SUITABILITY ANALYSIS FOR PADDY CULTIVATION SITES USING A MULTI CRITERIA EVALUATION AND GIS APPROACH
CASE STUDY: - IMBULPE DS DIVISION IN SRI LANKA

J.Anushiya1, I.A.K.S.Illeperuma2
1Dpt. Of Remote Sensing and GIS, Faculty of Geomatics,
Sabaragamuwa University of Sri Lanka, P.O.Box 02, Belihuloya, Ratnapura
Email: anushiya91@gmail.com
2Dpt. Of Remote Sensing and GIS, Faculty of Geomatics,
Sabaragamuwa University of Sri Lanka, P.O.Box 02, Belihuloya, Ratnapura
Email: Kalani@geo.sab.ac.lk

KEY WORDS: Land suitability Analysis, Analytical Hierarchy Process

ABSTRACT:
Rice is not only the staple food for nearly half of the world's population as the major daily source of calories and protein. Land suitability analysis is a prerequisite to achieving optimum utilization of the available land resources. Lack of knowledge on best combination of factors required for production of the rice has contributed to the low production. Therefore the main objective of this study was to evaluate the land suitability for cultivation of rice, in the Imbulpe Divisional Secretariat area in Ratnapura District of Sri Lanka.

To achieve this objective, multi-criteria decision making (MCDM) combined with the GIS was used to assess suitable areas for growing this crop. Several topographical (slope and aspect of the land), climatically factors (rainfall), soil properties (texture, pH, drainage and depth), and land use data were selected based on the literature review and experts' opinions for this analysis. A GIS-based Multi Criteria Decision Making technique was carried out for suitability analysis. An Analytical Hierarchical Process was used to rank the various suitability factors and the resulting weights were used to create the suitability map.

The result indicates that only 82.53sq.km (32.33%) area can be demarcated as 'highly' and 135.68sq.km (53.15%) as 'moderately' and 37.03sq.km (14.51%) as 'less' suitability categories in the study area. Further this stress that about 85% of the land extent is suitable for paddy cultivation within the study area. Finally, present land cover map was overlaid with the suitability map to identify variances between the present and potential land use. This analysis showed that present paddy cultivated area is about 17.0637sq.km i.e. 6.68% of total area and most of these areas lie in highly and moderately suitable areas. Further results shows that the spatial analytical hierarchy process integrated with GIS is a powerful support system to help decision makers to defining effective management plan for the best production of rice.

INTRODUCTION

Rice is not only the staple food as the major daily source of calories and protein, but is also a key source of employment and income for rural people in Sri Lanka Agricultural resources are considered to be one of the most important renewable and dynamic natural resources. Comprehensive, reliable and timely information on agricultural resources is very much necessary for a country, where agriculture is the mainstay of our national economy. 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. Both population increases and the process of urbanization have increased the pressure on agricultural resources. This increased pressure on the available land resources may result in land degradation. Reliable and accurate land evaluation is therefore indispensable to the decision-making processes involved in developing land use policies that will support sustainable rural development. The land suitability analysis allows identification of the main limiting factors of rice production and enables decision makers to develop crop management system (Halder, 2013). Optimizing rice production can be achieved through sustainable agriculture or farming. The concept of sustainable agriculture or farming involves producing quality products in an environmentally benign, socially acceptable and economically efficient way ensuring optimum utilization of the available natural resource for efficient agricultural production. Many of GIS-based land suitability analysis approaches are recently developed such as weighted overlay and modelling for land suitability analysis. Lack of knowledge on best combination of factors required for production of the rice has contributed to the low production. Efficient management of natural resources is essential for ensuring food supplies and sustainability in agricultural development.

Therefore this study was carried out to evaluate the land suitability for cultivation of rice, in the Imbulpe Divisional Secretariat area in Ratnapura District of Sri Lanka with Analytical Hierarchy Process (AHP) in integrating Multi Criteria Evaluation (MCE) technique with GIS. The specific objectives of this research were to develop a potential land suitability map for paddy cultivation based on climatic conditions, soil properties, landuse and topography factors of production and to identify potential areas for expanding and optimizing rice production in this selected study area.

MATERIALS AND METHODS

Study Area

This research attempts to develop the land suitability map to determine suitable land for paddy cultivation in Imbulpe Divisional Secretariat Division in Ratnapura District in Sri Lanka. The study area is bounded within 80° 44' 0" East to 148° E longitude and 6° 42' 0" North latitude and area covers around 225.264403km^2. Total population is 44436 approximately. There are 50 Grama Niladhari (GN) divisions within the study area.

Present paddy cultivation area is about 17.0637sq.km i.e. 6.68% of total area. The most appropriate season for rice cultivation is from October to February for all type of rice cultivation, when temperatures are opportune for grain filling with less risk of disease incidence. Annual average rainfall in this area varies from 900mm to 3,175mm. Mean annual temperature is 23 - 32 ^{0}C. Annual average humidity is 78 – 95 %.

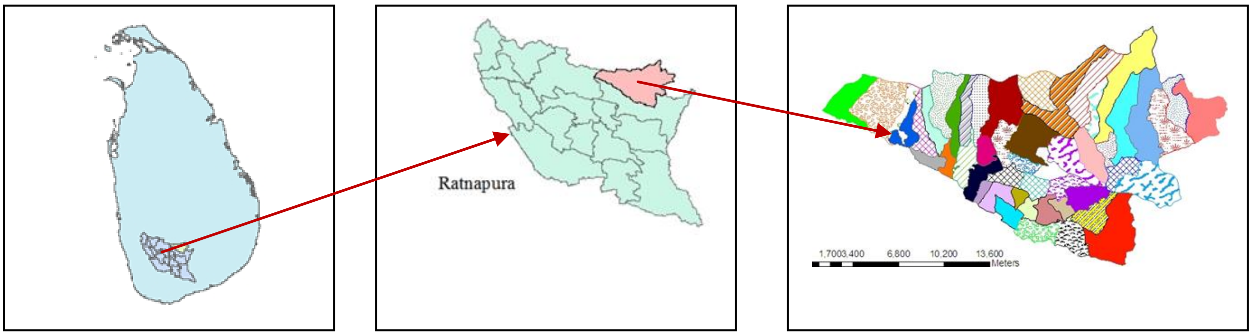

Figure 1: Location of Study Area

Parameters for suitability Analysis

Opinions of agronomist experts and literature review of various references helped in identifying critical requirements for suitable rice growing areas. Three main criteria; soil properties, climate and topography and seven sub-criteria; soil PH, soil texture, soil drainage, soil depth, rainfall, aspect, slope and landuse were identified and used for the land suitability analysis for paddy cultivation. A specific suitability level per factor for rice crop was defined in Table 1.

Table 1: Suitability levels of factors

Factors	Suitability levels		
	Less suitability	**Moderately suitability**	**Highly suitability**
Soil pH	<5 &>8	5 – 6 & 7 - 8	6 - 7
Soil Texture	SL, S	CL, SL, SC	SC, SCL
Soil Drainage	Excessive	Moderate	Poor
Soil Depth	Low depth	High depth	Moderate depth
Rainfall	>3500mm	2000mm - 3500 mm	1000mm – 2000 mm
Slope	30% – 100%	15% – 30%	0% – 15%
Aspect	S, E, W, SE, SW	-	Flat, N, NE & NW

Climatic information on rainfall was collected from the Metrological Department. It was assumed that temperature and humidity values are constant for every GN divisions since study area is small. Thematic map was generated for rainfall factor.

Soil properties on soil pH were measured from collected soil samples. And also soil texture, soil drainage and soil depth were determined using collected field data. Thematic maps were generated for all these factors. Soil depth and Soil pH maps were created using Inverse Distance Weighted (IDW) interpolation method. Soil texture and soil drainage map were created using proximity Thiessian spatial analysis. Topography information on spot height was collected from survey department. Thematic maps were generated for slope and aspect factor. Landuse data was collected from survey department and present landuse map was generated.

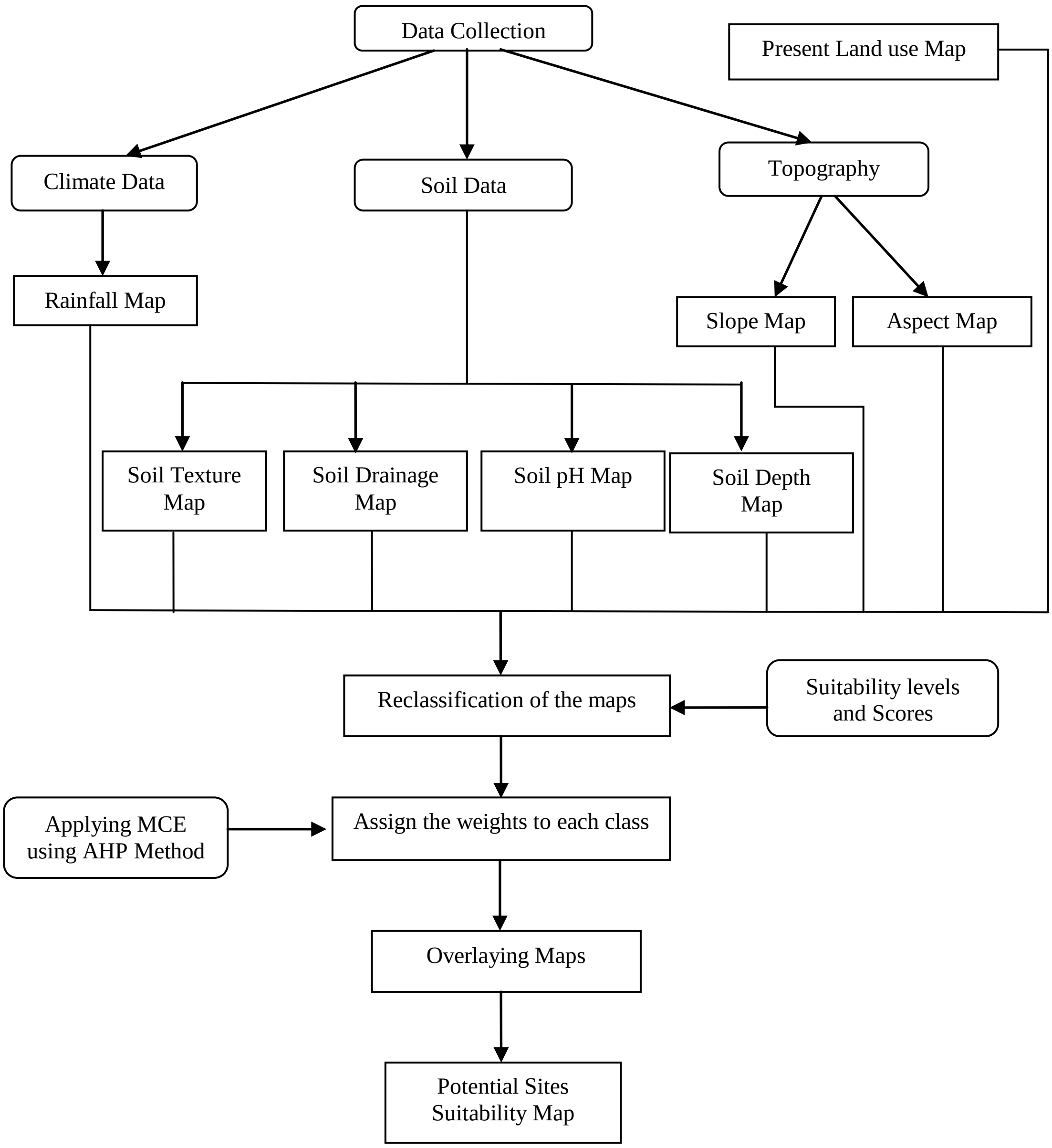

Figure 2:Flow chart of methodology followed in study area

Weight Assignment for the factors and Multi-Criteria Evaluation (MCE)

The purpose of weighting is to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate. Analytical Hierarchy Process (AHP) method of MCE was used to determine relative weight of factors. Factors established in this phase are not unique, but they are the most relevant. Expert opinion of crop specialization was very important in this phase. Based on local agronomists and literature review following variables have identified as relevant factors for suitable area analysis for rice growing: soil texture, soil pH, soil drainage, soil depth, slope, aspect and rainfall and present land use.

In the MCE procedure, it was necessary that the sum of the weights to be equal to one. The MCE method used (weighted linear combination) requires that all factors must be standardized (Eastman 1999) or transformed into units that can subsequently be compared (Malczewski 1999). In order to compute the weights for the factors, a pair wise comparison matrix (PWCM) was constructed using information obtained from expert's opinions and literature reviews, 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 2: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 judgments 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

Weights for factors were calculated by comparing each of every factors using Pair wise Comparison Matrix. The diagonal elements of Pair Wise Comparison Matrix (PWCM) are assigned the value of unity (i.e., when a factor is compared with itself).A rating of 9 indicates that in relation to the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative to the column factor, the row factor is less important (Mustafa et al., 2011).

In cases of rating value of 1 then the column and row factors are equally important. 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).Table 3 shows pair wise comparison matrix for the research.

The weight for each factor 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 n^{th} root of that product (where n is the number of elements in the row). The n^{th} roots are then normalized by dividing them with their sum.

Table 3:Pair Wise Comparison Matrix of Factors

	Land use	**Soil Texture**	**Soil Drainage**	**Soil pH**	**Soil Depth**	**Slope**	**Aspect**	**Rainfall**	**Weights**
Land use	1	3	3	5	5	7	9	9	0.3300
Soil Texture	1/3	1	1	5	7	7	7	9	0.2178
Soil Drainage	1/3	1	1	7	2	6	7	7	0.1879
Soil pH	1/5	1/5	1/7	1	3	5	5	7	0.1019
Soil Depth	1/5	1/7	1/2	1/3	1	3	5	5	0.0761
Slope	1/7	1/7	1/6	1/5	1/3	1	3	3	0.0402
Aspect	1/9	1/7	1/7	1/5	1/5	1/3	1	3	0.0198
Rainfall	1/9	1/9	1/7	1/7	1/5	1/3	1/3	1	0.0187
CR=0.1313									**Sum=0.9924**

To calculate consistency Ratio (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 Eigen value (λ_{max}). Then, the CI value is calculated by using the formula: CI = (λ_{max}-n)/ (n-1). In this study n = 8. Finally, the CR is obtained by dividing the CI value by the Random Consistency Index (RCI) generated by Prof. Saaty. Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable. In practice, CRs of more than 0.1 sometimes have to be accepted. A CR of zero (0) means that the judgments are perfectly consistent. Using above procedure, weights for each factor were calculated.

Overlaying Map Layers

The reclassified thematic map layers of each factor were weighted using the weights derived from the AHP process using Multi Criteria Evaluation. The weighted map layers were combined by performing the weighted sum overlay using spatial analyst tools. Finally, the potential suitability map for paddy cultivation areas was generated by using Arc GIS software.
Equation of the Weighted Sum overlaying process is given below.

$$\text{Weighted Sum} = W_{SoilpH}*(\sum_{i=1}^{3} S_i C_i)+W_{SoilTexture}*(\sum_{i=1}^{3} S_i C_i)+W_{SoilDepth}*(\sum_{i=1}^{3} S_i C_i)+W_{SoilDrainage}*(\sum_{i=1}^{3} S_i C_i)+$$

$$W_{Slope}*(\sum_{i=1}^{3} S_i C_i)+W_{Aspect}*(\sum_{i=1}^{3} S_i C_i)+W_{Rainfall}*(\sum_{i=1}^{3} S_i C_i)+ W_{Landuse}*(\sum_{i=1}^{2} S_i C_i)$$

RESULTS AND DISCUSSION

Spatial variations of sub criteria
`
The every criteria map has been reclassified into two or three classes as 'Highly suitable', 'Moderately suitable' and 'Less suitable' or 'Highly suitable' and 'Non suitable'. The spatial variation of each of the eight factors is discussed below.

Spatial variation of soil PH

The ideal pH range for the successful Paddy cultivation id 6.5 to 8.5. Acidic type of soil is found in all over this study area. The soil PH of the study area ranged from 4.94 to 7.1. It will act as a chief barrier to get high yield in Paddy cultivation.

The reclassified soil PH map shows that only 62.01% of the study area has the soil that having highly suitable pH for paddy cultivation. Figure 3and Table 4 show the spatial variation of soil pH over the area. Figure 3 and Table 4 further stress that almost all the area has suitable soil pH for paddy cultivation.

Table 4: Spatial variation of Soil pH

Suitability Classes	Soil pH Range	Area(Sq.km)	Area (%)
Highly suitable	6 - 7	158.29	62.01
Moderately suitable	5 ≤ pH < 6 & 7 ≤ pH ≤ 8	37.96	37.96
Less suitable	<5 &>8	0.082	0.03

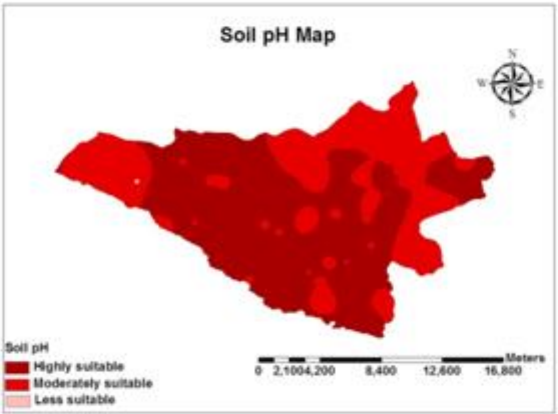

Figure 3: Suitability Rating Map of Soil pH

Spatial variation of Soil Texture

There are seven various type of soil texture classes have been found in this study area. Namely: Silty Clay Loam (SiCL), Silty Clay (SiC), Clay Loam (CL), Silty Loam (SiL), Sandy Loam (SL) and Sandy(S).

These soil textures have been reclassified into three suitability classes. The reclassified soil texture map shows that, 46.02% of the study area has highly suitable soil texture included Silty Clay and Silty Clay Loam. Figure 4 and Table 5 describe that 80% of area consists of appropriate soil texture for paddy cultivation.

Table 5: Spatial variation of Soil Texture

Suitability Classes	Soil Texture	Area(Sq.km)	Area (%)
Highly suitable	SiC, SiCL	117.48	46.02
Moderately suitable	CL, SiL, SC	93.89	36.78
Less suitable	SL, S	43.90	17.20

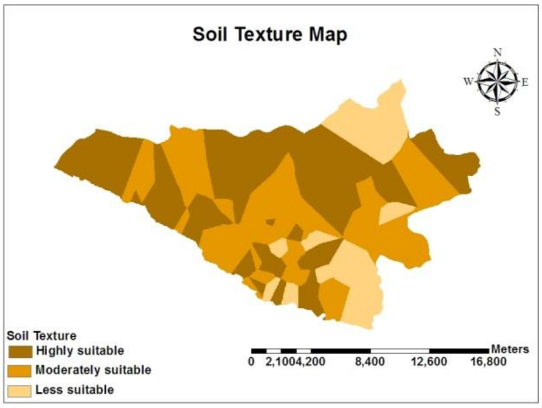

Figure 4: Suitability Rating Map of Soil Texture

Spatial variation of Soil Drainage

In this study it is identified that the study area has following three drainage classes;

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

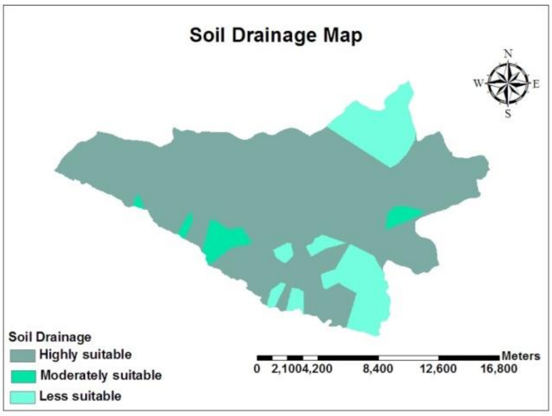

Figure 5: Suitability Rating Map of Soil Drainage

The result from the reclassified map shows that, 80.15% of the study area has poorly drained soil which is highly suitable for the paddy cultivation. Soil drainage pattern of the study area is described in Figure 5 and Table 6.

Table 6: Spatial variation of Soil Drainage

Suitability Classes	Soil Drainage	Area(Sq.km)	Area (%)
Highly suitable	Poorly drained	204.60	80.15
Moderately suitable	Moderately drained	9.13	3.58
Less suitable	Excessive drained	41.55	16.28

Spatial variation of Soil Depth

There are three soil depth classes in the study area. Namely; Low depth (<50 cm), Moderate depth (50 - 100cm), High depth (>100cm).The reclassified soil depth map reveals that, 77.12% of study area has moderately depth which is the highly suitable for the Paddy cultivation. Figure 6 and Table 7 shows the spatial variation of the soil depth over the area.

Table 7: Spatial variation of Soil Depth

Suitability Classes	Soil Depth	Area(Sq.km)	Area (%)
Highly suitable	Moderate (50cm≤soil depth≤100cm)	196.86	77.12
Moderately suitable	High (>100cm)	37.07	14.52
Less suitable	Low (<50cm)	21.35	8.36

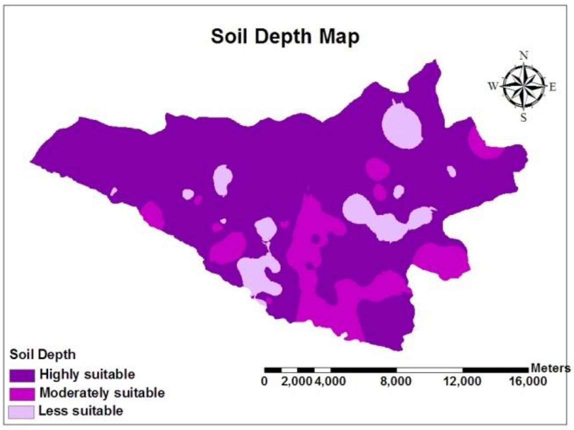

Figure 6: Suitability Rating Map of Soil

Spatial variation of Slope

Generally, deeper slope is not suitable for the paddy cultivation land. Because of the deeper slope will lead to leach out the fertile soil to the bottom of the surface. It will influence the depth of the soil and providing physical support to the paddy crops.

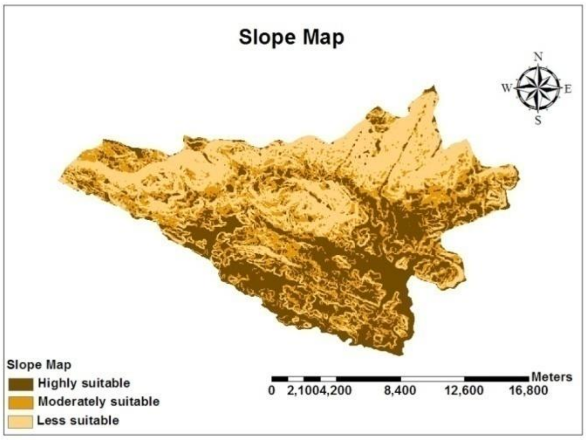

Figure 7: Suitability Rating Map of Slope

The reclassified slope map reveals that, 33.36% of the study area has slope of less than or equal to 15%, which is highly suitable for paddy cultivation. Figure 7 and Table 8 indicates that more than 50% of the area has proper slope characteristic for paddy cultivation.

Table 8: Spatial variation of Slope

Suitability Classes	Slope%	Area(Sq.km)	Area (%)
Highly suitable	≤ 15	85.16	33.36
Moderately suitable	15 – 30< 15 & ≤ 30	72.42	28.40
Less suitable	>30	97.70	38.27

Spatial variation of Aspect

Aspects will determine the available solar radiation over the paddy leaf area. High amount of solar radiation will enhance the rate of photosynthesis and ultimately yield per unit area will be increased.

Aspect reclassified map shows 26.78% of study area has suitable aspect value for the paddy cultivation. On the other hand it is important to note that according to the Figure 8 and Table 9. The percentage of 73.22% of land area does not have appropriate aspect value for paddy farming.

Table 9: Spatial variation of Aspect

Suitability Classes	Directions	Area(Sq.km)	Area (%)
Highly suitable	Flat, NW, N & NE	186.92	26.78
Non suitable	W, SW, W, SE & E	68.35	73.22

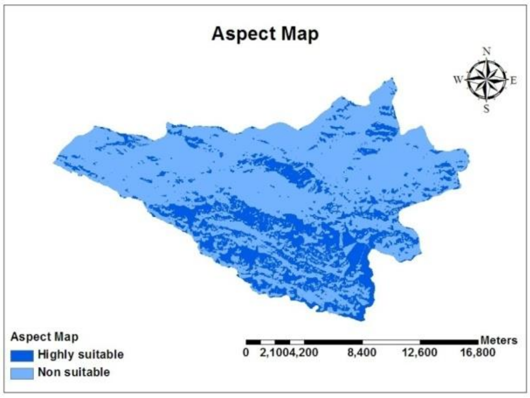

Figure 8: Suitability Rating Map of Aspect

Spatial variation of Rainfall

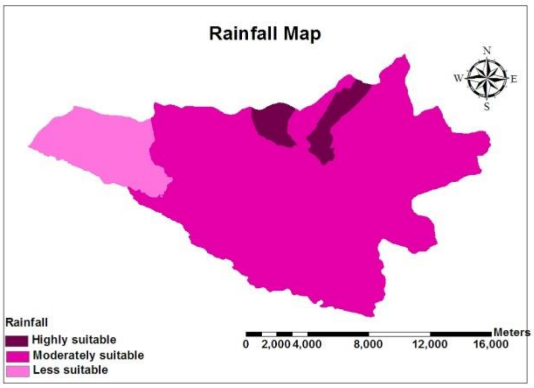

Figure 9: Suitability Rating Map of Rainfall

Paddy is cultivated under irrigation scheme in this study area. The crop water requirement for Paddy cultivation is about 4 acre feet. Sufficient amount of supplementary irrigation for Paddy cultivation is available in this area. The annual average rainfall varied between 1895mm - 4320mm in this study area. These values are reclassified into three suitability classes. Rainfall reclassified map shows in Figure 5.7 and classified data tabulated in table 10.

This map and table shows that only 5.42% of the study area receives between 1000mm - 2000mm of rainfall which is highly suitable for the paddy cultivation. However table highlighted that 82.11% of the area receives moderately suitable rainfall for paddy farming.

Table 10: Spatial variation of Rainfall

Suitability classes	Annual average rainfall(mm)	Area(Sq.km)	Area (%)
Highly suitable	1000- 2000mm	13.84	5.42
Moderately suitable	2000- 3500mm	209.62	82.11
Less suitable	>3500mm	31.82	12.46

Spatial variation of Landuse

Land use is the most important factor need to be considered for commercial cultivation of paddy. The current land use shows 6.68% of study area as 17.0637 km^2 paddy cultivated. Present land use classes in this area are shown in Figure 10 and Table 11.

These land use classes were reclassified into two suitability classes according to the suitable land for the paddy cultivation, namely highly suitable and non suitable and reclassified map is shown in figure 11. The reclassified land use map indicates 38% of study area has been highly suitable for the paddy cultivation area. Table 12 tabulates the suitable and non suitable landuses for paddy cultivation in the study area.

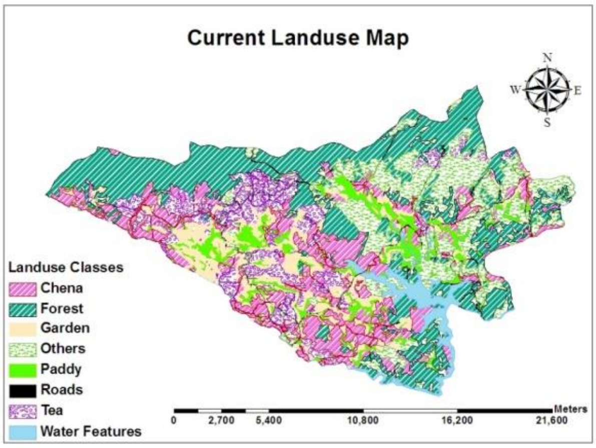

Figure 10: Map of Current Landuse Classes

Table 11: Areas of Current Landuse Classes

Landuse Classes	Area(Sq.km)	Area (%)
Paddy	17.08	6.69
Chena	44.43	17.41
Forest	75.39	29.53
Garden	26.91	10.54
Water features	10.58	4.14
Roads	6.71	2.63
Tea	25.32	9.88
Others	48.93	19.17

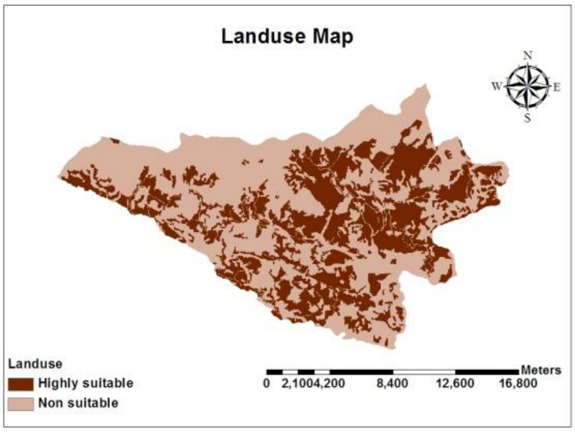

Figure 11: Suitability Rating Map of Landuse Classes

Table 12: Spatial variation and area of land use classes

Suitability classes	Land use classes	Area(Sq. km)	Area (%)
Highly suitable	Paddy, Chena, Scrub and Marsh	98.45	38.57
Non suitable	Water features, Transportation and Non vegetation	156.80	61.43

LAND SUITABILITY FOR PADDY CULTIVATION

Above seven reclassified maps were used for weighted overlaying process of spatial analysis tool to generate potential land suitability map. It indicates that 32.33%, 53.15%, and 14.51% of land area fallen into highly, moderately and less suitability class for paddy cultivation, respectively in this study area. Further this stress that about 85% of the land extent is suitable for paddy cultivation within the study area.

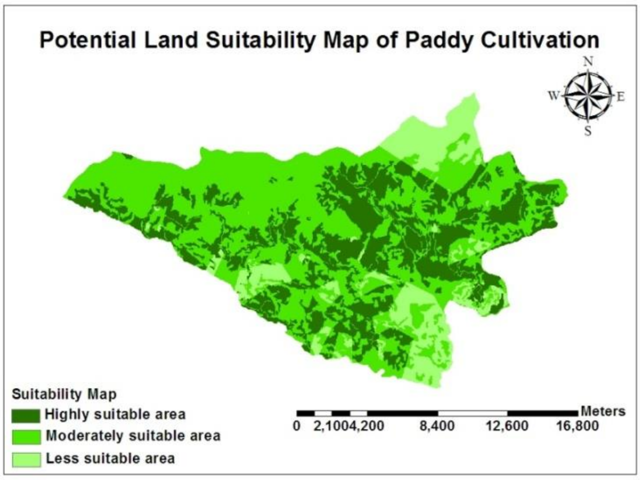

Figure 12: Potential Land suitability Map of Paddy Cultivation

However current land use map indicates that 6.68% area extent is under paddy cultivation within the study area. This information is of great importance to decision makers and, in particular, to departments of Agriculture for land use management to distinguish the capability of increasing paddy cultivation in this area. This study demonstrate that strong recommendation of first two suitability classes to be considered simultaneously for land allocation for new rice cultivation areas to get good return from rice production.

Table 13: Area of paddy land suitability classes

Suitability classes	**Area(Sq.km)**	**Area (%)**
Highly suitable	82.53	32.33
Moderately suitable	135.68	53.15
Less suitable	37.04	14.51

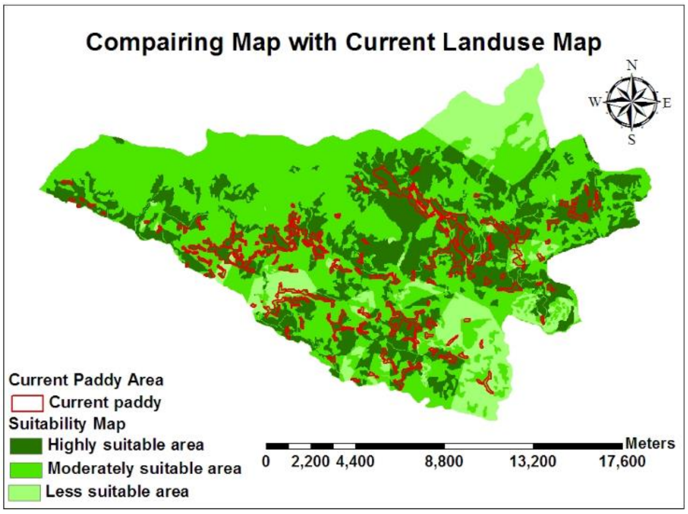

Figure 13: Comparing Map with Present Paddy Cultivation

According to the overlaying suitability map with current landuse map, 78% of study area has suitable areas for the Paddy Cultivation.

Table 14:Total potential area for paddy cultivation

	Area(Sq.km)	**Area (%)**
Suitable area for paddy cultivation	218.21	85.48
Current paddy area	17.08	6.69
Potential area for paddy cultivation	201.13	78.79

CONCLUSIONS AND RECOMMENDATIONS

The results demonstrate that present paddy cultivated areas are falls under the areas that are classified as 'highly suitable' and 'moderately suitable' for rice cultivation.The suitability map may be guide for decision makers considering crop substitution in order to achieve better agricultural production. Before extending the paddy cultivation areas must be go to the field and check the landuse types. Because of most of the Chena areas indicates the high suitable land for the paddy cultivation sites.

Land suitability map for rice established using GIS can enhance the planning alternatives within the area with a meaningful strategy in terms of location. Therefore, the present model will provide logical guidance for new land allocation for the cultivation of rice. GIS based AHP analysis is beneficial for land suitability analysis because of its capacity to integrate a large quantity of heterogeneous data, and obtaining the required weights can be relatively straightforward, even for a large number of criteria.

According to the expert's opinion, it was assumed that temperature and humidity values were constant for whole study area but with real data of these two factors results can be improved. Due to the time limitation, socio-economic factors and soil properties such as Nitrogen, Potassium and Phosphorous were not taken into account in this analysis. Model can be further developed with these factors to obtain better results. In the future study this method can be applied for mapping land suitability of other crops in the country and across the country with additional and more refined parameters.

REFERENCES

References from Literature:

Department of Agriculture, 2000: Department of Agriculture at the Turn of the Century. Department of Agriculture, Peradeniya, Sri Lanka.

Eastman JR,1999 Guide to GIS and image processing.

Halder, J,,2013, 'Land suitability assessment for crop cultivation by using remote sensing and GIS'.

Kihoro, J, Njoroge J, & Murage, 2013, 'Suitability analysis for rice growing sites using a multi-criteria evaluation and GIS approach in great Mwea region, Kenya'.

Malczewski J (1999) GIS and multi-criteria decision analysis.

Perveen F,(2007) Crop land suitability analysis using a multicriteria evaluation and GIS approach.

Saaty, T.L. (1980). The analytic hierarchy process.

References from websites:

http://www.agridept.gov.lk/

http://www.sciencepub.net/researcher