Assessing the Feasibility for Paddy Cultivation sites through Multi-Criteria Evaluation and GIS Approach: A Case Study of Ampara District, Sri Lanka

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Abstract: *Land suitability analysis is essential for the optimal use of available land resources. In Sri Lanka, rice serves as the staple food. However, the COVID-19 pandemic and economic challenges have led to significant food shortages. Paddy is the principal crop, with the Ampara district being the country's most prolific paddy-producing area. Despite the limited number of lands currently used for paddy cultivation, numerous other potential areas within Ampara could be developed to enhance rice production. Geographic Information Science (GIS) has proven to be a highly effective tool for natural resource management and agricultural research. Accordingly, this study aimed to produce a map identifying areas optimally suited for paddy cultivation, utilizing Multi-Criteria Decision Making (MCDM) integrated with GIS and open-access data. Selection criteria for this analysis included climatic factors (rainfall, temperature, and humidity), topographical elements (slope and aspect), soil characteristics (texture, pH, drainage, and depth), and land cover data, informed by literature reviews and expert opinions. The suitability analysis was conducted utilizing a GIS-based Multi-Criteria Decision-Making (MCMD) technique. The Analytical Hierarchical Process was employed to rank the various suitability factors, and the resulting weights were subsequently applied to generate the suitability map. Findings indicated that 73% of the currently used area is highly suitable, while 25% is moderately suitable. Overlaying the current land cover map with the suitability map highlighted discrepancies between current and potential land use, showing that 42% of the study area has potential for paddy cultivation, predominantly in areas classified as highly and moderately suitable. The findings suggest that integrating spatial analytical processes with GIS significantly enhances its effectiveness, providing a robust tool to aid decision-makers in developing strategies in the agricultural context.*

Keywords: Geographical Information Science (GIS), Land suitability, Multi-Criteria Decision Making (MCDM), Paddy Cultivation

Introduction

The study of crop-land integration is necessary to make the best use of the land resources available for sustainable agricultural output (Samanta et al., 2011). One of the world's main food crops is rice (Oryza sativa). Rice ranks second in agricultural production in the majority of Asian nations. In the past, Sri Lanka was one of the world's leading producers of rice, with paddy being the main crop that is mostly farmed there. Ampara, Kurunegala, Polonnaruwa, Matara, Hambantota, Batticaloa and Anuradhapura are the main paddy-growing regions. The study area of the research is Ampara district, dry part of Sri Lanka and Ampara district rank as first place in paddy production in Sri Lanka. The two main rice-growing seasons in Sri Lanka are Yala (April to August) and Maha (September to March of the following year), both of which are grown in the Ampara area. All of Sri Lanka's districts grow paddy as wetland crops, and the total area set aside for paddy cultivation is currently estimated to be over 708,000 hectares (Paddy Statistics, 2019). But paddy cultivation in the Ampara district did not reach its full potential. The district's farmers are ignorant of the elements that influence paddy cultivation and the level of relevance they have, which is one of the reasons for this scenario (Aslam, 2015). The world has started to discuss the importance of fresh foods from small-scale rural producers during the COVID-19 pandemic (C. Malavipathirana et al., 2022).

Also, Sri Lanka had to face some problems regarding food security, unable to provide adequate supply to demand, improving rice production is very important for that. Crop production plays a major role in food security and economic development of a country. Detailed, reliable and timely information on agricultural resources is much needed in a country where agriculture is the mainstay of our national economy. Earth's population is growing dramatically and farming communities have to produce more to meet the growing demand for food. Both population growth and urbanization have increased pressure on agricultural resources. This increased pressure on existing land resources can lead to land degradation (C. G. Malavipathirana et al., 2024).

As a result, decision-making procedures for creating land use policies that promote sustainable rural development depend on precise and reliable land evaluation (Anushiya & Illeperuma, n.d.). The primary reasons limiting rice production can be found through land suitability research, which also helps decision makers create crop management plans. Improving agricultural land management and offering suitable planting patterns to boost crop production while utilizing land resources effectively are two of Sri Lanka's most urgent concerns. Sustainable cultivation or farming can lead to optimal rice production. Sustainable cultivation or agriculture is the idea of producing high-quality goods in a way that is socially, environmentally, and economically acceptable while making the best possible use of the natural resources at hand to support productive agricultural practices.

Many GIS-based land suitability analysis approaches have recently developed such as weighted overlay and modelling for land suitability analysis. Low productivity has been caused by ignorance about the ideal ratio of elements needed for paddy production. Sustaining agricultural development and ensuring food supply require effective management of natural resources (Kihoro et al., 2013).

Therefore, the main objective of this study is to assess land suitability for paddy cultivation in Ampara district of Sri Lanka with Analytical Hierarchy Process (AHP) while integrating Multi Criteria Evaluation (MCE) technique with GIS. The specific objectives of this research were to prepare a potential land suitability map for rice cultivation based on climatic conditions, topography factors and soil characteristics and to identify potential areas for expansion and optimization of rice production in this selected study area.

Methodology

a. Study Area:

The study's target area, Ampara district, is located in the eastern province of southeast Sri Lanka. It takes up 4415 square kilometers of space (Wanninayaka et al., 2020). The northern districts of Batticaloa and Polonnaruwa, the eastern Indian Ocean, the south Hambantota district, the south-east Badulla district, the northwestern Matale and west-south Monaragala districts, and the east Indian Ocean are all about it. The Ampara District produced the most paddy, estimated at 313,708 metric tons, during the 2021 Yala season. 15% of the nation's total paddy production was produced in the Ampara District (Paddy Statistics, 2019). It represents the season's highest paddy production.

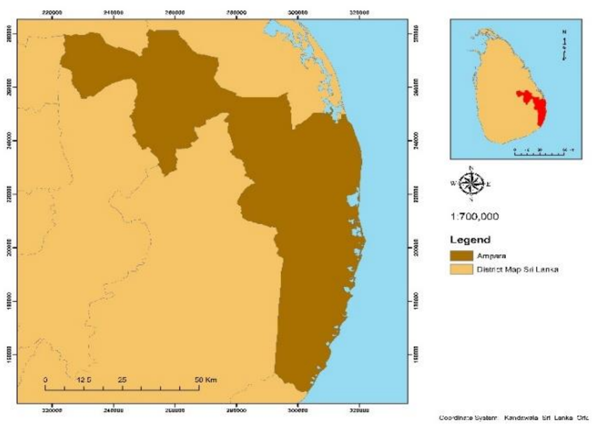

Figure 1: Location of the study area

Ampara district is located in in dry zone and the rain for this region is mainly from northeast monsoon and first inter monsoon, used to store in rainwater schemes aiming for irrigation purposes throughout the year. The average temperature in Ampara district is around 30℃, ranges from 24 ℃ to 36℃ while average rain fall is 1400 mm form department of meteorology (Asmath et al., 2021).

b. Data used for land suitability analysis:

Critical conditions for appropriate paddy cultivation regions were identified with the assistance of professional agronomist opinions and the literature referencing numerous sources. The land suitability analysis for paddy cultivation was conducted using nine sub-criteria, including soil pH, soil texture, soil drainage, soil depth, rainfall, temperature, humidity, aspect, and slope, in addition to three basic criteria, soil characteristics, climate, and topography. Table 1 provided a particuthe suitability level per factor for paddy cultivation. Climatic factors (rainfall, temperature, and humidity) was collected from the Meteorological Department. soil characteristics (texture, pH, drainage, and depth) was extracted from openly available soil map. 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 analysis. Slope and aspect maps were created using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM). Land use data was collected from the Survey Department and the present land use map was generated.

Table 1: Suitability levels of the nine parameters

Criteria	**References**						
	Very low suitability	**Low suitability**	**Moderately low suitability**	**Moderate suitability**	**Moderately high suitability**	**High suitability**	**Very high suitability**
Temperature	< 18	> 35	19 - 18	34 - 35	21 - 20	31 - 33	22 - 30
Soil Texture	Sand	Sandy Loam	Silt loam	Loam	Silty clay	Clay loam	clay
Soil drainage	excessively drained	somewhat excessively drained	very poorly drained	well drained	moderately well drained	poorly drained	imperfectly drained
Soil pH	< 4.0	> 8.4	4.0 – 5.0	7.8 – 8.4	5.1 – 5.5	7.4 – 7.8	5.6 – 7.3
Rainfall	More than 3500	3500-3000	3000-2500	2000 to 2500	1000-1250	1250-1500	1500 to2000

Slope	60–100%	30 – 60%	15 – 30%	8 – 15%	5 – 8%	2 – 5%	0 - 2%
Aspect	Flat	N, NW	W, SW	S	SE	NE	E
Soil depth	>15cm	0.1-15	0.5-0.1	0.30 to 0.50)	0.25-0.30	0.2-0.25	Low (<0.20)
Humidity	< 15	15 – 25	25 - 40	40 - 50	50 - 65	65 - 80	> 80

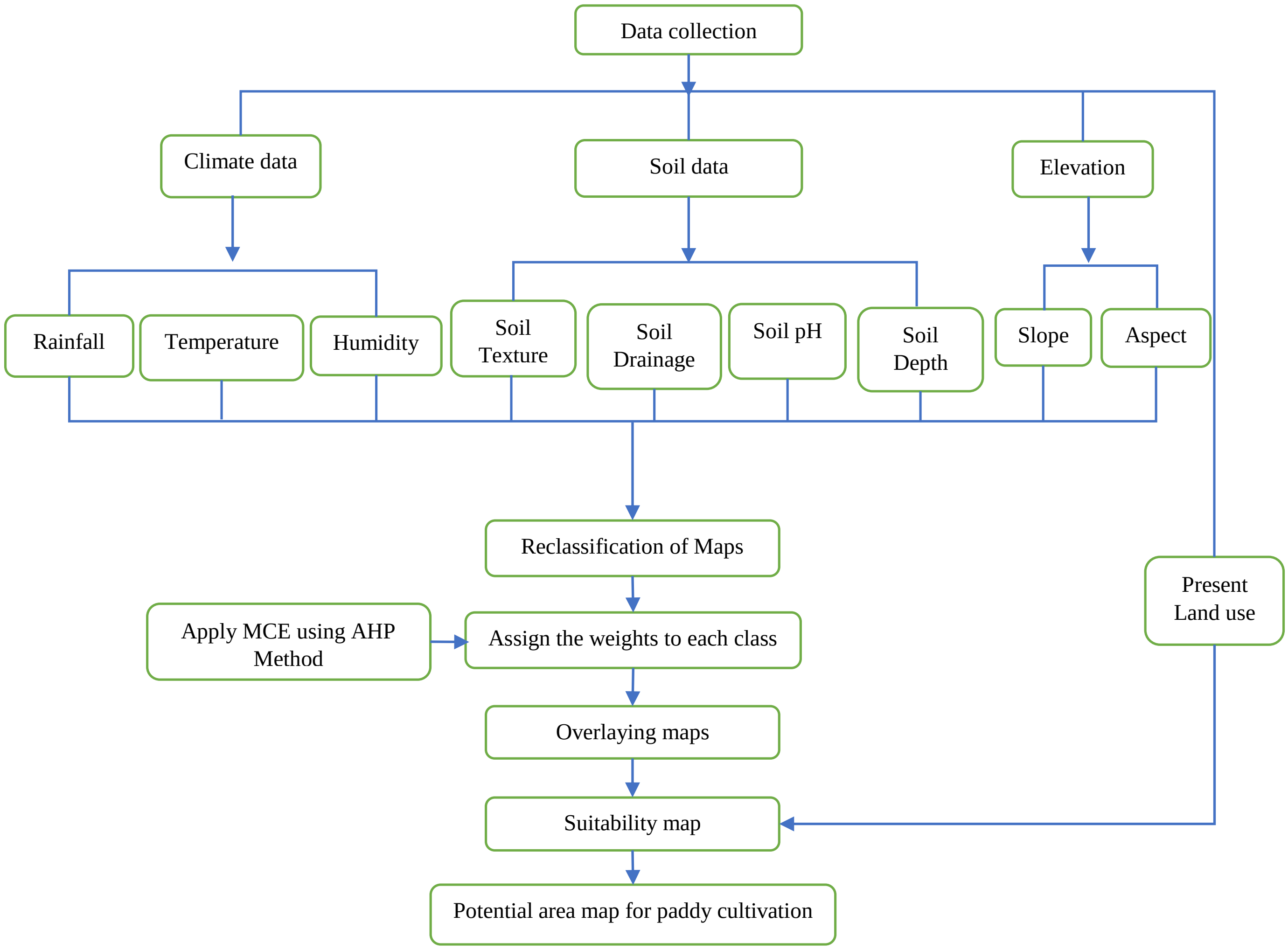

Figure 2 : Experimental Workflow

c. Assigning weight of factors and multi-criteria evaluation (MCE):

To convey each factor's preference or importance in relation to other factors' influence on crop yield and growth rate, weighting is used. elements that were identified were the most important. The criteria maps (one for each factor) were built using the suitability levels for each of the factors as the basis (Kihoro et al., 2013). The weights had to add up to one in order for the weighted linear combination method for MCE to work. To perform the weighted linear combination method (MCE method), all elements need to be converted into units that can be compared later.

All factors must be standardized or converted into units that can be compared later, in accordance with the weighted linear combination method utilized in this study. As indicated in Table 2, the factor maps were ranked using Saaty's underlying scale, which has values ranging from 1 to 7, after contacting with a local agricultural expert and reviewing relevant literature.

Table 2: Seven-point weighing scale for pair-wise comparison

Description	**Scale**
Very low suitability	1
Low suitability	2
Moderately low suitability	3
Moderate suitability	4
Moderately high suitability	5
High suitability	6
Very high suitability	7

Factor weights were computed by a pairwise comparison matrix comparison of two factors. In order to use the Pairwise Comparison Matrix, Saaty (1980) devised a scale with values ranging from 9 to 1/9. A value of 9 shows that with respect to the column factor, the row factor is more relevant (Vargas & St, 2022). Conversely, a rating of 1/9 means that the row factor is less significant in comparison to the column factor. In circumstances where the column and row factors are equally relevant, they have a rating value of 1. The research's pairwise comparison matrix is displayed in Table 3.

Table 3: Pairwise comparison matrix

	Temperature	**Soil Texture**	**Soil drainage**	**Soil pH**	**Rainfall**	**Slope**	**Aspect**	**Soil depth**	**Humidity**	**Weights**	**Influence %**
Temperature	**1**	1	2	2	3	3	4	5	6	0.208485	21
Soil Texture	1	**1**	1	2	3	4	5	5	6	0.198388	20
Soil drainage	1/2	1	**1**	2	3	5	4	5	5	0.183414	18
Soil pH	1/2	1/2	1/2	**1**	3	4	5	5	5	0.146943	15
Rainfall	1/3	1/3	1/3	1/3	**1**	3	4	5	4	0.097864	10
Slope	1/3	1/4	1/5	1/4	1/3	**1**	3	4	3	0.065498	7
Aspect	1/4	1/5	1/4	1/5	1/4	1/3	**1**	2	3	0.04312	4

Soil depth	1/5	1/5	1/5	1/5	1/5	1/4	1/2	**1**	2	0.031343	3
Humidity	1/6	1/6	1/5	1/5	1/4	1/3	1/3	1/2	**1**	0.024946	2
CR = 0.0576										**∑=1**	**100**

Elements are given the value of unity in the diagonal (e.g., when a factor is compared with itself). It is actually just necessary to fill in the lowest triangular half of the matrix because it is symmetrical (Kihoro et al., 2013). The remaining cells are therefore only the lower triangular half's reciprocals (for instance, since the relationship between temperature and slope is 3, the relationship between slope and temperature will be 1/3). It should be mentioned that the Consistency Ratio was used in criteria weighting to prevent bias.

$CI = (\lambda\ max - n)/(n - 1)$

$CR = CI/RI$

Where, λ max: The maximum eigenvalue

CI: Consistency Index

CR: Consistency Ratio

RI: Random Index

n: The number of criteria or sub-criteria in each pairwise comparison matrix

The MCE process in ArcGIS 10.5 was used to create the map of suitable locations once the composite layers and their weights were determined. Using weighted overlay and spatial analyst tools in ArcGIS 10.5, the suitability map for paddy cultivation (Figure 4) was identified.

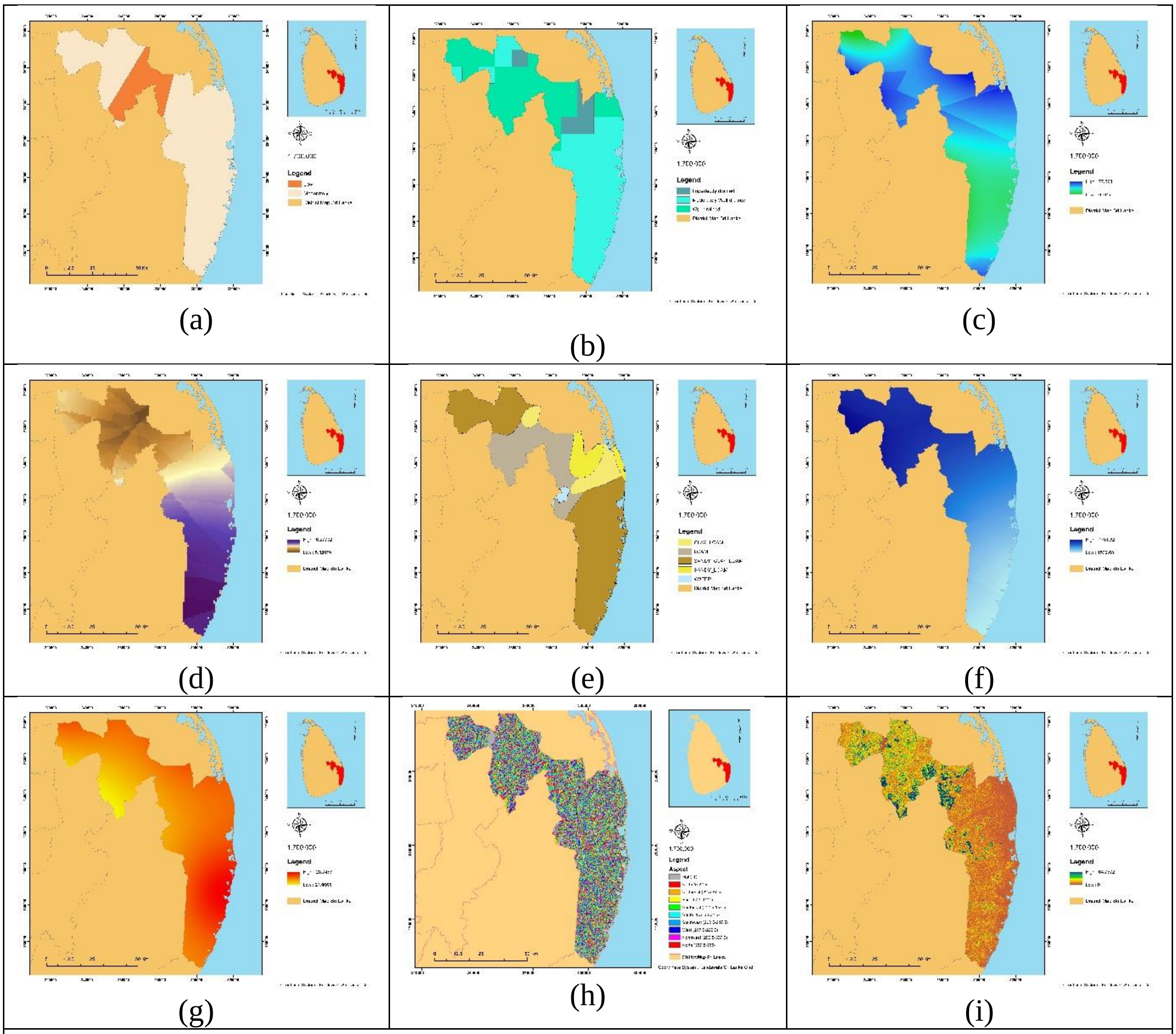

Figure 3: Suitability levels of the nine parameters (a) Soil depth suitability classes, (b) Soil drainage suitability classes, (c) Humidity suitability, (d) Soil pH suitability, (e) Soil Texture suitability classes, (f) Rainfall suitability, (g) Temperature suitability, (h) Aspect suitability classes, (i) Slope suitability

Results and Discussion

a. The suitability map for paddy production:

The suitability map for paddy cultivation, identified by weighted overlay using spatial analyst tools in ArcGIS 10.5, is shown in Figure 4. The number of hectares available to Each suitability class was as follows:

Table 4: Area of paddy land suitability classes

Type	Modelled land Extent in sqkm	Percentage
Unsuitable	19.901933	1%
Very low suitability	0.000007	0%
Low suitability	0.000017	0%
Moderately low suitability	0.000032	0%
Moderate suitability	0.00004	0%
Moderately high suitability	852.435085	25%
High suitability	2483.933228	73%
Very high suitability	44.763484	1%

The results showed that highly suitable (73%) and Moderately high suitable (25%) areas were found mostly in areas under current paddy cultivation. Moderately high suitability areas were

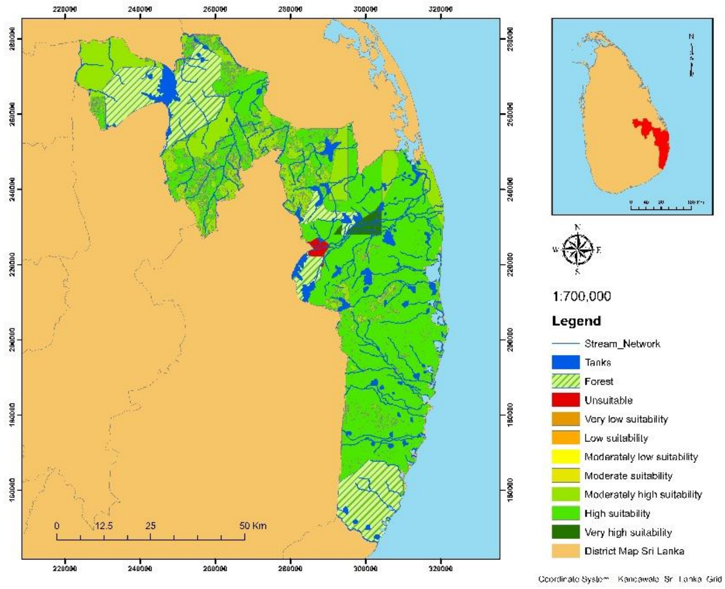

Figure 4: Suitability map for Paddy Cultivation

characterized by temperature level between 21 to 20 ^{0}C, soil texture class silty clay, Soil drainage moderately well drained, Soil pH between 5.1 to 5.5, Rainfall between 1000 to1250 mm, Slope level between 5% to 8%, Aspect SE, Soil depth between 0.25 to 0.30 and Humidity between 50 to 65. high suitability areas were characterized by temperature level between 31 to 33 ^{0}C, soil texture class clay loam, Soil drainage poorly drained, Soil pH between 7.4 to 7.8, Rainfall between 1250 to 1500 mm, Slope level between 2% to 5%, Aspect NE, Soil depth between 0.2 to 0.25 and Humidity between 65 to 80. Generally unsuitable areas were in mountainous/ rock areas with slope level >50%. According to this study, 19.901933sqkm (land extend in percentage 1%) was unsuitable for paddy cultivation.

b. Present land use land cover under paddy cultivation:

Figure 5, shows 10 land use/cover types, within the study area. The current paddy extent is 671.577855 Sqkm (15% from total study area).

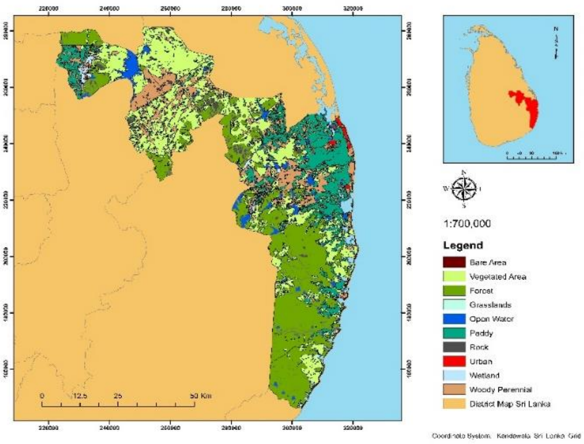

Figure 5: Land use land cover map

c. Comparison between existing Paddy - growing areas and proposed areas by the study:

To improve the results, the current land use/cover map (Figure 5) and the suitability map for paddy cultivation (Figure 4) were overlaid to identify differences and similarities between the present land use and the potential land use for the rice crop. This was done because the identification and accurate description of current and potential production areas are essential for research and agricultural development. According to the overlaying suitability map with current land use map, 82% of study area has high suitable areas for the Paddy Cultivation.

Table 5: The percentage of existing Paddy -growing areas intersected with each of the modelled suitability classes.

Category	Extent (percentage)
Unsuitable	0%
Very low suitability	0%
Low suitability	0%
Moderately low suitability	0%
Moderate suitability	0%
Moderately high suitability	14%
High suitability	82%
Very high suitability	4%

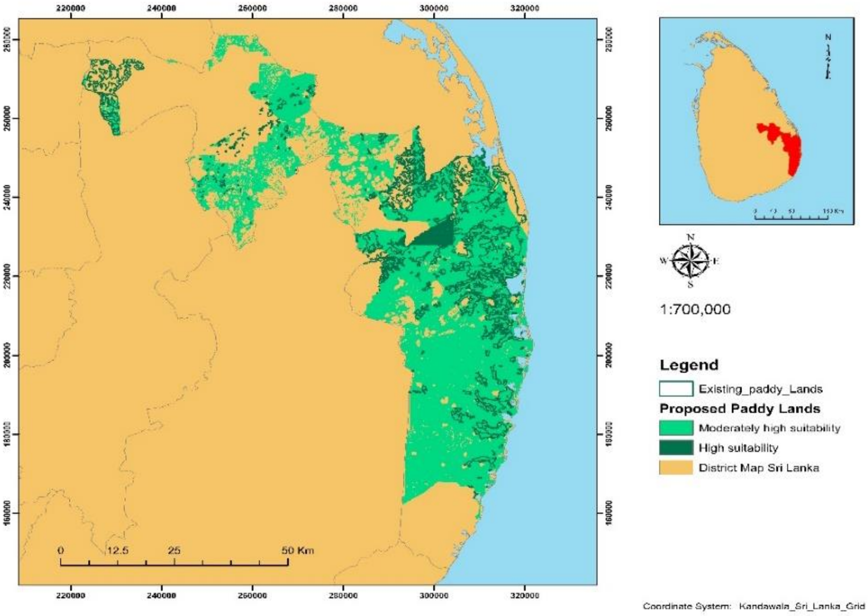

Figure 3: Potential area map for Paddy Cultivation

Conclusion and Recommendation

The results demonstrate that present paddy cultivated areas are falls under the areas that are classified as 'High suitability' and 'Moderately high suitability' for paddy cultivation. According to that analysis reveals 42% from total land extend has Potential for paddy cultivation. The suitability map may be a 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 land use types. Land suitability map for paddy cultivation 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 many criteria. 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.

Table 6: Total potential area for paddy cultivation

	Area (Sq.km)	Area (%)
Suitable area for paddy cultivation	2528.69671	57%
Current paddy	671.577855	15%
Potential area for paddy cultivation	1857.11886	42%

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