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A GEOGRAPHICAL INFORMATION SYSTEM-BASED MULTI-CRITERIA DECISION ANALYSIS OF POTATO CULTIVATION LAND SUITABILITY IN WELIMADA DIVISIONAL SECRETARIAT, SRI LANKA

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ABSTRACT: The purpose of the research was to apply the GIS approach to find land suitability for potato cultivation in Welimada Divisional Secretariat (DS). The task applied GIS-MCDA and Analytical Hierarchy Process (AHP). For the suitability classification, soil, physical, and socioeconomic factors were considered. While ph and salinity were sub-criteria under the soil elevation, slope, and water availability were sub-criteria under physical factors. Road and market proximity, land use were considered as sub-criteria under socio-economic factors. Suitability classification was performed through several steps including structuring, standardizing, calculating criteria weights, assign weights for criteria, and suitability assessment. As result, 41% of the total land was moderately suitable for potato cultivation and 23% of the area was highly suitable. Only 4% of the land was classified as least suitable and 14%, 15% of the land classified as low suitable and marginal suitable area respectively. These results provide knowledge about the interaction and relationship of the criteria. So, this research can be utilized as a model for fruitful potato cultivation practices as well as, it can be taken as a guide for future land use assessment in potato growing areas, especially in Sri Lanka.

KEYWORDS: Analytical Hierarchy Process, GIS, Land suitability, Multi-criteria decision analysis, Potato

INTRODUCTION

Solanum tuberosum, known as potatoes is a globally important crop-producing high yield of nutritionally valuable food in the form of tubers (Camire *et al*., 2009). Cultivation of potatoes has spread from the Andes of South America, where these originated to 160 countries around the world (Asfaw and Asfaw, 2017). Consumption of processed products was increased than fresh potatoes in recent decades (Camire *et al*., 2009). As potatoes become an integral part of the diets of an increasing number of humans, small differences in potato nutritional composition will have major impacts on the population's health. Potato Production in Sri Lanka has increased since the import of large bulks was banned in 1967 (Premasiri, 2006). Production is now successfully established in four districts viz Nuwara Eliya, Badulla, Jaffna, and Puttalam (Senanayake and Rathnayaka, 2015). The average yield is 16 t/ha[1] with proper cultivation practices and conditions. Potato has been one of the economically valuable crops grown in the hill areas of Sri Lanka and among those Badulla district represents 72% of the total extent of cultivation land. In Welimada Divisional Secretariat Division there are two growing seasons: one in November-December (*Maha*) and the other in June-July (*Yala*) in the paddy fields after the rice harvest(Premasiri, 2006). In Badulla district, potato is been cultivated at an altitude of 550-914m and has a mean monthly rainfall of approximately 144mm (1729mm annually). The large bulk of the potato harvest reaches the market at *Yala* season. Harvest is rapidly taking place in Welimada, Keppetipola, Boralanda,

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Bogahakumbura, and Uva paranagama (Senanayake and Rathnayaka, 2015).

In potato cultivation, the biophysical, socio-economic, and environmental parameters are very important for the yield performance level. The use of Geographic information system (GlS) and remote sensing technologies for modeling crop cultivation in Sri Lanka is a fairly complicated exercise since the parameters which affect potato production very often do not show linear relations (Suthakar, 2015).

Land suitability classification for agriculture is a very important piece of information in agriculture development and future planning (Elsheikh *et al*., 2015). Land suitability assessment for an agricultural purpose has been conducted to help decision-makers, agriculture development planners to determine how proper or appropriate it is for a particular use of the land in a particular location that is more suitable for certain agriculture use (Pooran *et al*., 2018). Main objective of the suitability analysis is to find out places that are most suitable for certain agricultural use (Mustak *et al*., 2015). Land suitability tools have been extensively applied to identify better management practices in agricultural areas (Halder, 2013). These tools evaluate the suitability of agricultural land to a specific practice or land use. Soil and landscape properties are essential in this type of evaluation, a fact that makes especially interesting the coupling of this type of model with Geographic Information Systems (GIS). MCDA using AHP could provide a superior database and guide map for decision-makers considering cropland substitution to achieve better agricultural production (Malczewski, 2004). GIS has contributed to the speed and efficiency of the overall planning process in agricultural land use suitability because quick and efficient access to a large amount of information was enabled by it, exhibiting relationships and patterns that are useful to combine with soil survey information for monitoring the Potato cultivation suitability analysis in Welimada Divisional Secretariat Division.

Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (Sathish and Niranjana, 2009). Land suitability analysis has to be carried out in such a way that local needs and conditions are reflected well in the final decisions (Mehrjardi, 2020). Hence, the study aimed to find the land suitability for potatoes in the study areas using the Multi-Criteria Decision Analysis (MCDA) with Analytical Hierarchical Process (AHP). The research was carried out in Kalabululanda, Alawathugoda, Keppetipola, Bibiligamuwa, Erabadda, and Thennakoonwela *Grama Niladari* divisions of Welimada Divisional Secretariat Division.

MATERIALS AND METHODS

Study area

Welimada DSD, is situated in the Central Hills of Sri Lanka. The total land area of the Welimada DS division is 187 km^2. It consists 60 Grama Niladhari Divisions. Due to the difficulty of data collection, the study area was restricted to only 6 GN divisions as provided in **Table 1** and **Fig. 1**.

Potato is well adapted to the climate conditions of the region namely rainfall

Table 1. Selected Grama Niladari divisions and the extent

GN division	Land area (km^2)
Keppetipola	3.10
Bibiligamuwa	2.45
Erabadda	4.2
Alawathugoda	3.1
Kalubululanda	3.0
Thennakoonwela	2.1
Total land area	**17.00**

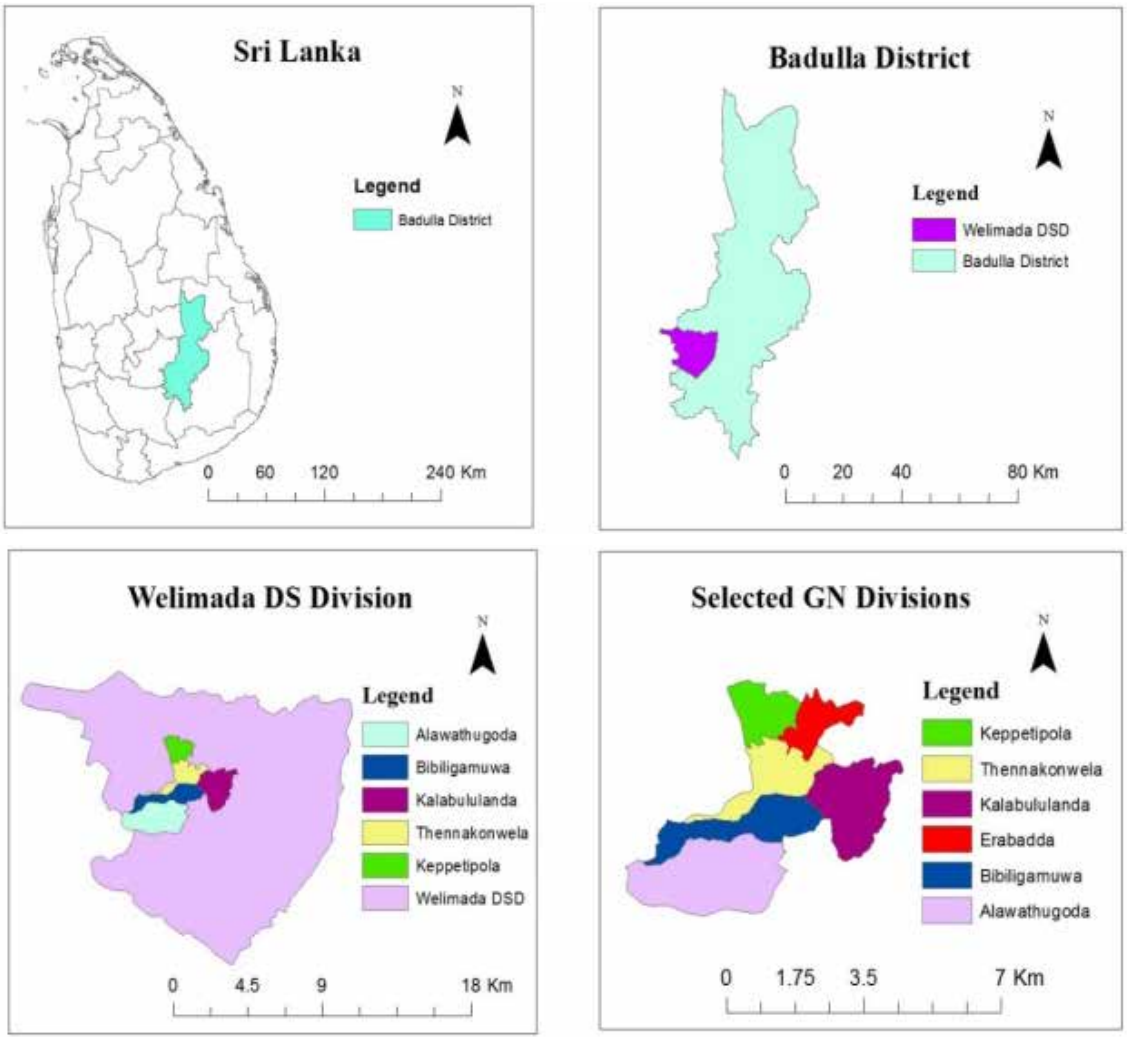

Fig 1. Location of the study area in Sri Lankan spatial context

pattern, temperature, soil condition, and humidity, which make ideal conditions for potato cultivation (Premasiri, 2006). The area receives an annual rainfall between 1,734 mm to 2,000 mm, mainly from the North-East monsoons. The maximum annual temperature is 27°C and the minimum annual temperature is 19°C. Average humidity is between 76-82% in the area and atmospheric pressure is about 1000 mbar (Premasiri, 2006). These climate variables also explain the reasons for high density of potato cultivation land and the relatively high number of farmers in Badulla district, particularly in Welimada. Therefore, the Welimada area was a suitable location for the study. In the study area, small landholding farmers grow potatoes mainly for commercial purposes (Premasiri, 2006).

General procedure for land suitability assessment

Structuring

Structuring refers to the identification of the main goal and sub-goals and the establishment of the criteria for evaluating the sub-goal and main goal. Evaluation of the potato land suitability was the main goal

in the study and identification of different land suitability classes was sub-goal. Since every crop has different requirements to meet a better harvest several criteria were taken into consideration in this hierarchy model as shown in **Fig 2**.

Eight sub-criteria were identified as being relevant to the land suitability evaluation of the selected crops including soil pH, soil salinity, road network, land use, market availability, elevation, slope, and water availability which significantly determine the potato cultivation in the study area.

Standardizing the criteria

All values need to be standardized to compare criteria with each other in the multi-criteria process that is transforming all parameters into the same scale of measurement. To perform standardization liner scale transformation (Malazewski, 2004) was used to measure on different units and different scales of measurements. Criterion standardization was performed using a raster reclassify spatial analysis tool in Arc map 10.5 to convert each sub-criterion into an equivalent measurement basis.

Criteria weighting for the potato land suitability

The pair-wise ratings were determined on a nine (9) degree was proposed by Satty (1990). A semi-structured questionnaire was designed to guide the experts to offer their opinion according to the hierarchical model constructed. Farmers who are living in the study area were not interviewed in this manner because of their weak knowledge to make pair-wise comparisons according to the 9 degree scales. Ten questionnaires were used

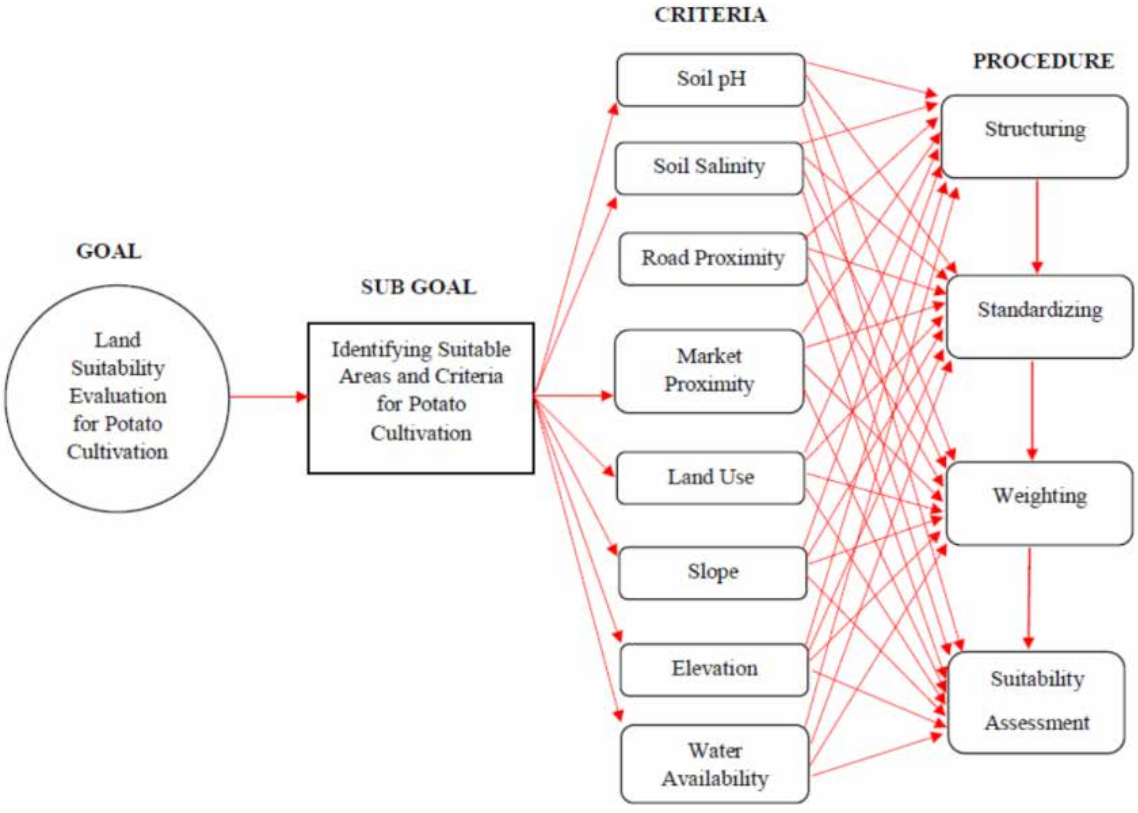

Fig 2. AHP procedure of the GIS-based Potato land suitability evaluation

section-wise for the study. A standardized eigenvector is extracted from each comparison matrix allowing assigning weights to main criteria and sub-criteria. The results of the AHP weight calculation are shown in **Table 2**.

Suitability assessment

The final step is to obtain the composite suitability map for potato cultivation. Weighted criteria are combined to produce a suitability map. This combination is carried out by a weighted linear combination (WLC) method. Consequently, the result is a continuous mapping of suitability to produce a composite suitability map. Through the above steps, suitability maps were classified into five classes as highly suitable, moderately suitable, marginally suitable, least suitable, and not suitable. With the aid of the Arc map 10.5 software (ESRI, USA) following spatial analysis was performed using the Arc model builder. Spatial techniques like euclidean distance (Buffering), clipping, vector to raster conversion, raster to vector conversion, raster reclassification, and weighted overlay were used through Arc map 10.5 as in **Fig 3**. Model builder is a tool for creating and mapping automated and self-documenting spatial models. It is provided as a common tool with Arc GIS, then it can be used for other models not requiring the spatial analysis functions. Model builder enables users to create process flow diagrams and scenarios to automate the modeling process. It is very significant for constructing and executing workflows. Under this research, Arc model builder was used to perform GIS-based spatial analysis.

Table 2. Final weights calculated by AHP

Code	Main Criteria	Weight	Sub Criteria	Weight
A	Soil Characteristics	0.4595	Soil pH	0.6946
			Soil Salinity	0.3032
B	Socio-economic Characteristics	0.3093	Road proximity	0.3327
			Land use	0.3523
			Market proximity	0.2961
C	Physical Characteristics	0.3148	Slope	0.3542
			Elevation	0.2024
			Water availability	0.5301

RESULTS AND DISCUSSION

Suitability levels for minor criteria

Salinity is an important criterion for cultivation practices. As per the soil sample test results obtained, values ranged between 0.0-0.25 (**Fig 4**). After reclassification, 0.0-0.16 value range was selected as a very high suitable area and >0.25> as a not suitable area for potato cultivation. In the reclassified suitability map for soil pH, five suitability classes were identified viz, not suitable, least suitable, moderately suitable, high suitable, and very high suitable. pH value range 5.0-5.4 was identified as very high suitable areas and 5.7-5.8 as the least suitable areas. In the reclassified road proximity map, four suitable classes were identified viz, least, moderate, high, and, very high suitable, and overall, the very high suitable was the most prominent class in the study area according to the road proximity. Land use was a major criterion that affects potato cultivation. In this study, homestead areas were identified as highly suitable for potato cultivation. The market proximity map indicated that the market centers were confined to the upper part of the study area. Reclassified slope map identified four classes as least, moderate, high, and very high suitable. Low slope areas were identified as suitable areas and the steep slope areas were identified as not suitable areas. In the elevation map, suitability was classified into four classes as least, moderately suitable, high suitable, and very high suitable. Low elevation areas were identified as very high and high suitable whereas the highest elevation areas as the least suitable areas. The majority of the study areas have water bodies. Therefore, it is

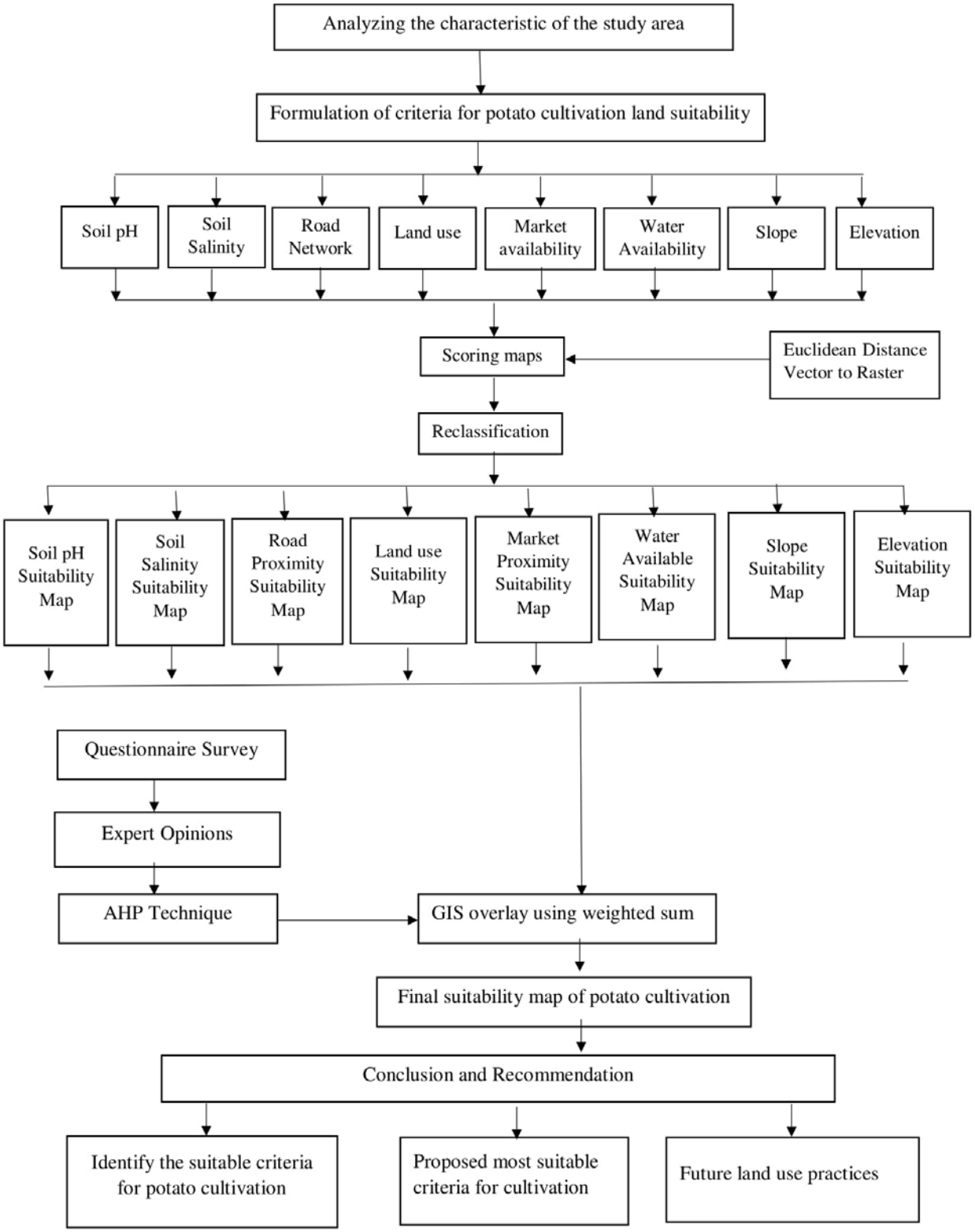

Fig 3. GIS spatial analysis procedure of the potato land suitability assessment

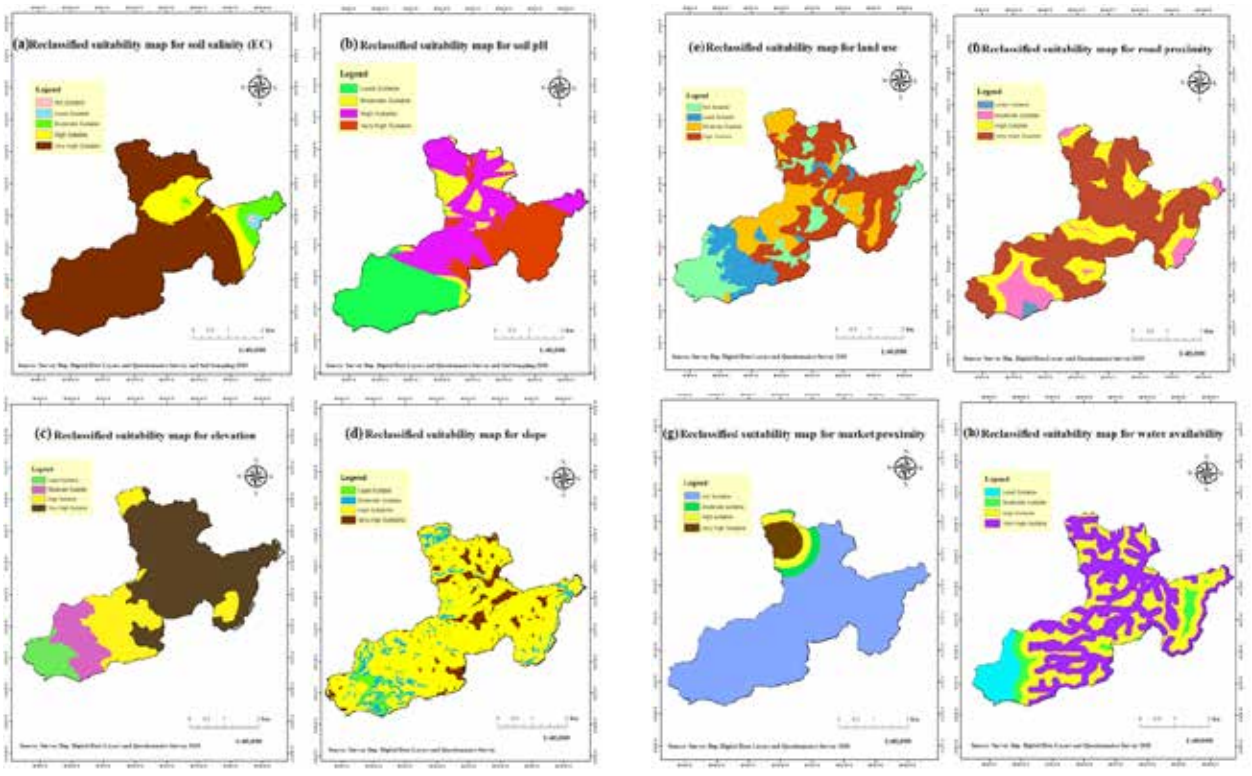

Fig 4. Potato land suitability for (a) Soil salinity,(b) Soil PH ,(c) Elevation,(d), Slope,(e) Land use,(f) Road proximity, (g) Market proximity, and (h) Water availability

possible to irrigate agricultural lands every time in the cultivation seasons. According to the reclassified water availability map, the majority of the study area was classified as very high suitable.

Suitability levels for major criteria

According to the final results obtained from the land suitability modeling through spatial analysis 6.04% (102.81 ha), and 11.13% (189.40 ha) land in the study area is highly suitable and low suitable respectively for potato cultivation under physical characteristics (**Fig 5** and **Table 3**). After overlying all socioeconomic criterion maps together it was indicated that 34.81% (592.99 ha), and 19.42% (330.29 ha) of the area are high and low suitable for potato cultivation.

Table 5. Potato cultivation land suitability on soil, physical, socioeconomic criteria, and overall suitability

Suitability class	Soil		Physical		Socio-economic		Overall	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Least Suitable	-	-	-	-	-	-	78.45	4.31
Low suitable	520.05	30.58 %	189.40	11.13	330.29	19.42	242.20	14.24
Marginally suitable	330.76	19.45 %	680.15	39.99	368.32	21.65	270.81	15.92
Moderately suitable	550.01	32.34 %	728.18	42.82	408.94	24.04	711.44	41.83
Highly suitable	299.72	17.62 %	102.81	6.04	592.99	34.81	402.64	23.83
Total	1700.54	100 %	1700.54	100	1700.54	100	1700.54	100

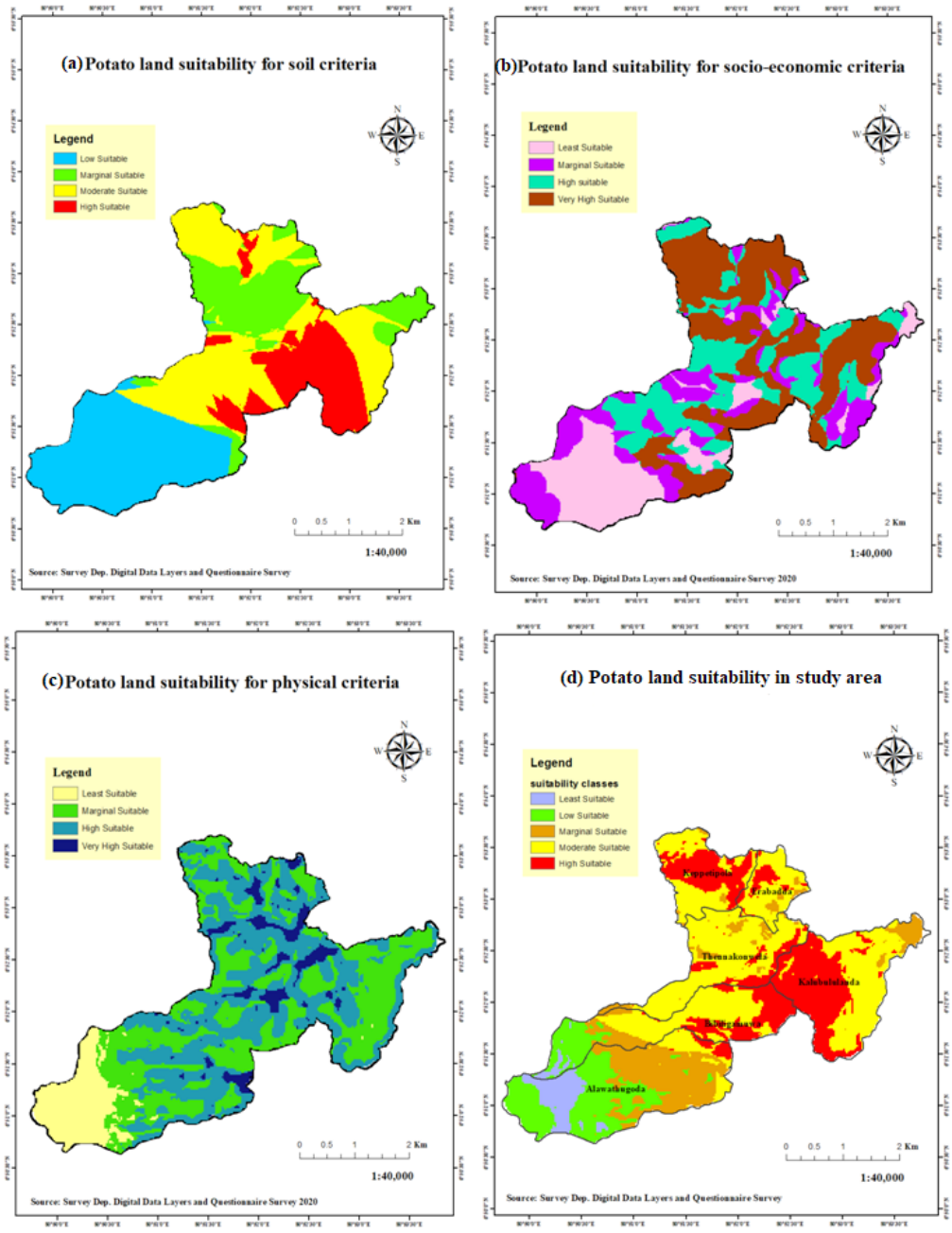

Fig 5. Potato Land suitability for (a) Soil criteria,(b) Socio -economic criteria,(c) Physical criteria, and (d) Overall potato land suitability

Under the soil characteristics 17.62% (299.72 ha), and 30.58% (520.05 ha) of the area were identified as high and low suitable for potato cultivation. After overly major criterion maps together it was revealed that 23.83 (402.64 ha) is highly suitable and 18.55% (320.65 ha) of the study area is low and least suitable for potato cultivation. Though minor criterion maps were identified some areas as not suitable for cultivation in any major criterion maps it was unable to detect any area in the not suitable category.

CONCLUSION

The potato Suitability map has come out through ranking and analysis which can be compared with the land-use zoning map of the survey department to find out common features and differences and also to find suitability. Resulted suitability map of the area revealed that most of the suitable areas are a match with the land use map of the survey department of Sri Lanka. Although the study was conducted upon only eight criteria the same research can be conducted in this area as well as other areas considering more soil criteria as soil texture, moisture content, soil type, nutrient condition to achieve more fruitful results since the results obtained it is clear that soil is most considerable criteria for potato cultivation in the area with compared to other two criteria. Though agricultural instructors and agrarian centers have used manual methods for finding locations for potato cultivation GIS-based MCDA platforms can be used to perform task much faster. The resulted map will provide fruitful information concerning the suitability area investigation for potato cultivation and local land-use practices as well this can be taken as a reliable and accurate guideline for future land use and cultivation practices in the study area. Classified maps will be useful for agricultural instructors, land-use planners, farmers, agricultural research centers, department of agriculture services. So, this research can be utilized as the land use planning guide for fruitful potato cultivation practices in the study area.

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