Road Accessibility to Potential Suitability Areas of Fruit Commodity in Hilly Areas of Nepal

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Abstract

The temperate mid-hills areas of Nepal are suited to a production of a range of fruit commodities, but suitable production areas are dependent on local climatic, soils and infrastructure such as roads and electricity supply. A rapid crop suitability analysis for the example of apple production was conducted, exploiting a set of soil, topographic and climatic parameters to indicate potential production areas. As a critical parameter to commercial production, road accessibility between farm and market was assessed using the latest available road network data (Strategic Road Network of Nepal, SRN), using the criteria of land within 1500 m of a road. The study was undertaken using multi-criteria decision analysis (MCDA) and Geospatial Analysis in Google Earth Engine (GEE) and ArcGIS environments. Only 6% of agriculture area of Nepal is suitable for apple production, of which 38% has limited road accessibility. The output is intended to assist policy and decision makers and horticulture development investors, with a process developed that could be implemented for other crops. Feedback is sought on the choice of factors and of the usability of the system.

Keywords: crop suitability, road accessibility, multi-criteria decision analysis, geospatial analysis, google earth engine

Introduction

Local apple production in Nepal occurred in Kali Gandaki valley before 1960 but first commercial (sent to Kathmandu) apple farming in Nepal started at Marpha, Mustang with the establishment of the horticultural farm in 1966, with introduction and new varieties of apples and production methods in 1966 (Subedi et al., 2018). Apple is now one of the important temperate fruits is grown in Nepal (www.fao.org/nepal/fao-inNepal) in terms of area, production and value (Ghimire et al., 2018). Jumla in Karnali and Mustang in Gandaki are now two major production areas. Acharya et al. (2018) reported apple production declined from 33,336 Mt in 2005 to 19,850 Mt in 2018, although area of apple cultivation increased by 46.24% from 8,216 ha in 2005 to 12,015 ha in 2016.

The agronomic potential to increase apple production in Nepal can be assessed through a land suitability analysis. The term “land” should not be used instead of “soil” as soil refers to only one aspect of land which can cover a particular type of vegetation, hydrological feature, physical infrastructures and so on. A land unit is defined in terms of a set of attributes that renders the land suitable for a particular purpose, or land use. Example land use type include residential, forest, or apple production. A combination of both land units and land use type defines a land use system. Agriculture land suitability or crop suitability is determined by an overlap of crop requirements meeting with the soil or land characteristics. FAO (1976) defines “suitability” is a measure of how well the qualities of a land unit match with the requirements of a particular form of land use.

Numerous methods can be found in various literatures and studies for crop suitability analysis, for example, analytical hierarchy process (AHP) (Akıncı et al., 2013), fuzzy logic technique (Prakash, 2003), multi-criteria decision making/analysis (Das et al., 2014) and genetic algorithm and artificial intelligence (Malczewski, 2004) with combination of Geographic Information System (GIS). Singha et al. (2016) suggested integration of RS and GIS, fuzzy-logic and application of multi-criteria evaluation using AHP to build an extensive database for decision makers for crop suitability analysis and better agricultural production. Most researchers recommend use of multi-criteria decision analysis (MCDA) with GIS for crop suitability analysis.

Road accessibility is an important aspect for commercial fruit production. It is defined as a spatial proximity of a road to the intended area. Accessibility is measured in various ways, for example, closest distance, density of road networks, minimal commute time (Zhang et al., 2011). Most frequently, Euclidean distance is used as a measure of spatial proximity between two points and distance threshold is employed on accessibility measures (Gutiérrez et al., 2008; Halden et al., 2000).

The current study presents a GIS-based rapid crop suitability for apple fruit tree along with the road accessibility to those areas in Nepal.

Materials and Methods

Study area

This study was conducted for whole Nepal which extends from the West (80° 4' E) to East (88° 12' E) and South (26° 22'N) to North (30° 27'N). Nepal is predominantly representing hills (41.68%) and mountains (35.21%), with elevations ranging from 60 m in the South to 8848.56m at Mount Everest in the North (CBS, 2017). According to Constitution of Nepal 2015 ("Constitution of Nepal," 2015), Nepal constitutes with 7 provinces, 77 districts and 753 municipalities (urban and rural) in new federal context of Nepal. Out of 77 districts, *21 districts in terai*, *40 districts in hill* and *16 districts in the mountain region*.

Crop requirements

In this present study, crop suitability analysis was performed for apple fruit tree. Nine different crop parameters (Table 3) were used for conducting crop suitability analysis and the parameters are (a) ***soil***: *soil texture, soil pH, soil depth, (b)* ***topographic***: *elevation, slope, aspect and (c)* ***climatic****: sunshine hour, temperature and precipitation*).

Table 3. Apple crop requirements

Parameter	Value*
annual mean temperature (°C)	21 to 24 (min to max: -7 to 30)
soil texture	loam-silt loam-loamy sand-sandy loam
soil pH	5.5 to 6.5
soil depth (m)	1.5 to 2
elevation (m)	1800 to 3800
sunshine (hr.)	5 to 6
slope (%)	3 to 35
aspect (°)	South-west (225±22.5)
annual rainfall (mm)	250 to 1,000

**Apple Farming Technology (Nepali Version) MoAD/GoN and AFACI; 2073 BS and Commercial Apple Farming (Nepali Version), NCFD, FY 2076/77*

Data sources

All of the crop suitability parameters are spatial in nature. Corresponding datasets are becoming freely available locally (DoS, 2021) and globally (Gorelick, 2013; Hengl et al., 2017; Hijmans et al., 2015). Ten geospatial datasets were used for crop suitability analysis for the identified crop parameters, broadly classified into three categories: (a) soil data, (b) topographic data and (c) climatic data. Soil data (texture, pH and depth) was used from SoilGrids (Hengl et al., 2017). For topographic data, a 90-meter spatial resolution of elevation data was used from SRTM (Van Zyl, 2001) from which slope and aspect were derived and sunshine hour was calculated. Climatic data, mainly temperature and precipitation data were used form WorldClim V1 with spatial resolution of 30 arc second (Hijmans et al., 2015). To delineate the agriculture area, landcover data of 30-meter spatial resolution was used from ICIMOD (Uddin et al., 2015). Beside these datasets, administrative boundary (municipality, province and country) from Survey Department (DoS, 2021) and road networks data from Department of Roads (DoR, 2021) were used for the analysis of crop suitability and road accessibility. The road network consisted of three major payment types: (a) earthen (not functional in wet weather), (b) gravel and c) pitched. The list of all these datasets including their resolution, source and use has been presented in Table 4.

Data preparation

The geospatial datasets acquired were from different sources with distinct spatial resolutions as can be seen from Table 4. To conduct crop suitability analysis, firstly, all the parametric datasets were brought into common coordinates system, spatial extent and spatial scale so that spatial overlay analysis (pixel to pixel overlay analysis) can be performed. All the datasets were processed to limit within spatial extent of Nepal with spatial resolution of 100 meters. Secondly, Boolean criterion rasters are prepared based on the suitable values range of each of the parameters (Table 3). Finally, agricultural area was extracted from landcover data which had been used to limit the crop suitability map within the agricultural land. However, it was found that some agriculture areas in Manang and Mustang districts were not found in the landcover data. Hence, those areas were digitized in Google Earth and updated the agriculture land accordingly.

Table 4. Datasets used for crop suitability analysis and mapping

Dataset	Resolution	Source	use
elevation	90 m	SRTM	deriving topography
slope	100 m	derived from SRTM	
aspect	100 m	derived from SRTM	
sunshine hour	100 m	derived from SRTM	
temperature	30 s	WorldClim V1*	tmin and tmax
precipitation	30 s	WorldClim V1	prec
soil texture	250 m	SoilGrids #	
soil pH	250 m	SoilGrids	
soil depth	250 m	SoilGrids	up to 2 meters
landcover	30 m	ICIMOD **	agriculture area
road network	centre line	DoR (2021)	road accessibility

@ https://srtm.csi.cgiar.org * ***https://doi.org/10.1002/joc.1276*** # *https://soilgrids.org/* ** *https://rds.icimod.org/*

Crop suitability analysis

Numerous methods can be found in various literatures for performing crop suitability analysis (Baniya, 2008; Das et al., 2014; Joshua et al., 2013; Mustafa et al., 2011). However, for a rapid crop suitability analysis for whole Nepal, Multi-Criteria Decision Analysis (MCDA) was exploited in spatial overlay analysis (a pixel to pixel overlay analysis) for suitability analysis. In a MCDA, for a given crop, all criteria are checked at pixel level and pixel by pixel across all the criterion rasters. If all the criteria of the defined parameters are met for a given pixel, then the pixel is marked as the suitable for the selected crop, otherwise it is flagged as not suitable. The crop suitability analysis was performed in Google Earth Engine (GEE) platform. The analysis was done with major three steps; a) defining the crop parameters, b) preparation of spatial datasets including Boolean criterion rasters, c) pixel-based MDCA. Overall methodology of crop suitability analysis has been presented in Figure 6. The crop suitability maps obtained covers whole area of Nepal regardless of landcover type. The resulting crop suitability map was masked by refined agriculture area of 2010 (Uddin et al., 2015) with spatial resolution of 30 meters and covering 29.50% area of the whole Nepal (147,516 km^2).

Road accessibility analysis

A Euclidian distance of 1500 m to the strategic road network of Nepal (DoR, 2021) was accepted as potential suitable for apple production. This distance was based on a walking speed of 3 km/hr. for 30 minutes.

Suitability vs accessibility

Both maps (suitability and accessibility) are overlaid to observe which suitable areas area accessible or not. A spatial overlay analysis was conducted to identify potential suitable areas with respect to 30 minutes walking distance from SRN.

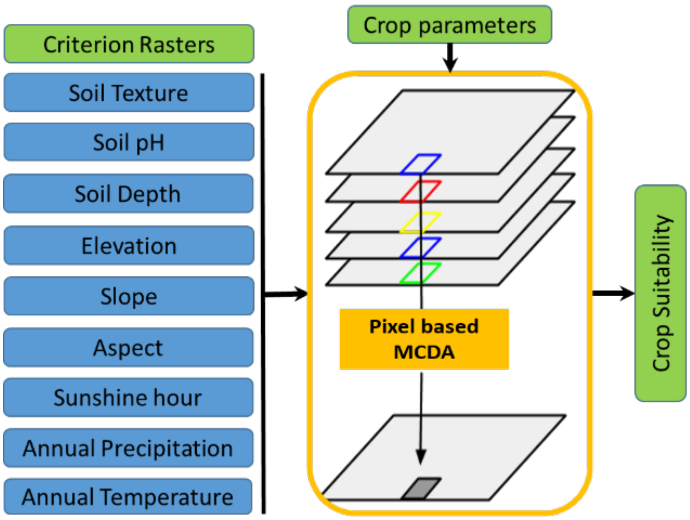

Figure 6. *Multi-Criteria Decision Analysis (MCDA) for Crop Suitability Analysis*

Results

Crop suitability

Only 6% of agriculture area of Nepal is suitable for apple production (Table 5), falling predominately in three states: (a) Karnali. (b) Sudur Pashchim and (c) Gandaki. Jumla district has the highest apple suitability area compared to other districts.

Table 5. Apple crop suitability and its road accessibility

Province	District	Agriculture (ha)	Suitability (ha)		Accessibility (%)
Koshi	Solukhumbu	26,824	142	163	-
	Taplejung	37,132	21		-
Gandaki	Baglung	64,477	861	4,691	6%
	Gorkha	75,013	553		-
	Kaski	49,532	81		-
	Lamjung	38,682	30		-
	Manang	918	539		9%
	Mustang	3,036	1,785		70%
	Myagdi	29,083	630		-
	Parbat	33,686	212		-
Karnali	Dailekh	82,141	477	51,637	17%
	Dolpa	12,021	2,201		34%
	Humla	27,722	11,839		33%
	Jajarkot	67,106	2,709		8%
	Jumla	19,884	13,315		67%
	Kalikot	45,715	9,607		34%
	Mugu	33,112	11,416		42%
	Rukum_w	39,121	73		-
Lumbini	Rolpa	80,904	890	1,095	4%
	Rukum_e	20,537	205		29%
Sudur Pashchim	Achham	80,624	137	7,928	-
	Bajhang	71,665	340		-
	Bajura	55,982	7,444		18%
	Darchula	42,044	7		86%
Total		1,036,961	65,514		38%

Road accessibility

62% of apple potential suitability areas (Table 5) were not within 1500 m of a road. Potential growing areas in Mustang and Jumla districts are highly accessible compared to other districts, with land in Rolpa district being least accessible (Figure 6).

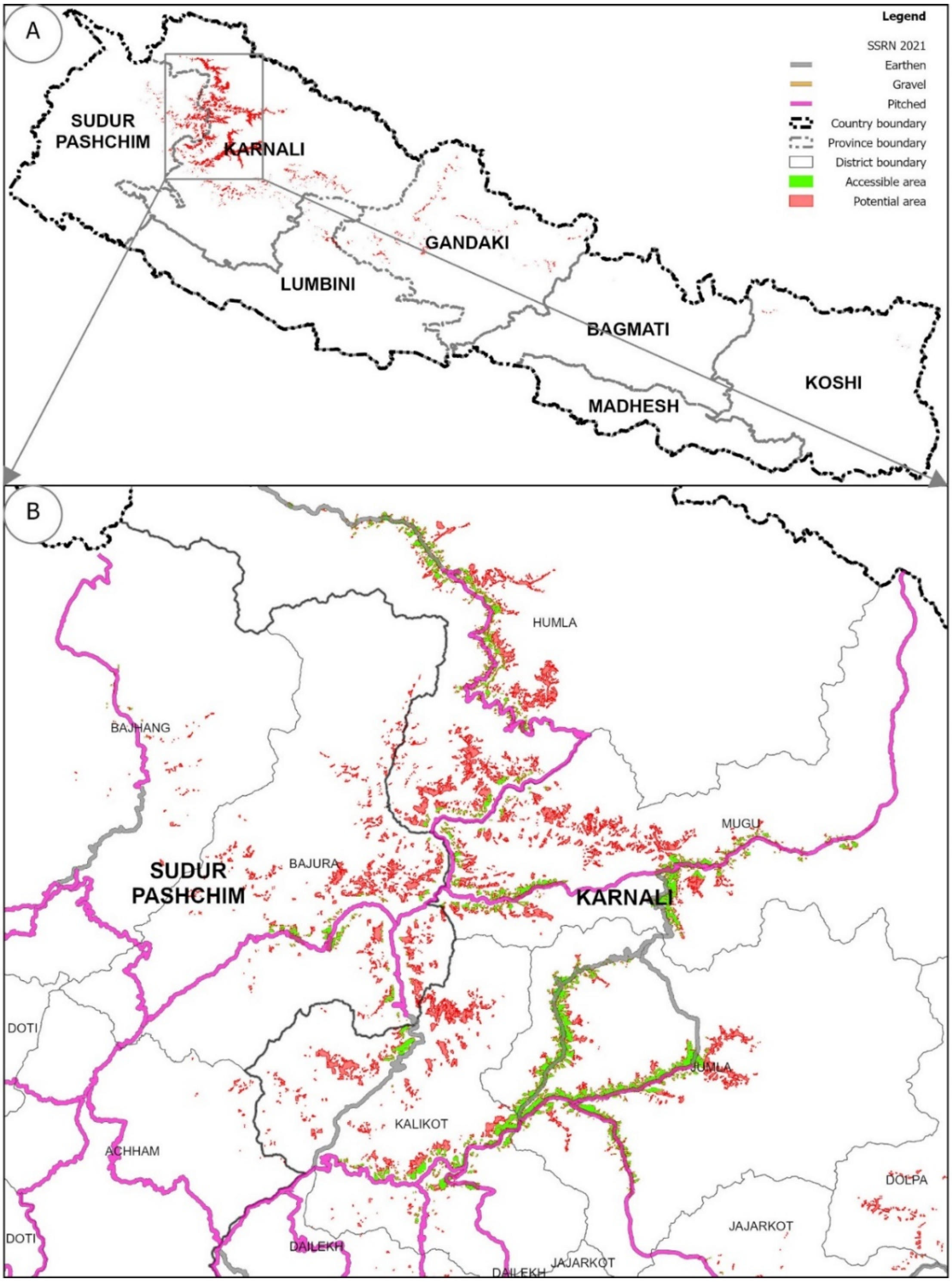

Figure 7. *Maps (A and B) showing suitable areas for apple production and strategic road network: (a) potentially suitable areas for apple in Nepal and (b) suitable areas with (green) and without (red) road access defined, zoomed from a rectangle in map A.*

Discussion

Crop parameters

The crop parameters: (a) ***soil***: *soil texture, soil pH, soil depth, (b)* ***topographic***: *elevation, slope, aspect and (c)* ***climatic****: sunshine hour, temperature and precipitation*) for each crop and their values ranges were collected from various literatures and sources. However, in this study, a common or generalized value range of each crop parameters were used. In consequence, the result achieved for the delineated crop suitability maps was generalized for all ecological zones i.e., for whole Nepal. Thus, the crop suitable maps can be used for identifying the pocket areas of specific crop at different geographic settings, for example, municipal, district and province level.

Data sources

In this study, geospatial datasets were collated from different sources. The spatial resolution of each dataset differs from each other. All the datasets were brought into a common spatial extent of Nepal with a spatial resolution of 100 meters i.e., one hectare pixel size. The spatial resolution ranges from 30 meters of landcover to 1000 meters of WorldClim (temperature and precipitation) data (ref. Table 4). While resampling of all datasets to 100 meters, landcover and elevation (90 m) were scaled down and WorldClim and Soil (250 m) were scaled up. In doing so, pixel values might have compromised in spatial interpolation which can reflect the accuracy of pixel values at 100 meters.

Validity of results

Since spatial resolution of 100 meters for all the datasets was used under this study, ground sampling distance (GSD) represents 100x100 square meters pixel or a one-hectare pixel in the ground. So less than one-hectare pixel agricultural area was not mapped as the suitable area in the map though landcover of 30 meters spatial resolution had been used. At the same time, these datasets were of different years, for example, agriculture area used from landcover was of 2010 and which might not be accurate for 2021, similarly for topographic and climatic data. For accurate mapping and generic practice, datasets of the targeted year should be used for implementation.

On the other hand, temperature and precipitation shifts south to north of Nepal are observed due to climate changes in recent days and likely to occur more in near future. Because of this, suitable crops are becoming not suitable and vice versa in some part of Nepal. In consequence, the crop parameters might have to be revisited with consideration of this climate. Therefore, it is recommended that crop suitability map shall be valid for certain period of time and needs further updates for the future in this climate changing context.

For road accessibility analysis, only SRN was employed regardless of condition, type and mode of transportation. There could be other rural road networks besides the SRN. Thus, result obtained for road accessibility could be used as an indicator that there is still poor road accessibility in hilly areas of Nepal, while there is highly potential area for fruit productions.

Conclusions

In present climate changing context, conducting crop suitability analysis is becoming very important step for agriculture development and future planning. In view of this, crop suitability analysis was conducted for apple tree in order to help decision makers, agriculture development planners and determine how proper or appropriate it is for a particular use of the land in a particular location to see how much area is suitable and accessible. Under this study, three main crop requirement parameters: (a) ***soil***: *soil texture, soil pH, soil depth, (b)* ***topographic***: *elevation, slope, aspect and (c)* ***climatic****: sunshine hour, temperature and precipitation*) have been used. The study has been accomplished with Multi-Criteria Decision Analysis (MCDA) in Google Earth Platform and ArcGIS environments. The main objective of this study was to demonstrate the potential suitable area along with road accessibility for commercial apple production. Apple is suitable only for 6% of agricultural area, mostly Karnali, Sudur Paschim and Gandaki states of Nepal with 38% road accessibility, which entails there is a hindrance in transportation. Jumla is highly potential with nearest market in Surkhet and Nepalgunj compared to popular Mustang (though with low suitability) in apple production with established infrastructure and researches. From this result, it is recommended to consider road accessibility analysis or assessment for adequacy of road infrastructure for commercial apple production in hilly areas of Nepal.

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