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Research Article

LAND SUITABILITY EVALUATION FOR CEREAL CROPS: A MULTI-CRITERIA APPROACH USING GIS AT PARBATIPUR VDC, CHITWAN, NEPAL

B. Neupane*¹, C.P. Shrivastav², S.C. Shah² and K. Sah³

¹Gokuleshwor Agriculture and Animal Science College, Baitaidi, Nepal

²Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal

³Soil Science Division, Nepal Agricultural Research Council, Khumaltar, Kathmandu, Nepal

*Corresponding author's email: neupanebikash09@gmail.com

Abstract

A research was conducted to evaluate the suitability of soils of different land unit for cereal crops productions at Parbatipur VDC, Chitwan, Nepal with the integrated use of Geographical Information system (GIS) and Multi-criteria evaluation (MCE). Existing geodatabase information from National Land Use Project (NLUP) was used as data for this research. The database was used to derive crop suitability using vector based index model in GIS along with multi-criteria analysis. The research revealed that for rice cultivation, 1.06 % (10.70ha) was highly suitable, 51.54 % (515.89ha) was moderately suitable, 3.39% (33.987 ha) was marginally suitable but 28.28 % (283.11 ha) was not suitable whereas for wheat cultivation, 7.6 % (76.73ha) was highly suitable, 44.91% (449.53 ha) was moderately suitable and 4.6% (46.26ha) was marginally suitable, but 27.15% (27.14ha) was not suitable. Similarly, for maize cultivation, 12.07% (120.83ha) was highly suitable, 40.19% (402.25ha) was moderately suitable and 0.53% (5.37ha) was marginally suitable, but 31.54% (315.72ha) was not suitable for maize production. Suitability data of this VDC shows that maize and wheat was highly suitable than rice cultivation. But, the area not suitable for rice, wheat and maize must be allocated for alternative uses to achieve optimum productions and further there must be new research for alternative crops in VDC. Hence, this research is useful to farmers and VDC level planners for optimum crops production.

Keywords: Suitability; Geographical information System; Multi-criteria evaluation

Introduction

Land suitability evaluation is a basis to achieve optimum utilization of the available land resources for sustainable agricultural production. Beek (1978), defined a land evaluation is a process of matching the selected land qualities and comparing them with land use requirements. Complex characters of land also considered as land quality, acts in a specific manner and effect on the suitability of land for a specific kind of use (Kavetskiy *et al.*, 2003). (Larson and Pierce, 1991), defined land quality as fitness for use and "the ability of a soil to work" (Karlen *et al.*, 1997).

For improved spatial decision making Multi Criteria Decision Making (MCDM) or Multi Criteria Evaluation (MCE) was developed as more alternatives are evaluated based on conflicting criteria, with the aid of pair-wise comparison matrix (PWCM) and analytical hierarchy process (AHP). For multiple criteria decision-making issues the effective tool is MCE (Malczewski, 2006). Use of GIS and MCE can assist land-use planners to develop decision-making processes (Malczewski, 1999). GIS helps in the manipulations of assessment factors and MCE integrates it to a suitability maps. Suitable lands for vegetable crops in Nepal was evaluated by Baniya (2008) and he concluded

that MCE with GIS is an important tool for aggregation of socio-economic and environmental data.

In order to enhance the soil fertility and soil water conservation technique, there had been considerable research in Nepal over the years. (Keatinge *et al.*, 1999; Acharya *et al.*, 2000). the decline in soil fertility is a major concern for most farmers (Turton *et al.*, 1995) and Shrestha *et al.* (2000) concluded that their adoption of improved techniques had been limited. The productivity of soil had been declined due to fertility depletion, imbalance of nutrients in soils, decline into organic matter context, which resulted into reducing physical and chemical properties of soils. So a research was carried out at VDC level at Parbatipur VDC in Chitwan district, Nepal in order to utilize the existing soil resource to achieve the sustainable agricultural production, integrating the MCE and GIS.

Material and Methods

Research area

The research was carried out in Parbatipur, VDC of western Chitwan (inner terai) district of central development region. The VDC covering area is about 1000.19 hectares. Geographically it is located between 27° 30' and 27° 35' North latitude and 83° 48' and 83° 51' East longitude.

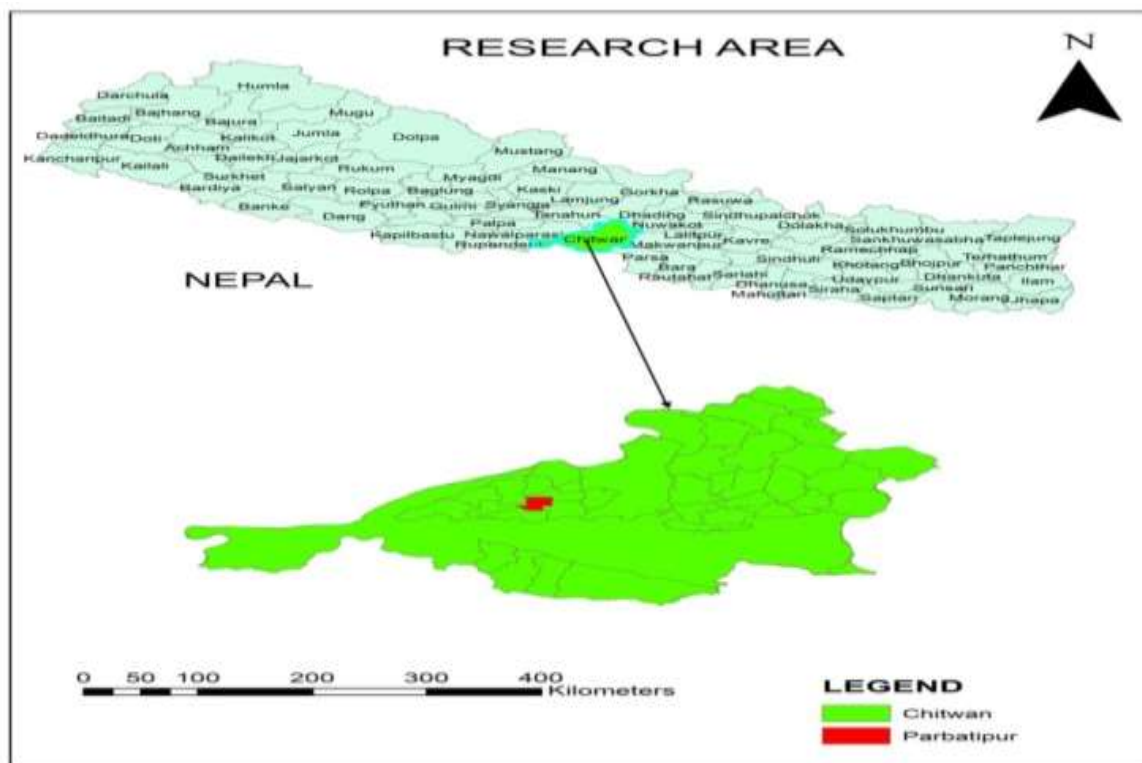


Fig. 1: Map of Nepal, Chitwan and Parbatipur VDC

Selection of cereals crops

Mainly three dominant crops prevalent on these areas were acquired for the research and they were Rice, Maize and Wheat. The cereal crops which were acquired for the research and their classification (Table 1).

Table 1: Cereals crops selected for research

Parbatipur VDC (crops)	Scientific name	Nepali name	Family
Rice	<i>Oryza sativa</i>	Dhan	Gramineae
Wheat	<i>Triticum aestivum</i>	Gahu	Poaceae
Maize	<i>Zea mays</i>	Makai	Gramineae

Database collection and attributes

Data sources for VDC were gathered from the Village Development Committee profile, soil attribute data, land use attribute data were gathered from the National Land Use Project (which surveyed the VDC in the year 2011 and 2012).

Preparation of thematic maps

Using ArcMap software thematic maps were created for each attribute data. Thematic maps include the maps of Land use, Land Capability, and Soil maps.

Classification of criteria acquired in the research

There were three criteria acquired for the research which are given below.

- Land Capability
- Soil
- Land Use

Application of MCE (Multi-criteria evaluation) approach using analytical hierarchy process (AHP)

Multi criteria evaluation was acquired by applying the various procedure of AHP (Analytical Hierarchy process). Analytical Hierarchy Process, introduced by Satty (1977) was used in decision-making, with the assumption that comparison of two elements is derived from their real-time importance. AHP was carried out by following the given steps below.

a. Generation of a hierarchy structure

AHP technique began with the structuring of the criteria and sub-criteria required for the land suitability and arranging them in a hierarchical form (Table 2). AHP method was applied for three criteria, i.e. Land capability, soil and Land use. The final goal of the research was suitability evaluation which occupied at the top most position in the hierarchy. The next level was the main criteria used for the analysis and finally the main criteria were subdivided into sub-criteria.

Table 2. Hierarchical organization for the criteria and sub-criteria acquired in the research

Goal	Criteria(level 1) W ₁	Sub-criteria(level 2) W ₂	Overall weight W
Multi- Criteria Land Suitability	Land Capability Classification(LCC)	Drainage , Slope , Flooding, Erosion	<p>W=W₁×W₂</p> <p>Overall weight × Fact value</p> <p>Thematic layer overlay</p>
	Soil	Texture, N, P, K, O.M,pH,Soil depth	
	Land Use	Wetland, Mixed land	

The main criteria are Land Capability Classification, Soil, Land use, The Land Capability Classification was sub-divide into the sub-criteria at level two. Similarly, criteria Soil and Land Use were divided into sub-criteria at level two.

b. Use of pairwise comparison matrix (PWCM)

The pair-wise comparison matrix (PWCM) was carried out for rating and weighting of the of different sub-criteria and criteria (Table 3). The fundamental scales given by satty’s for comparing the two criteria or subcriteria was used. The qualitative value from 1-9 scales was given by (satty and vargas,2001), considering the comparative importance of two criteria or sub criteria.

Table 3: Paired-wise comparison for the three criteria

	Criteria 1	Criteria 2	Criteria 3	Weightage
Criteria 1	1	1/3	5	0.2828
Criteria 2	3	1	7	0.6434
Criteria 3	1/5	1/7	1	0.0738
$\lambda_{max}=3.0$	CR=8.3			
9	%			

Where, CR= Consistency Ratio, λ_{max} = Principle eigen value

This process of comparing the criteria was carried out for three criteria and their sub-criteria to calculate the weightage (normalized priority vector). Further the process of calculation of consistency ratio was done as given below.

c. Calculation of consistency ratio

Step 1. Consistency index was calculated,

Consistency index (CI) = (λ_{max} -n)/(n-1)

Where n = number of criteria λ_{max} =Maximum eigen value

Step 2. Random consistency index (RI) was calculated (Table 4). RI value depends upon the number of criteria or sub-criteria acquired in the research

Step 3: Finally, Consistency ratio (CR) was calculated as below

CR=CI/RI

Where, RI= Random consistency, CI= Consistency index

CR value \leq 10% AHP is consistent, then further process was done

CR value $>$ 10% AHP is not consistent, revision of process was done

Determination of fact value

Fact value for each subcriteria was classified from the 0-9 scales with suitability order (Table 5)

Table 4: RI value at different number of criteria

N	1	2	3	4	5	6	7	8	9	10
R	0	0	0.5	0.9	1.1	1.2	1.3	1.4	1.4	1.4
I		8	0	2	4	2	1	5	9	

Source: (Permadi, 1992)

Use of weighted linear combination method to calculate index value

Fact value of sub-criteria was multiplied with the weight calculated from the PWCM. The weighted linear combination method was used to calculate the index value for following criteria and their sub-criteria.

a. Land Capability index

b. Soil rating index

c. Land use index

For example flood index (subcriteria of capability index) was calculated as given below:

Flood index = \sum Overall weight x fact value or score of its sub criteria

Where, Weightage = Normalized eigen vector as calculated in the Table 3.

Fact value = Fact value of sub-criteria as given in the Table 5.

Table 5: Fact value for criteria/sub-criteria

Fact value	Suitability order	Classification
9	Highly suitable	S1
7	Moderately Suitable	S2
5	Marginally Suitable	S3
1	Not suitable (Presently)	N1
0	Not suitable (Permanently)	N2

Final suitability index

Final suitability index is calculated in Arc-catalog software with addition of all indexes. Therefore suitability index = Land Capability index + soil index + land use index

GIS modeling

ArcMap and Arc-catalog software were used in GIS modeling (Fig.1). Weighted linear combination method was used to calculate index value of each sub-criteria considering its criteria in the Arc-catalog. Following shape file was created in ARC-GIS software for each crop.

- a. Land capability index.shp
- b. Soil rating index.shp
- c. Land use.shp

GIS model was run in the ArcMap and suitability Map was created for each cereal crops. The flowchart for GIS modeling is given below.

Table 6: Suitability area of rice under different classes

Rank	Suitability classes	Suitability orders	Area (ha)	Area (%)	Total Area (ha)
0	Not applicable	-	155.99	15.5	
1	Highly suitable	S1	10.70	1.06	
2	Moderately suitable	S2	515.89	51.54	1000.8
3	Marginally suitable	S3	33.98	3.39	
4	Not suitable presently	N	283.11	28.28	

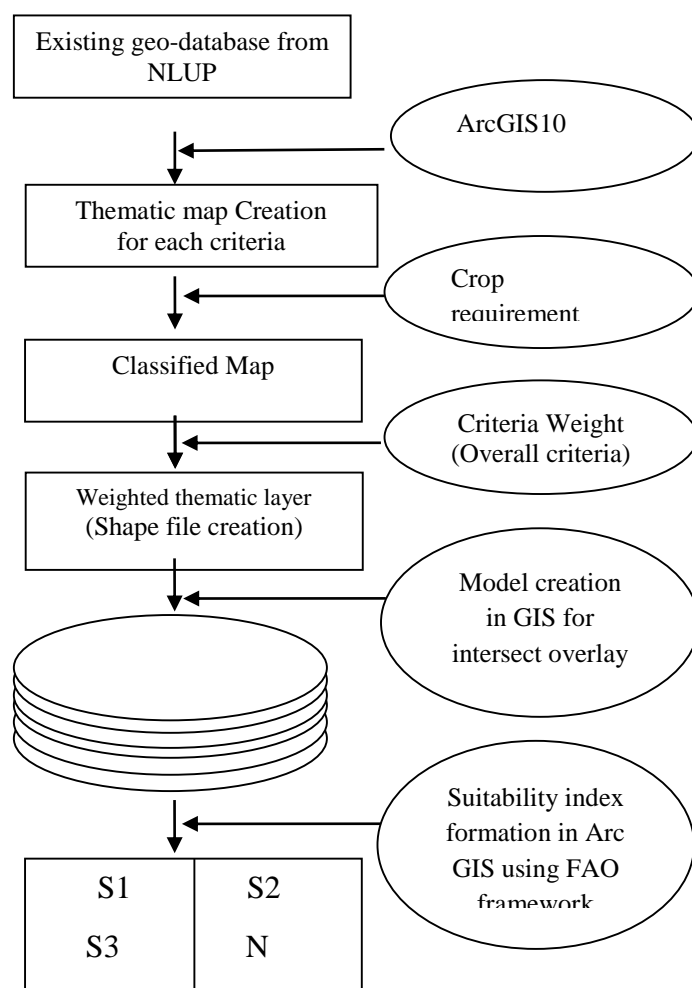


Fig.1 Flowchart showing GIS modeling in ArcMap software.

Results and Discussion

Suitability evaluation for rice

Suitability evaluation for rice in research area (Fig 2) revealed that only 10.70 ha (1.06%) was highly suitable for rice production, 515.89 ha (51.54%) was moderately suitable, and 33.987 ha (3.39%) was marginally suitable, while 283.11 ha (28.28%) was not suitable for rice cultivation presently (Table 6).

Table 7: Descriptive statistics for suitability index of rice of the research area

Count	Minimum	Maximum	Sum	Mean	Median	SD	CV
1042	6.33	50	36997.14	35.50	50	19.64	55%

Table 8: Suitability area of wheat under different classes

Rank	Suitability	Suitability orders	Area (ha)	Area (%)	Total area(ha)
0	Not applicable	-	155.99	15.55	
1	Highly suitable	S1	76.73	7.6	
2	Moderately suitable	S2	449.53	44.91	1000.8
3	Marginally suitable	S3	46.26	4.6	
4	Not suitable presently	N	271.65	27.14	

Table 9: Descriptive statistics for suitability index of wheat of the research area

Count	Minimum	Maximum	Sum	Mean	Median	SD	CV
1042	6.37	10	9371.61	8.99	10	1.38	13.85

Table 10: Suitability area of Maize under different classes

Rank	Area(ha)	Suitability classes	Suitability orders	Area (%)	Total area (ha)
0	155.99	Not applicable	-	15.55	
1	120.83	Highly suitable	S1	12.07	
2	402.25	Moderately suitable	S2	40.19	1000.8
3	5.37	Marginally suitable	S3	0.53	
4	315.72	Not suitable presently	N	31.54	

Rice suitability of the research area revealed a suitability index value with minimum index value 6.33 and 50 as maximum value (Table 7).

Suitability evaluation for wheat

Suitability evaluation for wheat in research area (Fig 3) revealed that only 76.73 ha (7.6%) was highly suitable for wheat production, 449.53 ha (44.91%) was moderately suitable, and 46.26 ha (4.6%) was marginally suitable, while 271.65 ha (27.14%) was not suitable for wheat cultivation presently (Table 8).

Wheat suitability of the research area revealed a suitability index with minimum index value 6.33 and 10 as maximum value (Table 9).

Suitability evaluation for maize

Suitability evaluation for Maize in research area (Fig 4) revealed that 120.83 ha (12.07%) was highly suitable, 402.25ha of area (40.19%) was moderately suitable, 5.37ha (0.53%) was marginally suitable and 315.72 ha (31.5%) was not suitable for maize production presently (Table 10).

Maize suitability of the research area shows that, suitability index with minimum index value 6.34 and 15 as maximum value (Table 11).

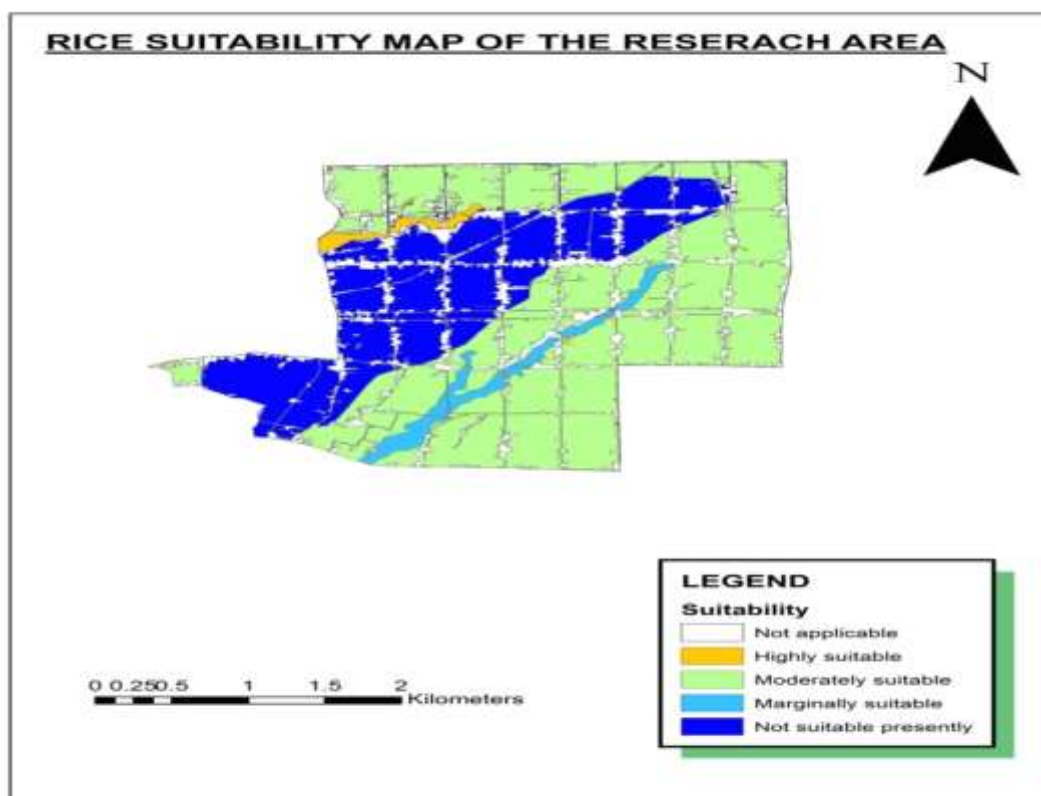


Fig. 2: Rice suitability map of the research locale of Parbatipur Village Development Committee, Chitwan, Nepal, 2014

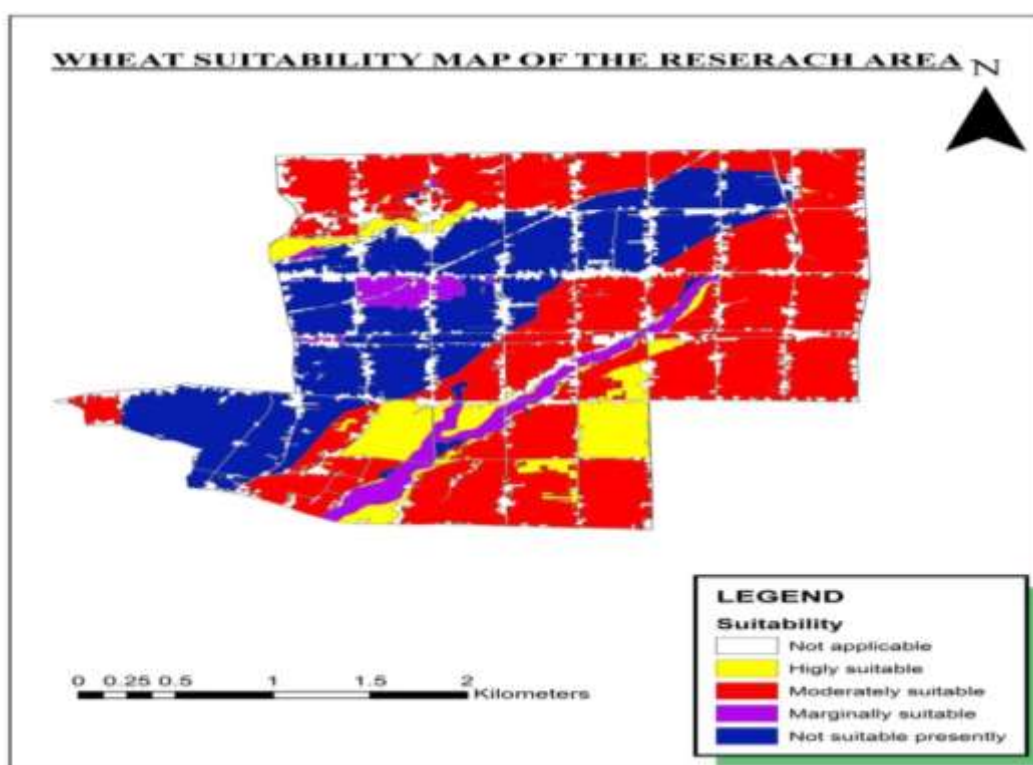


Fig 3: Wheat suitability map of the research locale of Parbatipur Village Development Committee, Chitwan, Nepal, 2014

Table 11. Descriptive statistics for suitability index of maize of the research area

Count	Minimum	Maximum	Sum	Mean	Median	SD	CV
1042	6.34	15	13230.94	12.69	15	3.24	25.53

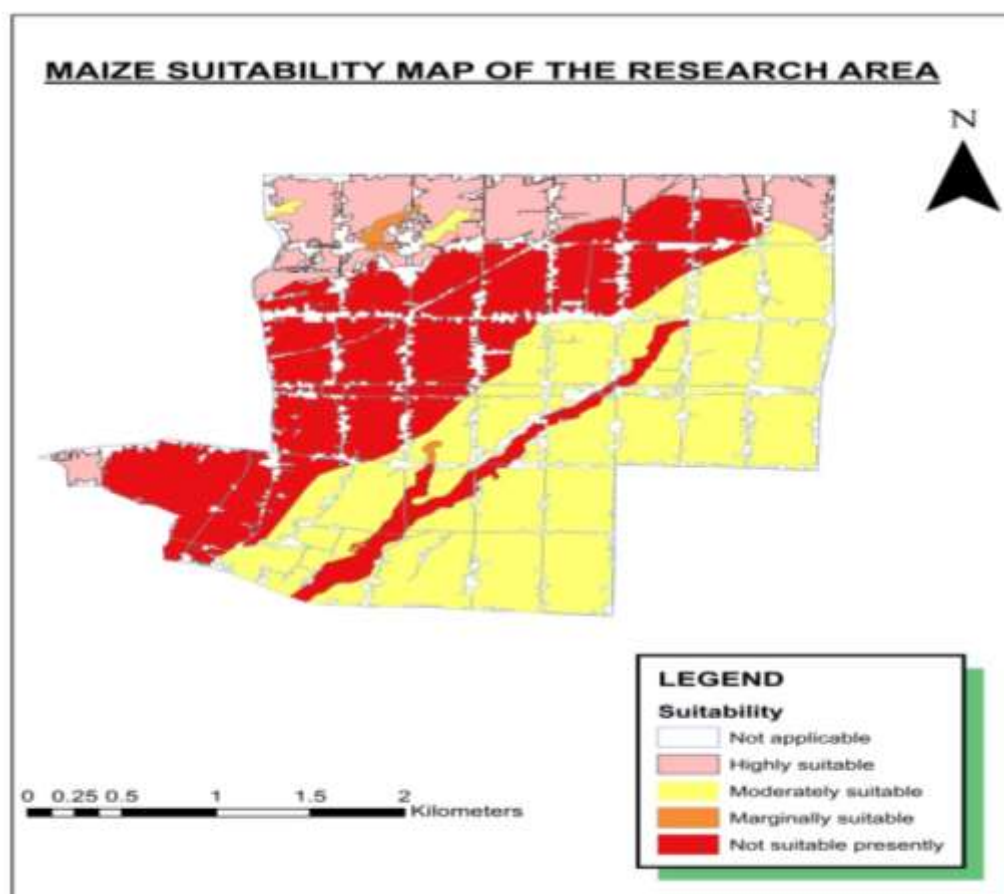


Fig 4: Maize suitability map of the research locale of Parbatipur Village Development Committee, Chitwan, Nepal, 2014

Conclusion

In this research, integration of MCE and GIS techniques was used to predict suitable areas for cereal crops production at VDC level which shows that maize and wheat cultivation was highly suitable than rice cultivation. The outcome obtained from this study also indicates that the integration of GIS and MCE could provide a good database and information for VDC level planners considering crop substitution to get better agricultural production. This approach had been used in some other countries. But in Nepal this approach is new and hence it must be implemented at VDC level and district level planning.

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