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Crop-land Suitability Analysis Using GIS and Remote Sensing in Nyandarua County, Kenya

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Abstract

Land suitability analysis is a method of land evaluation, which measures the degree of appropriateness of land for a certain use. The aim of this research was to identify and delineate the land that can best support potatoes, using GIS-based Multi Criteria Evaluation technique and Remote Sensing. The study was carried out in Nyandarua County in Kenya. Agriculture is the mainstay of local economy in the study area, but the production is very low because some of the crops being introduced are not doing well. There is need therefore to identify and delineate suitable areas for growing various crops to achieve maximum potential yield. Three suitability criteria i.e. soil (PH, texture, depth, drainage), climate (rainfall, temperature) and topography were evaluated based on agronomist experts opinions and FAO guideline for rainfed agriculture. An Analytical Hierarchical Process was used to determine relative importance of criteria and the resulting weights were used to construct the suitability maps/layers using GIS software. Finally, land suitability map was generated by overlaying these maps with current land cover map generated from Landsat images through supervised classification. The results of this research revealed that in the study area, 37.6% of the agricultural land is highly suitable for potatoes cultivation, 51.5% is moderately suitable and 10.9% is marginally suitable. The results can be used by the County government to advice the local farmers on the suitable areas for potatoes cultivation.

Keywords: Land suitability analysis, GIS, Remote sensing, Multi-Criteria Evaluation, AHP, Potatoes cultivation, Nyandarua.

1. Introduction

The population of the planet is growing dramatically and in order to meet the increasing demand for food, the farming community has to produce more and more. However, under present situation where land is scarce, it is impossible to bring more area under cultivation to satisfy the growing demand (Teka & Haftu 2012). In order to increase food production and provide food security, crops need to be grown in areas where they are best suited. In order to achieve this, the first and foremost requirement is carrying out land suitability analysis (Kihoro, Njoroge & Murage 2013). Land suitability analysis is a method of land evaluation, which measures the degree of appropriateness of land for a certain use. The analysis allows identification of the main limiting factors of crop production and enables decision makers to develop crop management system (Halder 2013).

Many of GIS-based land suitability analysis approaches such as Boolean overlay and modelling for land suitability analysis lack a well-defined mechanism for incorporating the decision-maker's preferences into the Geographic Information System (GIS) procedures. This may be solved by integrating GIS and Multi Criteria Evaluation (MCE) methods (Mustafa et al. 2011). Among the various MCE methods, the Analytical Hierarchy Process (AHP) is a well-known multi-criteria technique that has been incorporated into GIS-based suitability procedures to obtain the required weightings for different criteria. GIS based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria (Feizizadeh & Blaschke 2012). GIS based MCE approach has been widely used in land suitability analysis in other countries. However, in Kenya, from the available literature, the application of the method in potatoes suitability analysis has not been done.

Agriculture is the mainstay of local economy in Nyandarua County, but the production is very low. Hence, comprehensive, reliable and timely information on agricultural resources is very much necessary to ensure use of land in the most rational and optimal way. Over the years, farmers have been abandoning crops that are well established in the County, to venture into alternative crops. This has affected the total yield because some of the crops being introduced are not doing well. Nyandarua County has potential in agriculture that can absorb majority of youths seeking employment. The county government has plans of boosting production of potatoes, carrots and other crops that do well in the region (Kahenda 2013).

The main objective of the research was to identify and delineate the land that can best support potatoes in

Nyandarua County, using MCE technique. The specific objectives were to develop a spatial model for land suitability evaluation for potatoes cultivation using GIS, to classify agricultural land in the County into different suitability classes and to develop suitability maps for potatoes cultivation in Nyandarua County.

Mustafa et al. (2011) in the study of land suitability analysis for different crops using MCE approach, remote sensing and GIS, found that AHP is a useful method to determine the weights. Khoi and Murayama (2010) used a GIS-based MCE of biophysical factors and Landsat imagery to delineate the areas suitable for cropland in protected area-buffer zone of Tam Dao National Park region, Vietnam. Other studies using this approach include; Suitability analysis for rice growing sites using a MCE and GIS approach in great Mwea region in Kenya by Kihoro, Njoroge and Murage (2013) and land suitability analysis using MCE approach and GIS for Tabriz County, Iran, by Feizizadeh and Blaschke (2012).

2. Materials and Methods

2.1 Study area

The research was carried out in Nyandarua County, Kenya, covering an area of approximately 3,270 square km (Figure 1). The study area has a predictable weather patterns with temperatures ranging between 12°C during the cold months (June and July) and 25°C during the hot months (January and February) and rainfall of between 700mm and 1,500mm per annum. The county comprises five constituencies: Ol-Kalou, Ol-Joro-Orok, Kinangop, Kipipiri and Ndaragwa.

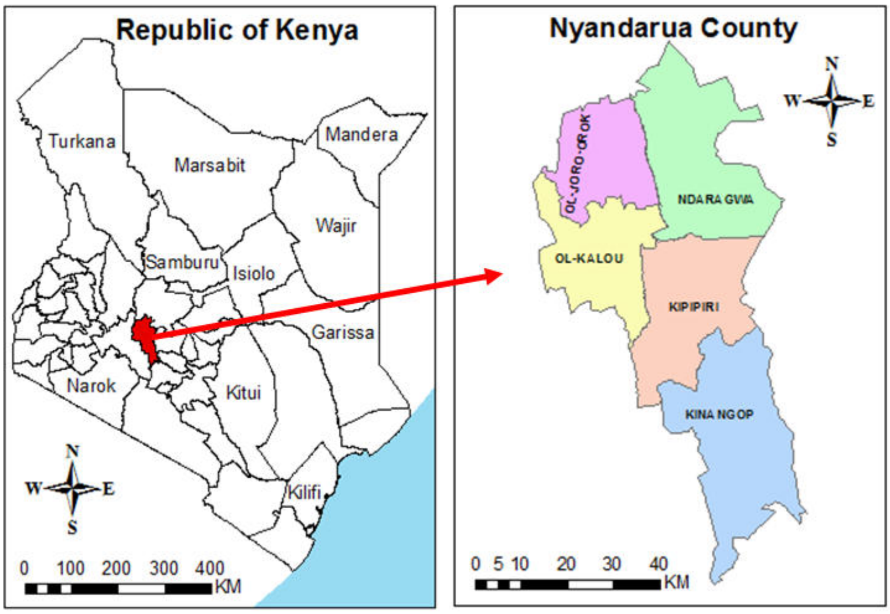

Figure 1: Location of the study area

Nyandarua County is home to 596,268 people, according to the 2009 National Census. The population which grows at 2.4% annually is expected to grow to 688,618 and 722,498 persons in 2015 and 2017 respectively. Farming is the major economic engagement, with dairy and crop production such as potatoes, wheat, maize, beans and vegetables as the mainstay of the local economy.

2.2 Methodology

2.2.1 Selection of evaluation criteria

A study by Kuria, Ngari and Waithaka (2011) has shown that it is important to consider other terrain features in addition to soil characteristics in order to come up with a more informed decision on optimal crop growing areas. Opinions of agronomist experts and literature review of various references helped in identifying three main criteria (soil, climate and topography) and seven sub-criteria (soil PH, soil texture, soil drainage, soil depth, rainfall, temperature and slope) necessary to determine suitable areas for growing potatoes.

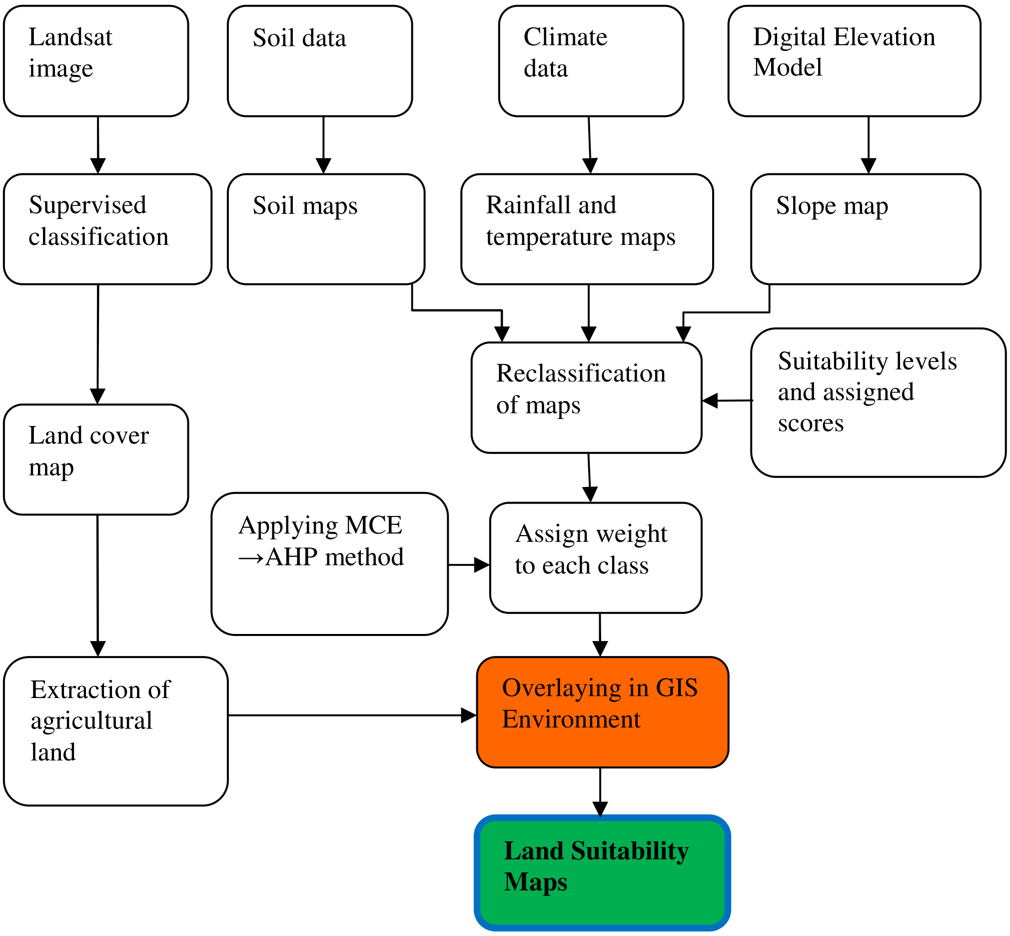

Figure 2: Methodological flowchart

The suitability levels were based on the structure of Food and Agriculture Organization (FAO) land suitability classification and ranked as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). Suitability levels for each of the sub-criteria were defined according to the FAO guideline for rainfed agriculture, literature review and agronomist expert's opinions (Table 1).

Table 1: Land use requirements of potatoes

		Suitability class and degrees of limitation			
Parameters	**Unit**	**S1**	**S2**	**S3**	**N**
Soil PH	Reaction	6.0 - 5.0	6.0 - 7.0 5.0 - 4.0	7.0 - 8.0 4.0 - 3.5	> 8.0 < 3.5
Soil texture	Class	Loamy	Sandy	Clayey	Very clayey
Soil depth	meters	≥ 0.75	0.75 – 0.50	0.50 - 0.25	< 0.25
Soil drainage	Class	Well/moderate	Imperfect	poor	very poor
Rainfall	mm	≥ 1,000	1,000 - 800	800 - 600	< 600
Mean Temperature	^{o}C	≤ 18	18 - 20	20 - 22	> 22
Slope	%	≤ 6	6 - 13	13 - 25	> 25

2.2.2 Data collection and preparation

Soil data (soil PH, soil texture, soil depth and soil drainage) was obtained from Kenya Soil Survey (KSS). Climate data (temperature and rainfall) was obtained from Kenya Meteorological Services (KMS). There is only one meteorological station in Nyandarua County. The climate data from the station and stations from neighbouring Counties of Nyeri, Kiambu and Nakuru were interpolated to get the climate information of Nyandarua County. Satellite image and Digital Elevation Model (DEM) were obtained from Regional Centre for Mapping of Resources for Development (RCMRD). The satellite image was from a Kenyan mosaic prepared from Landsat images acquired in 2013, with spatial resolution of 30m. The mosaic had been processed and rectified to WGS84 coordinate system. Slope information was obtained from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2), (Table 2).

Table 2: List of data used

Type of data	Description of data	Source of data
Soil data	Soil PH, soil depth, soil texture and soil drainage	KSS
Climate data	Rainfall and temperature data of Nyahururu Agromet Station, Nyeri Meteorological Station, Kabete Agromet Station, Naivasha Water Bailiff, National Animal Husbandry Res. Centre – Naivasha and Nakuru Meteorological Station: Duration: 1980 - 2013	KMS
Digital Elevation Model	ASTER GDEM V2 of 2011 Resolution: 30m	RCMRD
Satellite image	Landsat 8 of 2013. Spatial resolution: 30m	RCMRD
Ground truth data	20 samples collected using handheld GPS Accuracy: 1 - 10m	Field survey

Thematic maps for each of the soil parameters and slope were developed using ArcGIS 10.2 software. Annual rainfall and mean annual temperature thematic maps were generated using Inverse Distance Weighted (IDW) interpolation. IDW interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance (Mustafa et al. 2011). All the maps were geo-referenced to WGS84 coordinate system.

Supervised image classification was done using 20 training sites which had been picked using handheld GPS and the knowledge of the researcher on the relative locations of land cover types.

Suitability levels S1, S2, S3 and N were assigned score 9, 7, 5 and 3 respectively after discussion with experts. Classes with higher scores are most suitable for suitability evaluation. Using these scores and the defined suitability levels, all thematic maps were reclassified.

2.2.3 Applying MCE and Assigning weight of factors

To determine relative importance/weight of criteria and sub criteria, AHP method of MCE was used. In order to compute the weights for the criteria and sub-criteria, a pairwise comparison matrix (PWCM) was constructed using information obtained from experts through interviews, each factor was compared with the other factors, relative to its importance, on a scale from 1/9 to 9 introduced by Saaty (2008) (Table 3).

Table 3: The Saaty Rating Scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

The diagonal elements of PWCM are assigned the value of unity (i.e., when a factor is compared with itself). Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half (Kihoro, Njoroge & Murage 2013).

The weight for each criterion/sub-criterion was calculated through PWCM by determining the approximate eigenvector. This was done by multiplying together the elements in each row of the matrix and then taking the nth root of that product (where n is the number of elements in the row). The nth roots are then normalized by dividing them with their sum.

When performing pairwise comparison, some inconsistencies may typically arise. The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker. In the AHP, the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% (Triantaphyllou & Mann 1995).

To calculate CR, the consistency index (CI) is estimated by multiplying judgment matrix by the approximated eigenvector. Each component of the resulting matrix is then divided by the corresponding approximated eigenvector. This yields an approximation of the maximum eigenvalue (λ_{max}). Then, the CI value is calculated by using the formula: CI = (λ_{max}-n)/ (n-1). Finally, the CR is obtained by dividing the CI value by the Random Consistency Index (RCI) generated by Prof. Saaty (Table 4).

Table 4: Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 5: Pair wise comparison matrix of criteria

	Soil	Climate	Topography	n^{th} root of product of values	Eigenvector
Soil	1	3	7	2.759	0.649
Climate	1/3	1	5	1.186	0.279
Topography	1/7	1/5	1	0.306	0.072
Sum				**4.251**	**1**
λ_{max} =3.067	CI =0.034		CR =0.06		

Table 6: Pair wise comparison matrix of sub-criteria with respect to climate

	Temperature	Rainfall	n^{th} root of product of values	Eigenvector
Temperature	1	1/3	0.577	0.250
Rainfall	3	1	1.732	0.750
Sum			**2.309**	**1**
λ_{max} =2.00	CI =0.00	CR =0.00		

Table 7: Pair wise comparison matrix of sub-criteria with respect to soil

	Soil PH	Soil texture	Soil depth	Soil drainage	n^{th} root of product of values	Eigenvector
Soil PH	1	1/3	1/3	1/3	0.439	0.093
Soil texture	3	1	3	3	2.280	0.480
Soil depth	3	1/3	1	1/2	0.841	0.177
Soil drainage	3	1/3	2	1	1.189	0.250
Sum					**4.749**	**1**
λ_{max} =4.214	CI =0.071	CR =0.08				

2.2.4 Overlaying map layers

The reclassified thematic maps/layers of each variable were weighted using the weights derived from the AHP process. The weighted maps/layers were combined by performing the weighted overlay using spatial analyst tools. Finally, the suitability map was prepared.

3. Results and Discussion

3.1 Spatial variations of sub-criteria

The spatial variation of each of the seven sub-criteria is discussed below.

3.1.1 Spatial variation of soil PH

Soil PH provides the information about the solubility and thus potential availability or phyto-toxity of elements for crops and subsequently specifies the soil suitability for specific crop (Halder 2013). The soil PH of the study area ranged from 3.9 to 5.9. The reclassified soil PH map shows that only 18.7% of the study area has highly suitable soil PH (Figure 3 and Table 8).

Table 8: Spatial variation of soil PH

Suitability class	Soil PH range	Area (Ha)	Area (%)
S1	6.0 - 5.0	61275	18.7
S2	5.0 - 4.0	248399	76.0
S3	4.0 - 3.5	17361	5.3

3.1.2 Spatial variation of soil depth

Soil depth refers to the estimated depth in centimetre to which root growth is unrestricted by any physical or chemical impediment such as impenetrable or toxic layer. There are five soil depth classes in the study area namely; very shallow (< 30cm), shallow (30 - 50cm), moderately deep (50 - 100cm), deep (100 - 150cm) and very deep (≥ 150cm). The reclassified soil depth map reveals that, 55.4% of study area has very deep or deep soil (Figure 3 and Table 9).

Table 9: Spatial variation of soil depth

Suitability class	Soil depth	Area (Ha)	Area (%)
S1	Very deep/deep	181158	55.4
S2	Moderately deep	15713	4.8
S3	Shallow	40296	12.3
N	Very shallow	89868	27.5

3.1.3 Spatial variation of soil texture

Most of the physical characteristics of the soil depend upon texture class (Mustafa et al. 2011). There are four textural classes in the study area namely, very clayey (more than 60% clay), clayey (sandy clay, silty clay and clay texture classes), loamy (loam, sandy clay loam, clay loam, silt, silt loam and silty clay loam) and sandy (loamy sand and sandy loam texture classes). The reclassified soil texture map shows that, 32.7% of the study area has loamy soil (Figure 3 and Table 10).

Table 10: Spatial variation of soil texture

Suitability class	Soil texture	Area (Ha)	Area (%)
S1	Loamy	106729	32.7
S2	Sandy	16448	5.0
S3	Clayey	129172	39.5
N	Very clayey	74686	22.8

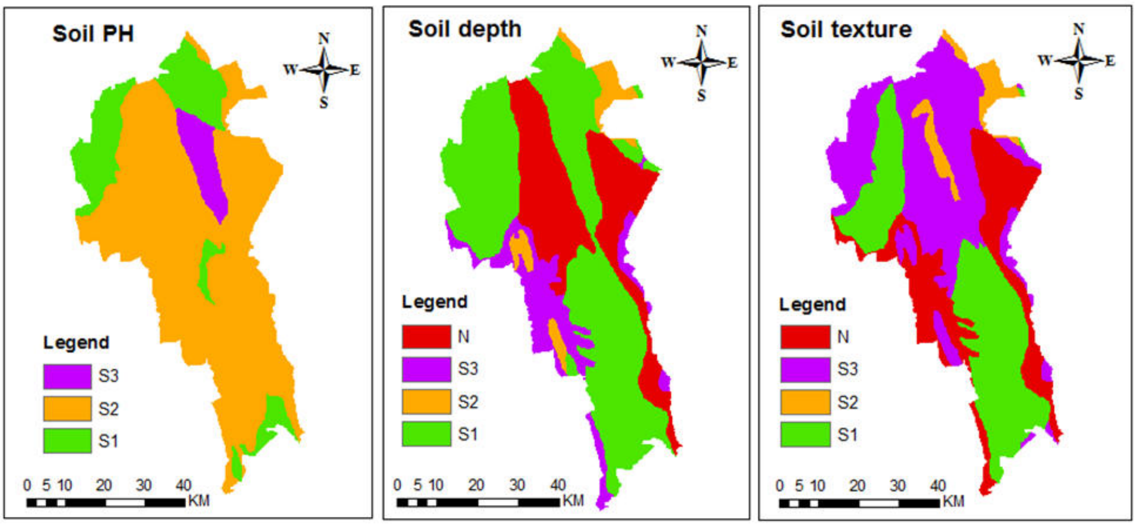

Figure 3: Spatial variation of soil PH, soil depth and soil texture

3.1.4 Spatial variation of soil drainage

The study area has the following drainage classes;

i.) Well drained; water is removed from the soil readily but not rapidly.

ii.) Moderately well drained; water is removed from the soil somewhat slowly during some periods of the year.

iii.) Imperfectly drained; water is removed slowly so that the soils are wet at shallow depth for a considerable period.

iv.) Poorly drained; water is removed so slowly that the soils are commonly wet for considerable periods.

The result from the reclassified map shows that, 82.0% of the study area has well/moderately well drained soil (Figure 4 and Table 11).

Table 11: Spatial variation of soil drainage

Suitability class	Soil drainage	Area (Ha)	Area (%)
S1	Well/ Moderately well drained	268208	82.0
S2	Imperfectly drained	51801	15.9
S3	Poorly drained	7026	2.1

3.1.5 Spatial variation of slope

The slope of the study area varied between 0 - 247percent. The reclassified slope map reveals that, 17.3% of the study area has slope of less than or equal to 6%, which is highly suitable for potatoes cultivation (Figure 4 and Table 12).

Table 12: Spatial variation of slope

Suitability class	Slope (%)	Area (Ha)	Area (%)
S1	≤ 6	56458	17.3
S2	6-13	112335	34.4
S3	13-25	85188	26.0
N	> 25	73054	22.3

3.1.6 Spatial variation of rainfall

The annual rainfall varied between 642mm and 1014mm per annum. Rainfall reclassified map shows that 6.9% of the study area receives at least 1000mm of rainfall, 73.9% receive between 1000mm - 800mm and 19.2% receive between 800mm - 600mm (Figure 4 and Table 13).

Table 13: Spatial variation of rainfall

Suitability class	Rainfall (mm)	Area (Ha)	Area (%)
S1	≥ 1000	22700	6.9
S2	1000-800	241601	73.9
S3	800-600	62734	19.2

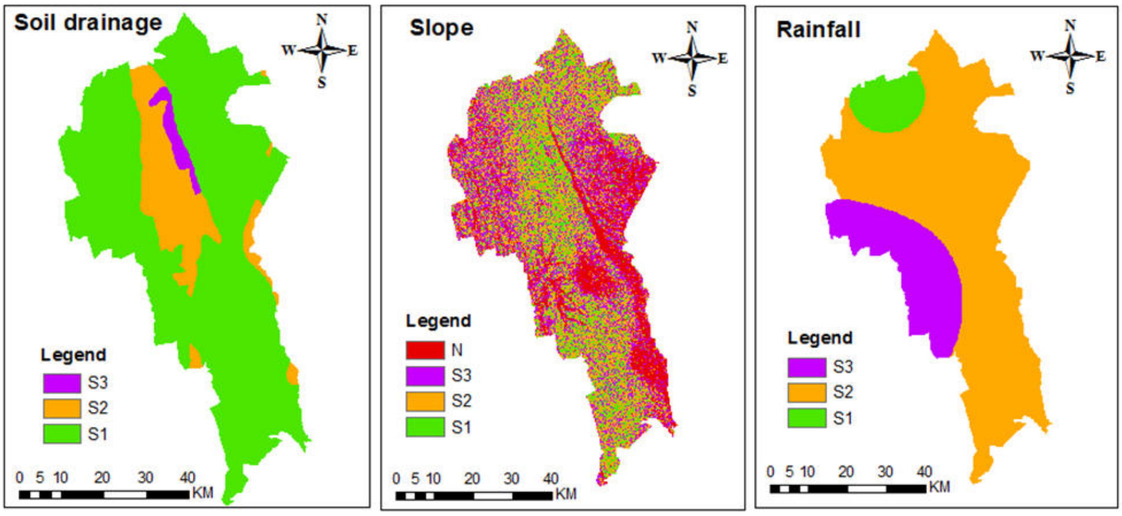

Figure 4: Spatial variation of soil drainage, slope and rainfall

3.1.7 Spatial variation of temperature

The mean annual temperature in the study area varied between 15^{o} C and 19^{o} C. The reclassified map shows that, 83.8% of the study area has temperatures of less than or equal to 18 ^{o}C and 16.2% has 18 ^{o}C - 19 ^{o}C (Figure 5 and Table 14).

Table 14: Spatial variation of temperature

Suitability class	Temperature (°C)	Area (Ha)	Area (%)
S1	≤18	274198	83.8
S2	18-19	52837	16.2

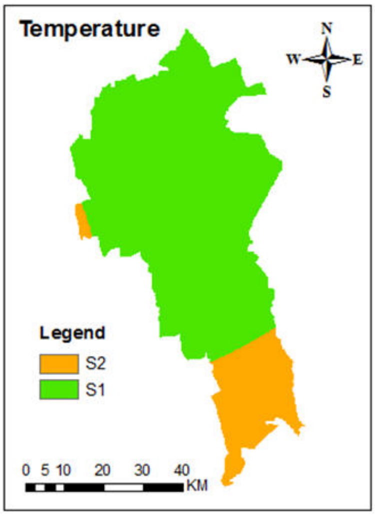

Figure 5: Spatial variation of temperature

3.2 Supervised classification results

Landsat satellite image of the study area was classified into four major land cover classes (agricultural land, water bodies, forest and rocky). The results revealed that, 68.3% of the study area is agricultural land, 25.0% is forest, 1.5% is water bodies and 5.2% is rocky (Figure 6 and Table 15).

Table 15: The area of different land cover

Land cover	Area (Ha)	Area (%)
Forest	81706	25.0
Rocky	17091	5.2
Water bodies	4825	1.5
Agricultural	223413	68.3

3.3 Land suitability for potatoes

The result of land suitability analysis reveals that 37.6% of the agricultural area is highly suitable for potatoes cultivation, 51.5% is moderately suitable and 10.9% is marginally suitable (Figure 6 and Table 16).

Table 16: The area of potatoes suitability classes

Suitability class	Area (Ha)	Area (%)
S1	84024	37.6
S2	115076	51.5
S3	24313	10.9

According to Nyandarua County integrated development plan 2013 - 2017 report, 16120 ha is currently under potatoes cultivation, this is only 7.2% of the total agricultural area.

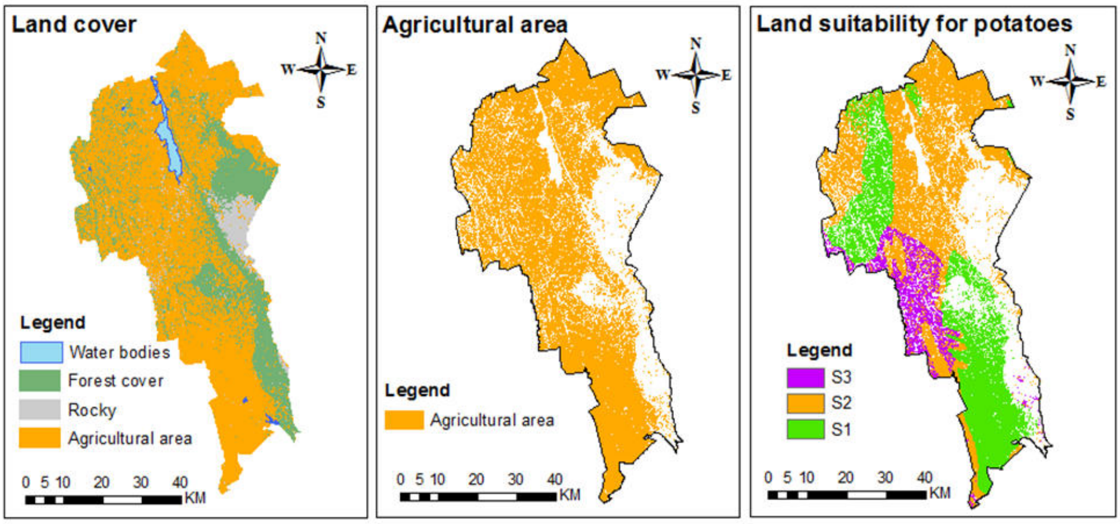

Figure 6: Land cover map, agricultural area and land suitability map for potatoes

4. Conclusion and Recommendation

All agricultural land in Nyandarua County is suitable for potatoes cultivation in varying degrees of suitability. The agricultural land has been ranked as highly suitable, moderately suitable or marginally suitable, after suitability analysis. Highly suitable area is characterised by well/moderately well drained soil, very deep/deep soil and loamy texture, while marginally suitable area is characterised by shallow soil and very clayey texture. Although the county is among the major producer of potatoes in the country, there remain some 206973 hectares that are potentially suitable for potatoes cultivation.

There is no agricultural land having severe limitations that can preclude cultivation of potatoes, but major limitations for potatoes cultivation in Nyandarua County include very shallow soil (Soil depth less than 30 cm) and very clayey texture (soil with more than 60% clay).

The results of the research are in agreement with the present ground situation based on preliminary evidence of site visits; the two major highly suitable belts constitute the area with the highest potatoes yield.

The county government may use the results of this research to advice the local farmers on the suitable areas for potatoes cultivation. This will ensure food security, increase food production to support the growing population hence alleviating poverty and reducing crime in the county. In the future study this method can be applied for mapping land suitability of other crops in the county and across the country with additional and more refined parameters.

References

Feizizadeh, B & Blaschke, T 2012, 'Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS', *Journal of Environmental Planning and Management,* vol. 1, pp. 1-23.

Halder, J, C 2013, 'Land suitability assessment for crop cultivation by using remote sensing and GIS', *Journal of Geography and Geology,* vol. 5, no. 30, pp. 65-74.

Kahenda, M 2013, *Governor Daniel Waithaka's big plan for Nyandarua County*, viewed 20 May 2014, <http://www.standardmedia.co.ke/?articleID=2000092103&story_title=governor-s-big-plan-for-nyandarua-county>.

Khoi, D, D & Murayama, Y 2010, 'Delineation of suitable cropland areas using a GIS based multi-criteria evaluation approach in the Tam Dao National Park Region, Vietnam', *Sustainability,* vol. 2, pp. 2024-2043.

Kihoro, J, Njoroge J, B & Murage, H 2013, 'Suitability analysis for rice growing sites using a multi-criteria evaluation and GIS approach in great Mwea region, Kenya', *SpringerPlus*, vol. 2, 265-274.

Kuria, D, Ngari, D & Waithaka, E 2011, 'Using geographic information systems (GIS) to determine land suitability for rice crop growing in the Tana delta', *Journal of Geography and Regional Planning*, vol. 4, no. 9, pp. 525-532.

Mustafa, A, A, Singh, M, Sahoo, R N, Ahmed, N, Khanna, M, Sarangi, A & Mishra, A, K 2011, 'Land suitability analysis for different crops: a multi criteria decision making approach using remote sensing and GIS. *Researcher*, vol. 3, no. 12, pp. 61-84.

Saaty, T, L 2008, 'Decision making with the analytic hierarchy process', *Int. J. Services Sciences,* vol. 1, no. 1, pp. 83–98.

Teka, K & Haftu, M 2012, 'Land suitability characterization for crop and fruit production in midlands of Tigray, Ethiopia', *CNCS, Mekelle University*, vol. 4, no. 1, pp. 64-76.

Triantaphyllou, E & Mann, S, H 1995, 'Using the analytic hierarchy process for decision making in engineering applications: some challenges', *Inter'l Journal of Industrial Engineering: Applications and Practice*, vol. 2, no. 1, pp. 35-44.