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Suitable site selection for plantation of olive by using multi-criteria analysis along with GIS in ten mountainous district of Northwestern Nepal

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Abstract

Olea cuspidata (wild olive) is naturally grown on mountainous region of Northwestern Nepal. This species has higher importance in respect to it's environmentally as well as economically benefits for humankind. It can highly flourish even in the poor and stony soils of the marginal mountain areas that indirectly helps in soil conservation. Presence of Wild olive in some mountainous district of Northwestern Nepal proves that there is potentiality of olive plantation in those regions. The research was carried out on 2014 to find potential or suitable sites for the plantation of this species in ten mountainous districts of Northwestern Nepal by using the MCA technique along with GIS analysis. For analysis of site suitability six different criteria were chosen among which three of them were climatic (Maximum temperature, Minimum temperature, and Precipitation), and three were terrain (Altitude, Aspect and Slope). The criteria map of each of the six parameters of the study area were collected and prepared in ArcGIS 10. The determination of criteria is one of the foremost steps of MCA process so it was determined based on observed data (empirical data) of the existing olive trees. The criteria was then reclassified into four classes (i.e. '1'as unsuitable; '2'as least suitable; '3'as moderately suitable; and '4'as highly suitable). After reclassification of criteria, weightage was assigned to each of the criteria according to their importance and contributions for the growth and development of olive tree. Weightage was assigned by the help of experts and calculated out by the AHP (Analytical Hierarchy Process). Then, the reclassified criterion maps were added in weighted overlay table with the determined weightage percentage. After processing, the suitability map of the study area for the plantation of olive was generated. The final map revealed that about 1.02% (30165.75ha) were highly suitable, 15.52% (553131.18ha) were moderately suitable, 6.25% (232097.22ha) were least suitable and 77.20% (2567282.58ha) were unsuitable of total study area. Among 10 districts, Bajura, Kalikot, Mugu and Humla were potential for highly suitable zone for plantation of olive. About 70% of area in Achaam was found to be potential zone for moderately suitable site for olive plantation following with 45%, 29%, 26%, and 19% in Jajarkot, Kalikot, Rukum and Bajhang respectively. More than 90% of area seemed to be unsuitable for olive plantation in Dolpa, Humla, and Jumla district.

Keywords: GIS, MCA, olive, overlay, suitability.

Introduction

Olea cuspidata (wild olive) is naturally grown on mountainous region of Northwestern Nepal. The latest surveys reported that Bajura, Mugu, Dolpa and Humla were the four major districts where this wild olive species was present[1]. This species has great advantages as comparing to other fruit crops as this species can highly flourish even in the poor and stony soils of the marginal mountain areas with altitude varies from 1,100 to 3,000m above mean sea level[2]. *Olea cuspidata* can grow on that soil for which other crops are considered to be unsuitable. These special characteristics of the Olea distinguish it from other crops and signifies its higher importance in respect to it's environmentally as well as economically benefits for humankind. Despite of its importance, olive crop is not getting enough attention from Local level and National level towards its conservation and promotion. Destruction of olive forest in the Himalayan alpine vegetation of Bajura has been documented by the government authorities in the last 50 years[3]. In Nepal, the most prominent threats to wild olives is due to the collection of this species as a firewood by the local people[4]. It is categorized as a rare species by IUCN[5].

Since the initiation of human civilization, the olive tree has been introduced due to its noteworthiness value. In many countries the olive products are taken as remarkable goods. It is reported that, out of seven species in the island of Israel, olive is registered as most significant species[6]. In Quran also, olive is acclaimed as a valuable tree due to its benefits of oil and fruits to humankind[7]. Besides the commercial uses, there are environmental benefits of olive farming also. It helps in conservation of soil by reducing the soil erosion, slowing run-off and improving water penetration. Well-managed olive plantations have structural diversity (trees, understory, patches

of natural vegetation etc) that provides a variety of habitats due to which olive orchard ensures rich biodiversity too[8]. It is either an agricultural crops or tree crops, it is always important to determine the suitable site prior to plantation that can only ensure the qualitative and quantitative production sustainably. The suitable site selection is the chief factor for every types of crops that have effects on sustainable productivity. Selection of site is preventive strategies that are adapted early to any plant species and or animal species for the sustainable production and sustainable management system. Appropriate site selection for the plantation of crop will be blessing for the rural people as they will not have to be jobless as well as insecurities problems of food will also be improved. It is supposed that the olive was started to cultivate since 1960s in different parts of Nepal but they could not flourish well due to lack of proper site selection. In order to introduce olives in different regions of Nepal, various activities were initiated in past without any proper scientific research and studies[9]. Research on suitable site selection for sustainable plantation of olive in Nepal seems to be most vital and handy. Considering these points, identifying suitable areas for the plantation of olive in Mountainous districts of Northwestern Nepal in a scientific way was the main aim of this research.

Study area: Ten mountainous district of Northwestern Nepal was selected for study area where the wild olives are found naturally. Those ten districts are named as Achham, Bajhang, Bajura, Dolpa, Humla, Jajarkot, Jumla, Kalikot, Mugu and Rukum (Figure-1). Total area of 10 studied districts is 33,748 sq. km (22.93% of total geographic area of Nepal). Among the studied districts, Dolpa is the largest district as well as of Nepal also which covers around 70.2% of Trans-Himalayan zones (i.e. the zone that lies between elevation zones of 3,000m to 6,400m). These ten districts extend from 28°43'48"N to 30°0' 18"N latitude and 81°15'6"E to 83°4'44"E longitude. Each of these districts have different climatic zones ranging from tropical to nival zone (Table-1).

Materials and methods

Mainly two kinds of data were used in this research. One kind of data was vector data that consists of the GPS point of standing wild olive trees. The other data was raster data, which consists of the information on climatic condition and terrain parameters of the study area. As some region of the study area (i.e. Bajura District) is densely populated by the wild olives from which the location of each of the 1704 superior olive tree that were flourish highly was provided by the olive development project. Aster 30m resolution DEM (downloaded from earthexplorer.usgs.gov) and its derivation (slope and aspect) was used in the analysis to take into account the feasible altitude, slope and aspect for olive growing. As a climate dataset, minimum and maximum temperature, and annual precipitation of the study area were selected. Temperature and precipitation are the major governing factor for the distribution of olive. These three climatic datasets were freely downloaded from (WorldClim, 2014-version 1.4) which consists of free climatic data. WorldClim is a set of climate layers (climate grids) of world with 1 square kilometer of spatial resolution[10]. Those climatic data characterizes the time of 1950 – 2000. These data were downloaded as a ESRI grid (raster) format having a resolution of nearly 1km (0.93*0.93=0.86km²). After collection of the required dataset they were refined and developed as per our necessities for the research. The various tools of ArcGIS 10 have been used to develop the data into final mode. All the Raster datasets were projected into datum of WGS 1984 and UTM zone of 44N with 30 m resolution.

Table-1: Differnt climatic zones of ten district along with respective area coverage.

Districts	Area Sq. Km	Climatic zones (%)					
		Upper tropical 300-100m	Subtropical 1000-2000m	Temperate 2000-3000m	Sub-alpine 3000-4000m	Alpine 4000-5000m	Nival above 5000m
Achham	1680	27.4	58.3	12.2	1.0	1.1	-
Bajhang	3,422	0.5	18.0	26.5	16.6	8.4	30.0
Bajura	2,188	0.6	19.7	36.4	25.2	11.2	6.4
Dolpa	7,889	-	0.3	5.1	12.2	8.2	3.2
Humla	5,655	-	2.3	8.9	19.4	58.7	10.7
Jajarkot	2,230	5.9	37.3	34.6	16.9	2.3	3.0
Jumla	2,531	-	-	25.3	49.7	13.9	7.3
Kalikot	1,741	1.8	20.6	39.4	37.3	0.85	-
Mugu	3,535	-	5.65	19.3	20.6	17.7	5.3
Rukum	2,877	2.9	26.0	32.6	23.0	14.9	0.7

Results and discussion

Selection of parameters: Six different parameters were selected that highly governs the growth of olive. Those parameters were altitude, slope, aspect, maximum and minimum temperature, and annual precipitation. The datasets of six criteria maps (Figure-2) were prepared and classified into five or more than five classes in order to examine the study areas more clearly in different ranges of climatic and physical zones.

Determination of range of criteria based on GPS point of wild olives (Empirical data): We have point dataset which consists of 1704 GPS point of wild olive tree that were grown with better-quality in the Bajura district (one of the districts among our 10 studied districts). These points have only location while other attribute was unknown. To know the values of our selected parameter, we decided to extract the values from the six raster data of terrain and climatic parameters (i.e. altitude, slope, aspect, minimum temperature, maximum temperature and precipitation). By the help of "Extract Multi Values to Points" of spatial Analyst tools in ArcGIS 10, the raster values of six variables were generated. After extracting the values of six variables (Climatic and terrain), the minimum and maximum value for each of the variables was observed (Table-2) which helps to determine the range for each of the parameters.

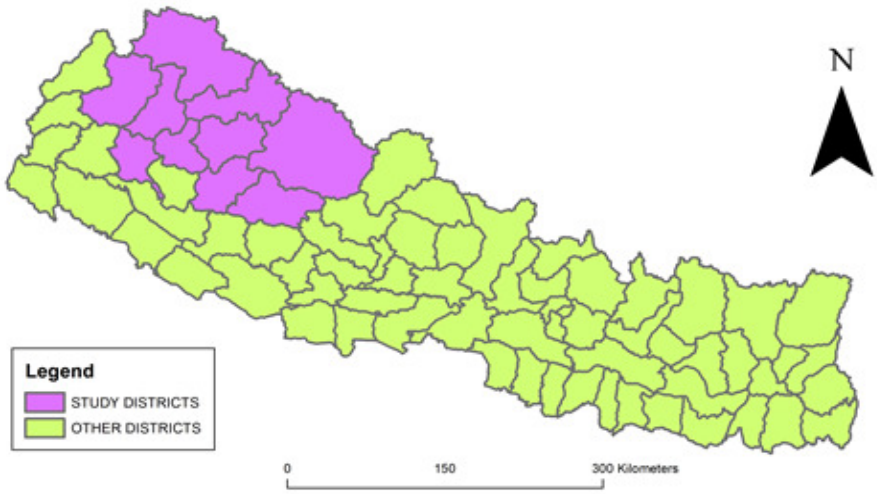

Figure-1: Study area.

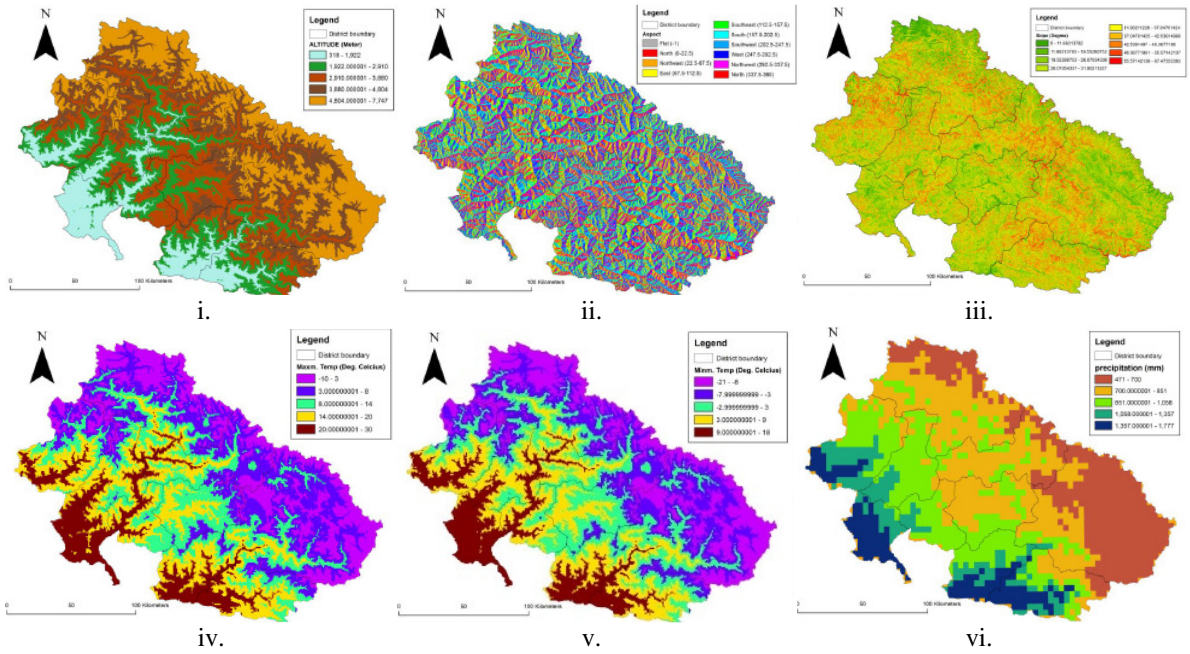

Figure-2: Six different parameters maps of study area; i. altitude, ii. aspect, iii. slope, iv. Max. temperature, v. Min. temperature and vi. Annual precipitation.

Table-2: Ranges of values for different six parameters.

Criteria	Ranges of values
Altitude (m)	950-2500
Aspect (°)	All direction (0-360)
Slope (°)	2-55
Minimum Temperature (°C)	8-16
Maximum Temperature (°C)	20-28
Precipitation (mm)	753-1000

Reclassification: The range of selected criteria (i.e. elevation, aspect, slope, max. temperature, min. temperature and precipitation) that were defined on the basis of empirical data was reclassified into 4 class. The classes or categories represent number 1 to 4, where 1 represents unsuitable area, and categories 2, 3, and 4 represents least suitable, moderately suitable and highly suitable area for olive plantation, respectively. The categorization of the parameters was based on number of occurrence of tree in each of the range of values of Table-2.

For example, in altitude parameters, the number of wild olive stands are high in the range of 1060m to 1700m, so this range of altitude is reclassified into the value of 4 which indicates that this zone is highly suitable for olive plantation. While above 2500m there was not presence point of any olive stand so, this zone was reclassified into category 1, which denoted that the area was unsuitable for olive plantation. Similar logic was applied to remaining all of the parameters and reclassified into four classes, which are shown in Table-3.

In Table-3 values are classified into 4 classes according to the number of occurrence of tree in the certain ranges of values. For example, the rank 1 was given to those values where number of tree were less than or equal to 10 or are completely absent, rank 2 was given to those ranges of value where the number of recorded tree were less or equal to 200. Similarly, rank 3 was given to those ranges of value where numbers of trees are 200-1000 and rank 4 was assigned to those ranges of values where occurrences of trees were greater than 1000. After reclassification of values, the criteria maps was also generated by using reclassify tool of Spatial Analyst Tool in ArcGIS 10 (Figure-3).

Assigning weightage: After reclassification of each of the parameters, the next important step during the multi-criteria analysis is to assign a weightage percent to each of the parameters according to their importance[11]. Each of the variables has their own importance and contribution that influence the growth of olive. However, it is hard task to judge the importance of variables by ourselves. One cannot assign the weight to variables arbitrarily as it is the most sensitive task of decision making in Multi-criteria analysis (MCA) that can bring the significant changes in result. For determining the appropriate weightage percentage to each of variables, AHP (Analytical Hierarchy process) developed by Thomas L. Satty in 1970s was applied. AHP is a measurement theory that is used to compare the parameters pair wisely to derive priority scale based on expert's judgments[12]. It is also based on mathematics and psychology for the pair wise comparison with a scale of 1-9. In this research, few experts in the field of ecology and focal species (*O.cuspidata*) were interviewed according to standard AHP questionnaire and asked to estimate the importance of the selected parameters for suitable site selection of olive. According to their opinions, each of the parameters were ranked from scale 1-9 and prepared a pairwise matrix table (Table-4).

Table-3: Reclassification of values of six different parameters.

Parameters	Reclassified values			
	1 (Unsuitable)	2 (Least suitable)	3 (Moderately suitable)	4 (Highly Suitable)
Altitude (meters)	>2500 <700	700-900 2150-2500	950-1060 1700-2150	1060-1700
Aspect (degree)	-1 (Flat)	0-67.5 (North)	67.5-112.5 (East)	112.5-360 (SE, W, NW, N)
Slope (degree)	0-2 > 51	45-51	2-10 40-45	10-40
Max. temperature (°C)	<16	26-28	16-20	20-26
Min. temperature (°C)	<7 16-18	7-10	14-16	10-14
Precipitation (mm)	>1000 <753	975-1000	753-890	890-975

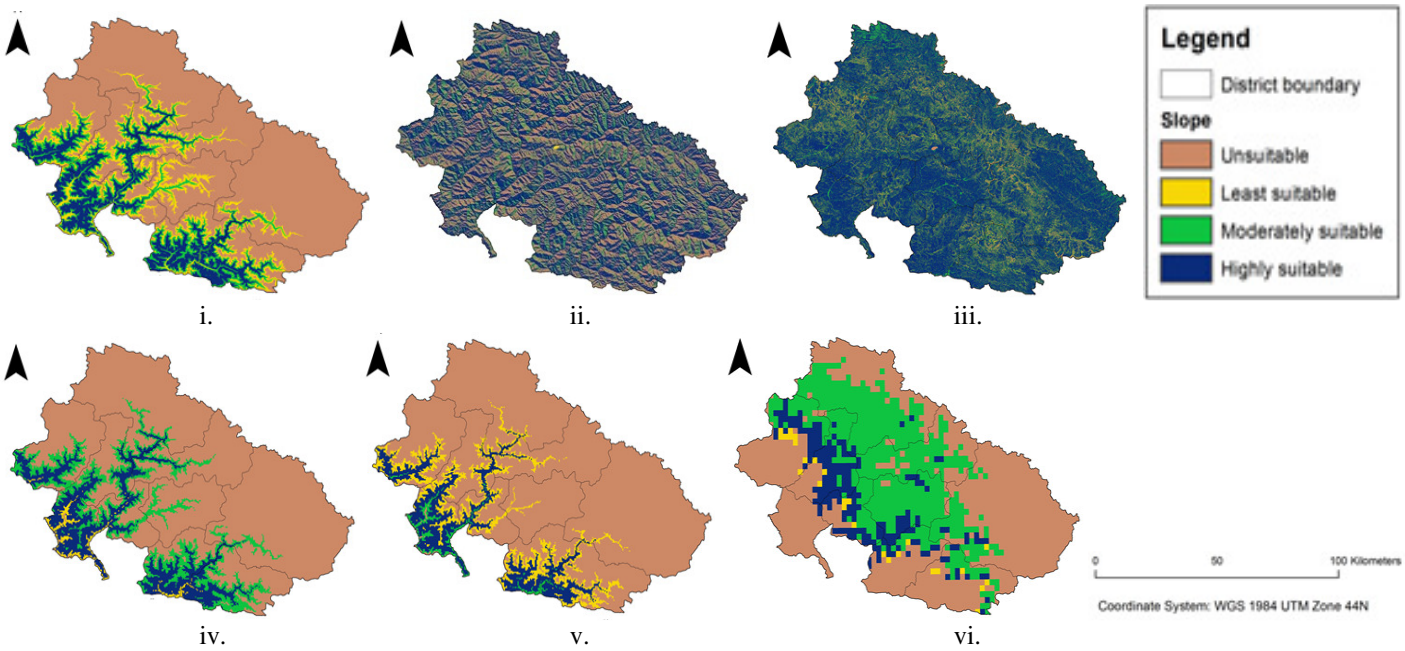

Figure-3: Reclassification map of all six parameters: i. altitude, ii. aspect, iii. slope, iv. Max. temperature, v. Min. temperature, vi. annual precipitation.

Table-4: Weighted scheme during AHP in pairwise matrix.

Parameters	Altitude	Aspect	Slope	Maximum Temperature	Minimum Temperature	Precipitation
Altitude	1	5	1	1	1	1
Aspect	0.2	1	1	0.33	0.33	0.33
Slope	1	1	1	1	1	1
Maximum Temperature	1	3	1	1	1	0.33
Minimum Temperature	1	3	1	1	1	0.33
Precipitation	1	3	1	3	3	1

Table-4 is one of the important steps of the AHP that was generated from the opinion of experts who were interviewed and asked to rank the parameter from scale 1 to 9 according to their importance. It finally helped to determine the weightage percentage for each of the selected parameters as shown on Table-5.

Table-5: Weightage % of each parameters computed from AHP.

Parameters	Computed Weightage %	Parameters	Computed Weightage %
Altitude	20	Maximum Temperature	15
Aspect	8	Minimum Temperature	15
Slope	15	Precipitation	27

Among the six parameters, the highest weightage was given to precipitation and altitude. According to interviewed experts, altitude and precipitation were most crucial factor for the suitable site selection of olive. For instance, if all other parameters are suitable and altitude is too high, then in that case the site would be considered as very unsuitable. There was limitation in altitude for the distribution of olive. Precipitation is very sensitive factor for the olive tree, which should be neither too low nor too high. In the suitable altitude also, if the precipitation is not in equilibrium condition, then olive cannot flourish well. Similarly, Aspect was weighted as low compared to other parameters because of the ability of the olive plant to grow in any direction of slope (Aspect) either handsomely or scantily. While the remaining three parameters viz. slope, Minimum and Maximum temperatures were weighted as intermediately because of their moderate importance for the suitable site selection of olive.

Multi-Criteria Analysis (MCA): Multi-criteria analysis that is also called as Multi-criteria evaluation (MCE) is popular methods applied to a wide range of natural resource management for decision making[13]. This method helps individual or groups for integrating as a final evaluation by taking explicit account of multiple criteria. It supports a logical and well-structured decision-making process. There are various ways to conduct Multi-criteria analysis, among which 'Weighted Overlay' is widely used tool to solve multi-criteria problems like suitability modeling[14]. Weighted Overlay applies a common measurement scale of values indifferent inputs for creating an assimilated analysis. By the help of weighted overlay tool available on Overlay Toolset of Spatial Analyst Tools in ArcGIS 10, we performed the multiple criteria analysis for suitable site selection for olive plantation. Various steps was followed during the weighted overlay operation. First, selection of an evaluation scale of 1 to 4 by 1was done because our input raster were already reclassified to a common measurement scale of 1-4 (unsuitable 1 to most suitable 4). It is always important to select an evaluation scale that matches the scale used while reclassifying. In second steps, we added the raster data of six reclassified parameters map. Thirdly, the cell values for each input raster in the analysis were assigned from the evaluation scale. This makes it possible to perform arithmetic operations that originally held dissimilar types of values. We can change the default values assigned to each cell according to importance or suitability. In our case we changed the cell of altitude parameter having value 1 (unsuitable) to restricted value. In fourth steps, based on the importance of parameters, each of them were weighted or assigned a influence percentage. This is one of the important steps of MCA in weighted overlay. The value from AHP (Table-5) determined the weightage percentage for each of the parameters. Then, finally, the Weighted Overlay tool was run.

Suitable site: The suitable sites for plantation of olive tree in 10 districts of Northwestern Nepal was identified by the help of GIS and MCA techniques. Land suitability mapping and analysis is one of the most important utilities of GIS that are used for different kinds of geographic planning and management[15]. Similarly, multi-criteria analysis combined with GIS is focus on selection of land to meet a particular objective based on a various attributes that is possess by the selected areas[15]. The suitability map was classified into 4 classes (Unsuitable; Least suitable; Moderately suitable; Highly suitable). Unsuitable areas are those areas where none of the selected parameters were suitable and it is also an area where the altitudes above the 2500m are restricted. This area occupied 2567282.58ha. Similarly, areas occupied by least suitable, moderately suitable and highly suitable were 232097.22ha, 553131.18ha and 30165.75ha respectively.

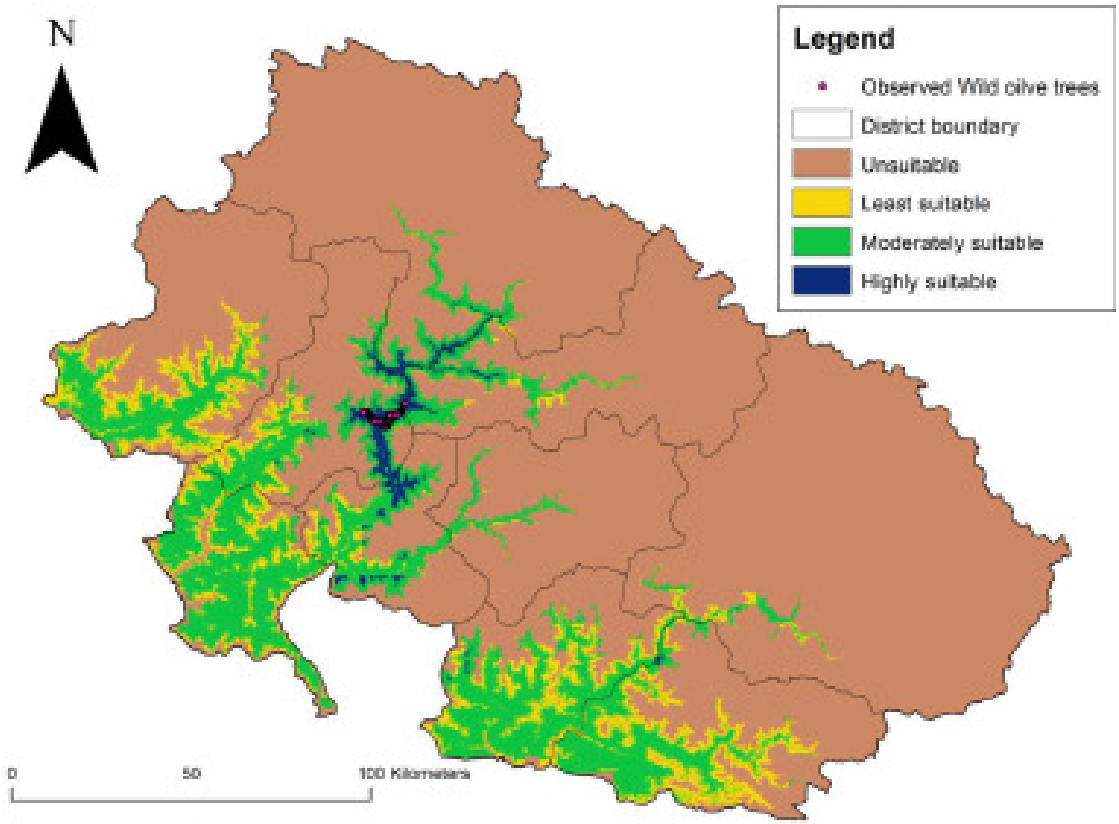

Figure-4: Suitable site selection for plantation of olive in ten mountainous districts of North-Western Nepal by MCA techniques based on criteria determination from observed data of existing wild olive trees.

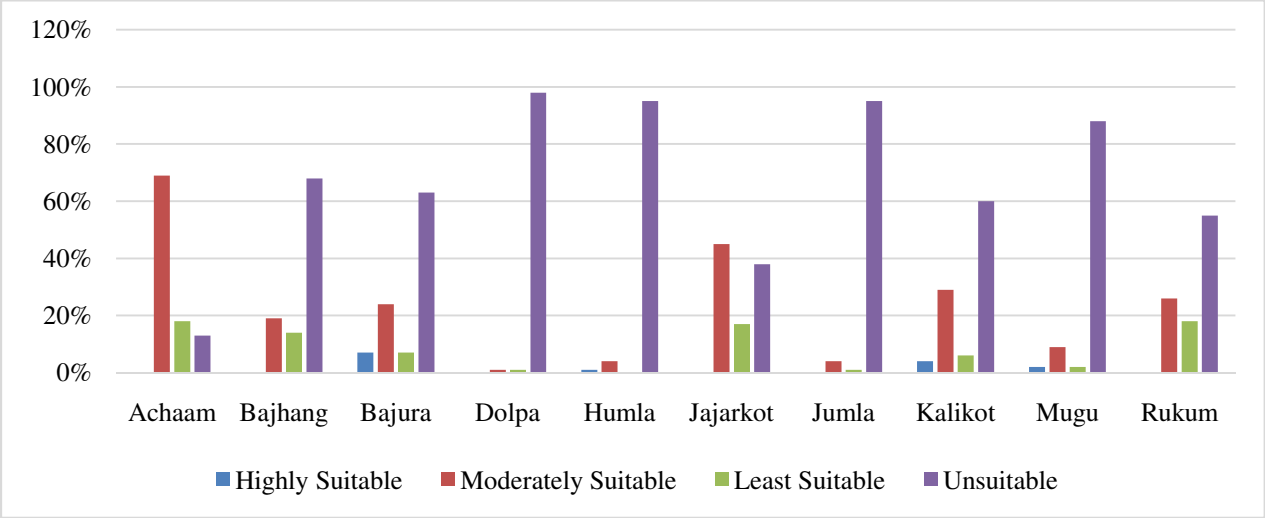

Figure-5: Coverage of suitability zones in ten mountainous district.

Conclusion

In this research, we focused on to select the suitable site for olive plantation on Northwestern mountainous district of Nepal by applying the multi-criteria analysis along with GIS. In MCA, the foremost part is to characterize a criteria for the particular species to which the suitable site selection is being conducted. Criteria and its ranges were determined from the empirical data, that is a observed and recorded point location of already existing olive trees. The final map revealed that about 1.02% (30165.75 ha) are highly suitable, 15.52% (553131.18ha) were moderately suitable, 6.25% (232097.22ha) were least suitable and 77.20% (2567282.58ha) were unsuitable of total study area. Among 10 districts, Bajura, Kalikot, Mugu and Humla are potential for highly suitable zone for plantation of olive. About 70% of area in Achaam is potential zone for moderately suitable site for olive plantation following with 45%, 29%, 26%, and 19% in Jajarkot, Kalikot, Rukum and Bajhang respectively. More than 90% of area seemed to be unsuitable for olive plantation in Dolpa, Humla, and Jumla district. This research established that GIS based multi-criteria overlay analysis of the six parameters will be of huge importance in selecting the suitable site for olive plantation. In this research, we determined the range of criteria merely from empirical data but it is suggested to determine the ranges of criteria from literature review too, and combined both of them.

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