison, aggregation of the judgments, formation of unweighted supermatrix, formation of weighted supermatrix and the formation of limit supermatrix. These processes are explained in the subsequent subsections. Igabi, a Local Government Area in Kaduna State, Nigeria was selected for this study. The area was subdivided into nine (9) zones; a - i, using the river bodies in the area as the boundaries (Figure 1).

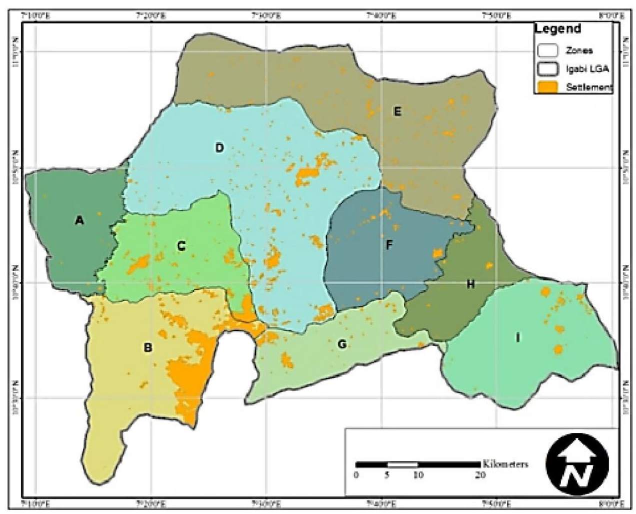


Figure 1: Igabi subdivided into zones

Evaluation of Compatible Cropping Area

The CCA, said to be the first process in ground preparation of the ANP with EFKs, was extracted through the process of Locational Suitability Analysis (LOSA). The purpose of this LOSA is to determine whether the area in question is suitable in it proposed allocation, with regard to the terrain and compatibility with other land uses. It was done to identify compatible and suitable areas for crop cultivation from the existing and potential farmland. In conducting the LOSA, the land use and land covers in the area as well as the topography of the area were assessed. The process involves Land Inventory to obtain CCA after eliminating all limitations or constraints. This was done for each of the zones. The Land Inventory for each of the zones was obtained using the subdivided map of the study area, produced from updated Land Use Land Cover (LULC) data of

2015. The constraints were extracted from the LULC data of 2015 to produce the CCA. The eliminated constraints were; built up areas, existing developments, water bodies, forest reserves and mountainous regions. The CCA is shown in Figure 2. They are areas that can be put into farming activities in each of the zones. The CCA is further subjected to Land Suitability and Capability Analysis (LSCA).

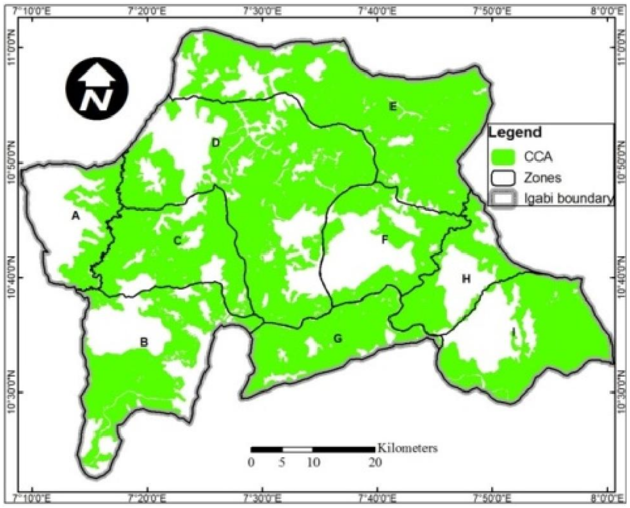


Figure 2: Compatible Cropping Areas

Assessment of Land Suitability and Capability and Climatic Factors

One of the most valuable natural resource for sustainable development is soil (Raji, 2011). Hence, a significant input in ALUP, are the edaphic factors (i.e. soil biochemical and physical parameters) and climatic factors. In order to evaluate the soil characteristics of the area with the view to ascertain how suitable it is for agricultural development, the LSCA were carried out for each zone. It is the basis for sustainable farmland-use planning. They were carried out due to non-availability of these data for each zone separately from secondary sources. It was obtained by testing samples of the soil in soil laboratory.

Three soil samples were collected from each of the zones. Due to non-availability of auger, hoe was used to collect a portion of soil of about 1kg from the surface to the depth of about 10cm. These were taken to soil laboratory for the tests. The aim is to determine the soil biochemical and physical characteristics of each zone. The parameters requested were the prescription of FAO (1979). The chemical parameters includes soil reaction (pH), carbon and nitrogen, gypsum and calcium carbonate, electrical conductivity of saturation extract (ECe), Soluble salts, Exchangeable cations, Exchangeable sodium percentage (ESP) or adjusted sodium absorption ratio of saturation extract (SAR), Cation exchange capacity (CEC), total exchangeable bases (TEB) and base saturation %, Available phosphorus. The physical parameters include soil depth, presence of organic matter, grain size and distribution (texture), soil structure and porosity, infiltration rate, hydraulic conductivity or permeability, available water capacity, plastic and liquid limits, soil strength, linear extensibility. The services of experts in the field of soil analysis were employed. The soil scientist conducted the soil test and computations.

Climatic factors of the area were obtained from National Bureau of Statistics (NBS) and past research works on the area. The climate data obtained from the NBS are records of 2005 to 2009, while the climatic data from the previous studies focused on the research works they were intended for, in terms of their temporal structure. For the purpose of this research work, the data obtained from the NBS were used. Unlike the edaphic factors that were evaluated at zonal levels within Igabi, LGA, the climatic data cover the entire Kaduna state. The climatic factors of the area were evaluated with regard to their effect in crop yield, i.e. temperature regime, rainfall probability with reference to crop water requirement and humidity. These were evaluated with regard to drought hazard and the length of crop growing season. These evaluations were carried out by the EFK to determine the suitable crop for each zone using the Pairwise Comparison method (PCM). Figure 3 is the ANP with EFK network processed using the software.

Aggregation of Judgements

The result of the edaphic factors for each zone and the climatic data for the state were presented to EFKs for the PCM using a questionnaire. The judgment of four (4) experts was used. They are one (1) crop scientist and three (3) agronomists. Although the four (4) experts are from different states in the northern parts of Nigeria, they are familiar with the area.

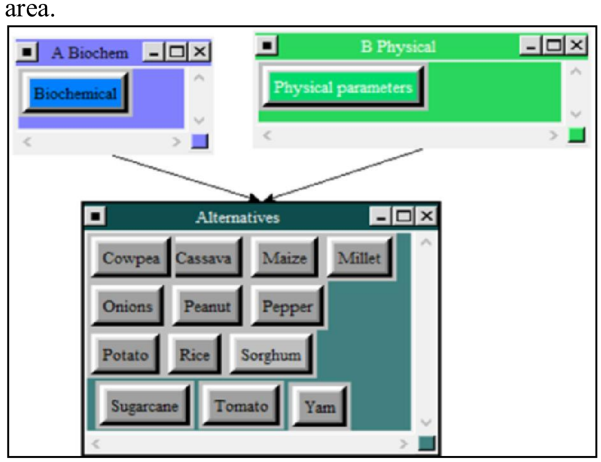


Figure 3: Nodes connection in ANP network

The four (4) experts were used so as to obtain reliable result. The expectation is that they might give different opinion for each of the zones. The crop scientist suggested initial classification of the crop suitability based on FAO Land suitability classifications to be carried out so as to guide the pairwise comparison. These include three (3) suitability classes and two (2) non suitability classes. The suitability are highly suitable coded as S3, moderately suitable coded as S2 and marginally suitable class coded as S1. The two (2) non suitability classes are the currently not suitable class coded as N1 and permanently not suitable coded as N2.

Four (4) sets of judgements were obtained after conducting pairwise comparison with the opinion of the four (4) EFKs. The judgements were aggregated using the simple arithmetic average. Unweighted supermatrix, weighted supermatrix and limit supermatrix were then formed. Superdecision Software was used to process them.

Synthesized Priorities

The synthesized priorities for each of the nine (9) zones is presented using descriptive analysis. It shows the order of priority of each crop in every zone with regard to the edaphic and the climatic factors. This is to say it presents the order of cultivation advantage for each of the crops in each of the zones based on the LSCA of the area. The adopted presentation format are simple on-table bar charts, regular descriptive charts and maps.

Only the priorities are presented. None of the tables involved in the process is shown because it would be cumbersome to present all the tables at the course of the analysis. They include tables on all the pairwise comparison, the unweighted supermatrices, the weighted supermatrices and the limit supermatrices.

Validation of Experts' Opinion

Due to prominence of the statistical analysis as espoused by Keller and Gaciu (2012) and Creswell (2013), it was adopted for the validation of the process. The expert's opinion of the 4 EFKs, were compared to one another in order to determine whether there exist significant difference among them. The decision is to reject the H_0 (null hypothesis) at 0.05 significance level i.e. if the P-value is less than the α-value 0.05 and accept alternative hypothesis, and then conclude that there is no significant difference among the opinion of the 4 EFKs with regard to the priority of each of the crops in Igabi based on the LSCA. Otherwise, the null hypothesis is accepted. Statistical analysis was computed in Spatial Package for the Social Sciences (SPSS) software version 22.

The aggregated soil parameters for each of the zones were obtained as shown in Table 1. It is the outcome of the computed soil parameters for each zone that was obtained through soil test by soil scientist.

Table 1: Computed Soil Parameters

	Lat	Long.	Depth	Sand	Silt	Clay	Texture	OC	pH	EA	EB	ECEC	PBS
A	10.75	7.226	55	828	76	96	Loamy sand	7.78	6.07	0.1	3.139	3.239	96.91
B	10.56	7.325	70	872	48	80	Sand	6.94	5.55	0.11	3.612	3.722	97.04
C	10.72	7.374	25	768	128	104	Sandy loam	5.19	5.9	0.08	3.481	3.561	97.75
D	10.81	7.528	25	752	136	112	Sandy loam	3.4	5.49	0.1	3.626	3.726	97.32
E	10.92	7.688	25	808	76	116	Loamy sand	4.82	5.48	0.14	3.475	3.615	96.23
F	10.72	7.641	25	812	68	120	Loamy sand	5.73	5.5	0.1	4.357	4.457	97.76
G	10.56	7.515	200	828	92	80	Loamy sand	4.92	5.53	0.1	3.973	4.073	97.55
H	10.65	7.755	200	772	112	116	Sandy loam	6.47	6.35	0.12	3.943	4.063	97.05
I	10.61	7.85	155	788	108	104	Sandy loam	7.9	6.39	0.08	6.275	6.355	98.72

As explained, a crop scientist was given the result of the soil parameters. He carried out initial classification of the crops suitabilities based on the soil parameters. He then transferred the initial classification into pairwise comparison table, as suggested by him. This expert was the only one among the EFKs that conducted the initial classification. The other three (3) EFKs only filled the pairwise comparison questionnaire with reference to the computed soil parameters. The result of the initial classification presented is from one (1) expert shown in Table 2. Colour were used to determine the level of crop suitability for each zone.

Table 2: Initial Classification of the Crop Suitability

Zones	A	B	C	D	E	F	G	H	I
Cassava	S3	S3	N1	N1	N1	N1	S1	S1	S1
Cowpea	S3	S3	S3	S3	S3	S3	S2	S2	S2
Maize	S3	N1	N1	N1	N1	N1	S3	S2	S2
Millet	S2	S2	S3	S3	S3	S3	S2	S2	S2
Onions	S2	S2	S2	S3	S3	S3	S1	S1	S1
Peanut	S2	S2	S3	S3	S3	S3	S2	S1	S1
Pepper	S3	S3	S3	S3	S3	S3	S2	S2	S2
Potato	N1	S3	N1	N1	N1	N1	S1	S1	S1
Rice	S3	N2	N1	N1	N1	N1	N1	S3	S3
Sorghum	S2	S3	S3	S3	S3	S3	S2	S2	S2
Sugarcane	S3	N2	N1	N1	N1	N1	N1	S3	S3
Tomato	S3	N1	S3	S3	S3	S3	S3	S2	S2
Yam	N1	N2	N2	N2	N2	N2	S2	S2	S2

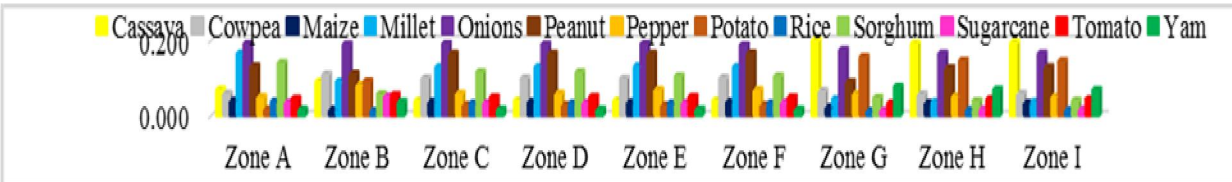
The result reveals that all the crops fall within the five (5) classes, which renges from the highly suitable (S3) and presented in blue colour, moderately suitable (S2) being represented by dark green colour. The last suitability level is termed as marginally suitable (S1) and presented by light green. The remaining two (2) suitability classes are the non suitable classes are the currently not suitable class (N1) represent by light red colour and the and the permanently not suitable (N2) represented by dark red colour.

The suitability classification reveals that yam has the worse suitability rating because it is only moderately suitable in three (3) zones namely G, H and I. Rice and sugarcane are also not suitable in six (6) zones but highly suitable in zones A, H and I. The classification also revealed that maize and potato are not suitable in five (5) zones, while cassava cultivation is not suitable in four (4) zones, i.e. A, G, H and I zones are suitable for maize, B, G, H and I zones are suitable for potato cultivation, while A, B, G, H and I are suitable for cassava cultivation. Tomato is suitable in all the zones except zone B. Lastly, the classification indicates that cowpea (beans), millet, onions, peanut, pepper and sorghum are suitable in all the zones though their suitability levels differ, from one zone to another.

Synthesized Priorities of Judgement of Experts with Formal Knowledge

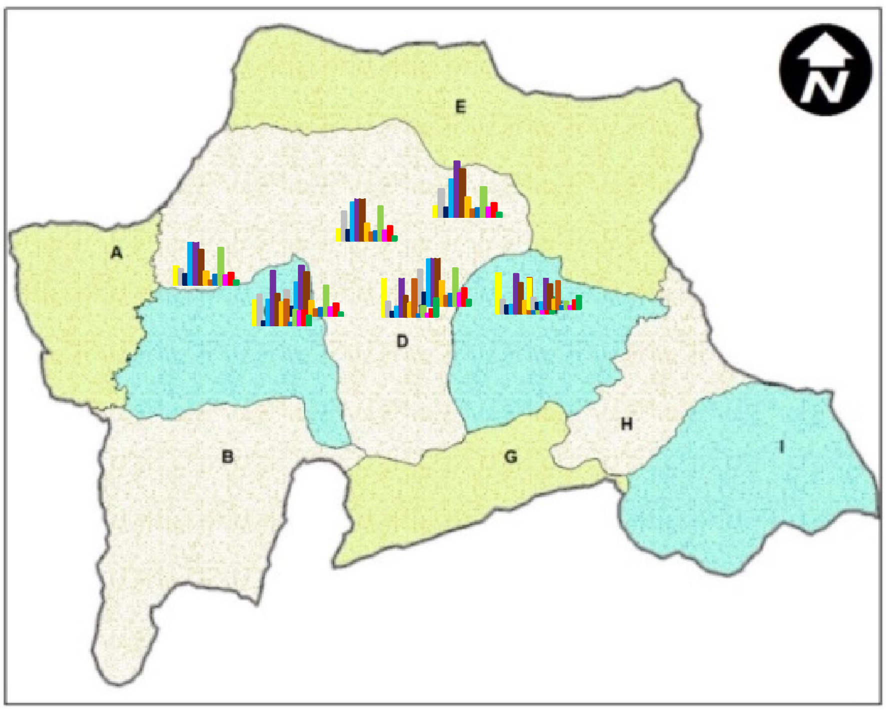
The result of the syncronized pairwise comparison of LSCA approach for each zone is shown in Figure 4 and the spatial context in Figure 5. The result is consistent with the suitability classification presented above, although it goes beyond grouping of the crops into suitability classes by determining the order of priority of each crop.

It reveals that according to the formal farming science processes determined by soil characteristics, onions is the most suitable to be grown in all the zones except zones G, H and I, where it became the second most suitable after cassava. However, cassava is only priotized in these three (3) zones. This is the same with potato, which is placed as the third prioritized crop in the G, H and I zones. Peanut is also among the most suitable crops in all the zones. All the four (4) crops identified as prioritized crops in one zone or the other i.e. onions, cassava, potato and peanut are tubar crops. Conversely, yam which is also a tubar crop does not fall within the priotized crops. Other crops identified as next priotized crops in the A, B, C, D, E and F zones include millet, sorghum and cowpea (beans).



Cassava	0.069	0.091	0.040	0.040	0.040	0.041	0.202	0.192	0.194
Cowpea	0.059	0.110	0.099	0.099	0.099	0.100	0.066	0.058	0.059
Maize	0.040	0.017	0.037	0.037	0.036	0.037	0.023	0.035	0.034
Millet	0.165	0.091	0.129	0.129	0.131	0.130	0.044	0.037	0.037
Onions	0.191	0.190	0.191	0.189	0.191	0.188	0.175	0.165	0.165
Peanut	0.132	0.112	0.165	0.166	0.165	0.167	0.090	0.127	0.129
Pepper	0.050	0.082	0.059	0.059	0.069	0.069	0.058	0.052	0.051
Potato	0.017	0.092	0.029	0.029	0.029	0.029	0.157	0.147	0.145
Rice	0.038	0.013	0.033	0.033	0.033	0.034	0.013	0.016	0.016
Sorghum	0.140	0.058	0.116	0.116	0.105	0.105	0.048	0.040	0.040
Sugarcane	0.036	0.052	0.035	0.035	0.035	0.035	0.015	0.017	0.017
Tomato	0.045	0.055	0.049	0.050	0.050	0.049	0.033	0.044	0.045
Yam	0.017	0.037	0.017	0.017	0.017	0.017	0.077	0.070	0.069

Figure 4: Synthesized priorities at Zonal level



Cassava	Cowpea	Maize	Millet	Onions	Peanut	Pepper
Potato	Rice	Sorghum	Sugarcane	Tomato	Yam	

Figure 5: Spatial context of prioritized crop according to EFK judgment

Test of Significant Difference of Experts' Priorities

The expert's opinion of the 4 EFKs, were compared to one another in order to determine whether there exists significant difference among them. The result, shown in Table 3 denotes; that there is no significant difference between the means. Therefore, it is concluded that there is no significant difference between the opinion of the 4 EFKs with regard to the priority of each of the crops in Igabi based on the

LSCA. Hence the EFK judgment is valid. The statistics (mean and standard deviation) is shown in Table 4.

Table 3: One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
V2	5.127	12	.000	3.769	2.17	5.37
V3	5.781	12	.000	3.769	2.35	5.19
V4	5.781	12	.000	3.769	2.35	5.19
V5	5.781	12	.000	3.769	2.35	5.19

Table 4: One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
V2	13	3.77	2.651	.735
V3	13	3.77	2.351	.652
V4	13	3.77	2.351	.652
V5	13	3.77	2.351	.652

Conclusion

Spatial Multi Criteria Analysis has become reputable tool in agricultural and other forms of land uses decision making, due to it ability to evaluate multi-dimentional spatial elements. Cropland suitability assessment was conducted in this study using Analytic Network Process. The use of block of an area for distinctive evaluation provides in depth and reliable information for understanding the characteristics of the area. Compatible cropping area was first conducted followed by Land suitability and capability analysis. The opinion of several exparts were evaluated using pairwise comparison technique and suitable crops were determined. A new approach to validation of ANP using inferential statistics was carried out. The expert's opinion of 4 experts, were compared to one another using inferential and discriptive statistics. It was obtained that there is no significant difference among the expert's opinions. This type of framework needs to be adopted by dicision makers in crop farming. This will enable the success of sustainable agricultural intensification. Replicating the process would benefit other regions to assess the suitable crops for every distinctive area. The study offers the opportunity for the entire process to be adopted by underdeveloped countries that might consider this approach to meet their critical crop farming need.

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