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Assessment of Crop Site Suitability of Under-Utilized Land Using Multi-Criteria Decision and Geospatial Techniques

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Abstract

Site suitability study for agriculture or crops are an important technique in deciding potential agricultural types, planning and activities. Site suitability analysis is an assessment of an area to determine its appropriateness for a particular use of the land (such as growing varieties of crop) in a particular location. Assessment of crops site suitability can be done from various approaches and one of the mostly used approach is utilizing geographical information system (GIS) geospatial analysis based on a multi-criteria decision-making method. A widely used multi-attribute technique that has been incorporated into the GIS-based crop site suitability procedure is the Analytical Hierarchy Process (AHP) for multiple factors assessment integrating physical (slope and topography) and socio-economic factors (land use/land cover, distance from road and water bodies localities). This research is conducted to analyse land criteria factors (i.e., physical, and socio-economic) to assess crop site suitability for under-utilized land in selected districts of the Selangor state. The findings show that the proposed method is able to outline the crop site suitability area in Selangor based on four different suitability categories of not suitable, less suitable, moderately suitable and highly suitable. The integration between GIS and AHP significantly provides an effective approach in assessing crop site suitability for better land use/land cover and agriculture management and production.

1. Introduction

Site suitability study for agriculture/crop is an important technique in deciding potential agricultural types, planning and activities. Site suitability analysis is an assessment of an area to determine its appropriateness for a particular use of the land (such as growing varieties of crop) in a particular location. Assessment of crop site suitability can be done from various approaches. One of the widely used approaches is through utilizing geographical information system (GIS) geospatial analysis based on a multi-criteria decision-making method. A widely used multi-attribute technique that has been incorporated into the GIS-based crop site suitability procedure is the Analytical Hierarchy Process (AHP).

Many previous studies in Malaysia and internationally has been carried out for crop site suitability analysis by integrating physical factor (i.e., climate, soil texture, soil reaction, nutrient availability, and slope etc.) and socioeconomic factor (land use/land cover, demographic, distance from road and water bodies localities etc.). Various studies on site suitability for different crops have been performed by researchers around the world utilizing GIS AHP technique. In Malaysia, limited studies were conducted for crop site suitability such as rubber plantation site in Negeri Sembilan [1], Bambara groundnut (Kacang Poi) in Semenyih, Selangor [2] and organic farming in Sabak Bernam [3]. Different crops site suitability analysis at international level were conducted in Haripur, Bangladesh [4] for wheat cultivation, in Iran and Kenya for rice cultivation [5], [6], in Agra district, UP, India for sugarcane, pearl millet, mustard and rice [7] in East Khasi Hills District of Meghalaya and India for orange and pineapple [8].

GIS is a computer-based and one of the most dynamic computer application systems utilizing spatial and attribute data. GIS is a system designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data. It is widely used for various applications such as agriculture, environment, disaster, climate modelling, land use planning etc. For agriculture purposes, GIS has been proved to be an effective technology ranging from recording data, predicting crop growth, supporting pesticide control and food safety regulations. The land assessment framework of the Food and Agriculture Organization (FAO) has also been widely used and land suitability for crops can be assessed in terms of suitability ratings from highly suitable to unsuitable, based on topographic, climatic, and soil-based factors by FAO in 1976. Multi-criteria decision analysis (MCDA) examines probabilities according to multiple criteria and objectives. Geographic information systems (GIS) and multi-criteria decision analysis (MCDA) is normally used to evaluate land suitability of single crop or multiple crops [9], [10], [11], [12], [13].

The Analytic Hierarchy Processing (AHP) introduced by [18] is one of the broadly used and the best approach to handle multiple and heterogeneous factors as it relies on a hierarchical structure to represent the relative importance of factors in a multi-criteria decision situation and used for land suitability assessment [14], [10], [15], [16]. Therefore, this research adopted the AHP and GIS weighted overlay techniques to assess the suitable areas for crop plantation for land under-utilized such as grassland or undeveloped land in Kuala Selangor and Kuala Langat, Selangor, Malaysia.

2. Materials and Methods

The overall methodology for GIS project implementation consists of data acquisition (primary and secondary data), physical and socioeconomic factors or parameters determination based on an expert opinion feedback (using questionnaire), AHP parameter weightage assessment, and GIS spatial analysis to produce a site suitability map for crops.

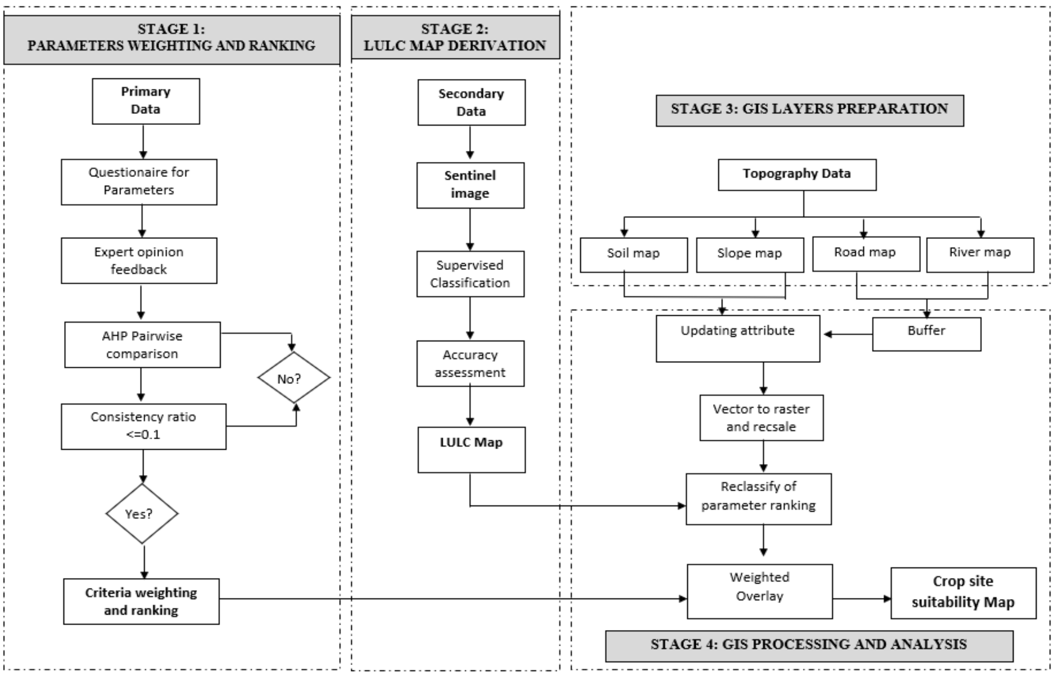

Fig. 1 *The overall methodology for crop site suitability area using GIS analysis*

The methods mainly focused on three parts known as Analytical Hierarchy Process (AHP) parameter weighting, scoring, and ranking using selected parameters such as topography, climatology, and soil data. The second part is land use/land cover (LULC) map derivation from the satellite images of Sentinel-2A data with 10-meter spatial resolution. The last part is spatial analysis using GIS techniques to find the crop site suitability area based on weighted overlay technique. Two different software were used for data processing, the first one is ERDAS Imagine software used for the digital image processing of satellite data. The second software is ArcGIS mainly used for spatial analysis. Overall methodology as presented in Fig 1.

The primary data is obtained from interviews with the experts while the secondary data are collected from various national organizations. These data include digital maps and other data for different physical and socio-economic aspects of the study area. Topography data in shapefile GIS format is acquired from the Department of Survey and Mapping Malaysia (JUPEM) for the year 2022. The data is vital in recognizing and identifying the area to be analysed in order to determine crop suitability. The map also consists of a contour layer that can be converted into DEM to determine the suitable slope for further land development/crop plantation as required in this project. The map of soil types and soil conditions is obtained from the Department of Agriculture (DOA) for Selangor state using a similar format of shapefile to be easily overlaid with other data such as LULC map, road map, etc. The data with the scale of 1:50,000 and in vector polygon map data format which include soil series and soil texture attributes. Soil texture map is used for map weighted overlay process in ArcGIS software.

A digital image processing software (i.e. ERDAS Imagine) is utilized to produce LULC map using supervised classification Maximum Likelihood method due to prior geography knowledge of the study area and good understanding with the spectral properties of the LULC classes. The algorithm separates unknown pixels in an image based on reflectance values into desired LULC classes. For this research, the supervised classification method has been used for the two districts (i.e Kuala Selangor and Kuala Langat) of Selangor using ERDAS IMAGINE and ArcMap softwares'. Supervised classification is one of the methods that allows the user to select a pixel in the image that represents a certain class of land use/land cover categories. All of the pixels in the data will be classified according to LULC categories consisting of water bodies, mangrove, forest area, bare land, oil palm, paddy area, built-up area, peatland and grassland.

The Analytic Hierarchy Process (AHP) has been widely used for multi-criteria decision making of crop site suitability in many agricultures or crop plantation such as rubber, oil palm, wheat, barley and many more [17], [18]. The AHP procedure is to construct a decision matrix expressing the importance of relative values from 1 (equal importance) to 9 (more important) of chosen criteria or parameters such as slope, soil texture, road accessibility and LULC categories. Each of these criteria selection judgments will be assigned a number (1 to 9) based on a rating scale [19]. The Consistency Ratio (CR) is used to measure how consistent the judgements have been relative to large samples of purely random judgements. If the CR is more than 0.1, then the judgment is considered as inconsistent or unaccepted. The exercise is considered valueless or must be repeated. The Consistency Index (CI), Random Index (RI) and Consistency Ratio (CR) is based on the following Eq. (1):

$$CI = \lambda \max - n / \text{n-1} \quad (1)$$

where CI is the consistency index, λ_{max} is the average value of each factor, and n is the numbers of the parameter used in Eq. (2).

$$CR = CI/RI \quad (2)$$

where CR is the consistency ratio.

Criteria for crop site suitability is proposed based on the expert opinion as well as from the literature review. For crop site suitability assessment using GIS, five sub-parameters were identified known as slope, soil texture, land use/land cover (LULC) categories, water accessibility distance and road accessibility distance (Table 1). These sub-parameters are chosen based on DOA guidelines, expert opinion feedback and the previous research publications which focused on crop site suitability assessment [20].

After the land crop suitability parameters and their relative sub-parameters have been finalized using AHP equations and requirements, GIS mapping and overlying exercise is then performed to assess the crops suitable for the land under-utilized. The weighted overlay method was then used to generate crop suitability maps in the study area. All the generated thematic layers in raster format with 10m spatial resolution were integrated in ArcGIS® to derive a map depicting the suitable areas for the crop plantation of the study area. The total weight of each map of the final integrated layer was computed using Eq. (3).

$$C_{s=}SL_w SL_r + SO_w SO_r + RD_w RD_r + RV_w RV_r + LU_w LU_r \quad (3)$$

where, *w* represents the weight of each criterion, and *r* represents the rating of each criterion namely: Slope (SL), Soil (SO), Road buffer (RD), River buffer (RV) and LULC (LU). *Cs* is the crop suitability index, which is a dimensionless number that identifies the suitable sites for the crop's plantation in the area.

The study area is classified into four (4) classes based on the minimum and maximum of the criteria maps. The outcomes for all parts of the research area are divided into Not suitable areas (S1), Less suitability (S2), Moderately suitability (S3) and Highly suitability (S4) areas. The percentage area will be calculated once the suitability categories are outlined and presented in the result section.

Table 1 *Topography sub-parameter ranking based on suitability classes*

Parameter and sub-parameter requirements	Parameter Ranking			
	1 (Not Suitable)	2 (Less Suitable)	3 (Moderately Suitable)	4 (Highly Suitable)
Topography				
Slope (degree)	>12	6-12	4-6	0-4
Soil texture	Clay	Sandy loam	Sandy clay loam	Clay loam/Loam
LULC categories	Built-up/ Water bodies/ Forest reserve	-	-	Bare land/ Grassland/ Agriculture
Water accessibility (m)	>2000	1500-2000	1500-1000	0-1000
Road accessibility (m)	>2000	1500-2000	1500-1000	0-1000

3. Results and Discussion

Pairwise comparison is performed first for the topography and soil parameters as described in Table 2 based on expert opinion feedback using questionnaire and rating scale as proposed by [19]. The expert feedback were obtained from the lecturers of UiTM from Agrotechnology Faculty and also from the DOA, Selangor. The slope and the soil texture parameters were the two most important parameters and given highest consideration based on expert opinion feedback.

Table 2 *A pairwise comparison matrix for each criterion*

Criteria	Slope	Soil texture	LULC	Water accessibility	Road accessibility
Slope	1	3	5	7	7
Soil texture	1/3	1	5	3	5
LULC	1/5	1/5	1	3	3
Water accessibility	1/7	1/3	1/3	1	3
Road accessibility	1/7	1/5	1/3	1/3	1

The next step is the calculation of a list of relative weights, importance, or value of each parameter. It is also known as priority vector or eigenvector calculation (Table 3). Average random consistency indices are referred before the calculation of CR (Eq. (2)) is done. The evaluation begins by determining the relative weight of the initial value based on pairwise comparison. Normalization procedure is calculated by dividing each value by the total column value for each parameter and the total sum value for each parameter is equal to 1 (Table 3). Subsequently, the calculation of priority vector or also known as Eigenvector is calculated. Eigenvector shows the relative weights between each parameter by calculating the average of all parameters.

Calculation of consistency is followed to determine whether the parameter chosen, and the values based on expert opinion feedback have been consistent. The consistency index is based on maximum eigenvalue which is

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calculated by summing the total values of each element in the eigenvector by the respective column total of the original comparison matrix. The final result for weightage is to be used in weighted overlay GIS analysis as shown in Table 4 for topography and soil sub-parameters. The value of RI is 1.12. The CR value obtained is 0.08. The AHP ranking and weightage quantification based on topography and soil parameters indicated that slope parameter is the main factor that contributed the highest influence of 50%, followed by soil texture of 27%, LULC of 12%, road accessibility of 7% and river accessibility by 4%. Slopes of less than 12^0 is used as maximum area for crop planting under-utilized lines to avoid any issue related to soil stability or soil erosion (Table 4).

Table 3 *Normalization calculation for each parameter*

Criteria	Slope	Soil texture	LULC	Water accessibility	Road accessibility	Eigenvector
Slope	0.5498	0.6338	0.4286	0.4884	0.3684	0.494
Soil texture	0.1831	0.2113	0.4286	0.2093	0.2632	0.259
LULC	0.1100	0.0423	0.0857	0.2093	0.1579	0.121
Water accessibility	0.0786	0.0704	0.0285	0.0698	0.1579	0.081
Road accessibility	0.0786	0.0423	0.0285	0.0232	0.0526	0.045
Total Sum	1.0000	1.0000	1.0000	1.0000	1.0000	

Table 4 *Topography sub-parameters AHP weighting values derivation*

No.	Main Parameters	Sub-Parameters	Crop Suitability Weightage derivation (%)
1.	Topography	Slope	50%
		Soil texture	27%
		LULC	12%
		Road accessibility	7%
		Water accessibility	4%
TOTAL (%)			100.00%

3.1 Land Use/Land Cover Map Derivation

Kuala Selangor is represented by seven (7) LULC categories known as Bare land, Built-up, Forest, Mangrove, Oil palm, Paddy and Water bodies as shown in Fig. 4(a). The total area (in hectare) is 119,623.14 ha. The largest LULC area is contributed by forest with 41,917.5 ha or 35% followed by oil palm with an area of 37,729.81 ha which is 31% of the total area of Kuala Selangor. The lowest total area value is water bodies with 2,635.44 ha (2.20%) followed by mangrove areas with a total area of 3,253.91 ha (2.72%) (Fig. 2).

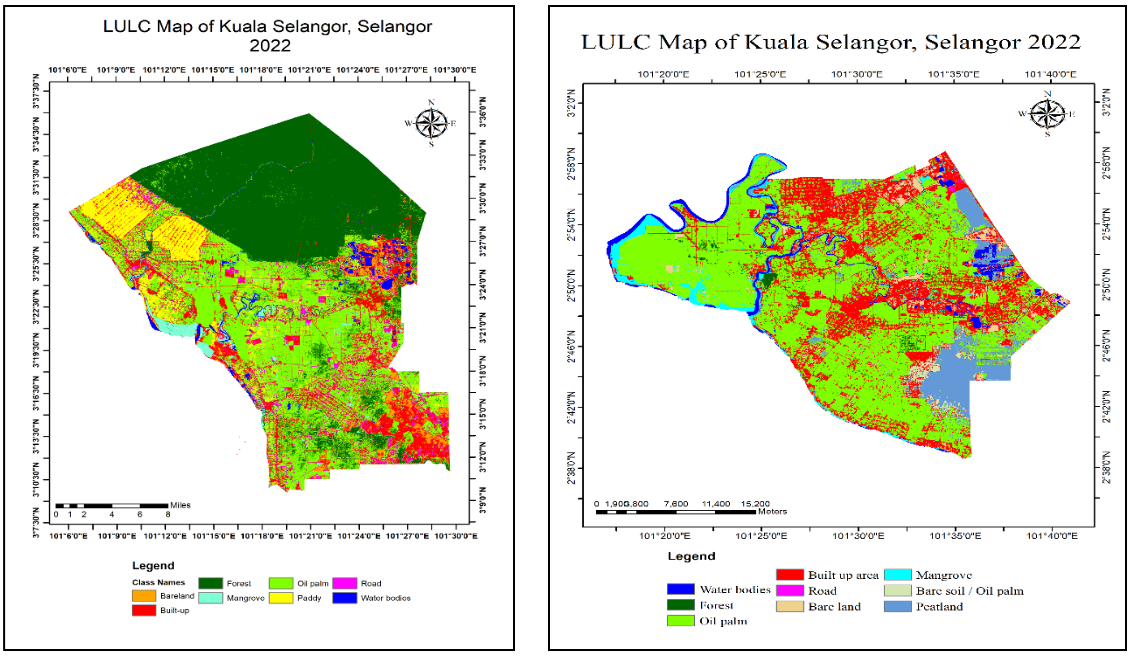


Fig. 2 *LULC Maps of Kuala Selangor and Kuala Langat from Sentinel data*

Kuala Langat is represented by eight (8) LULC categories known as Bare land, Built-up, Forest, Mangrove, Oil palm, Road, Peatland, Water bodies and Bare soil/Oil Palm (Fig. 2). Bare soil/Oil Palm area is the area when oil palm trees were cut down and exposed the bare soil area before next cycle of oil palm planting take over. Therefore, it is categorized as Bare soil/Oil Palm since the bare soil is located within the oil palm area. The oil palm is the highest area which is 45,953.7 ha or 53% followed by built up area with an area of 21,295.9 ha (25%). The lowest total area value is forest area with 864.74 ha (1%) followed by bare soil/ oil palm area with a total area of 1,488.49 ha (2%). The total area for Kuala Langat district is 8,6021.79 ha. Accuracy assessment done using random sampling and referring to google earth and original satellite data produced about 81% and 80% for the Kuala Selangor and Kuala Langat respectively.

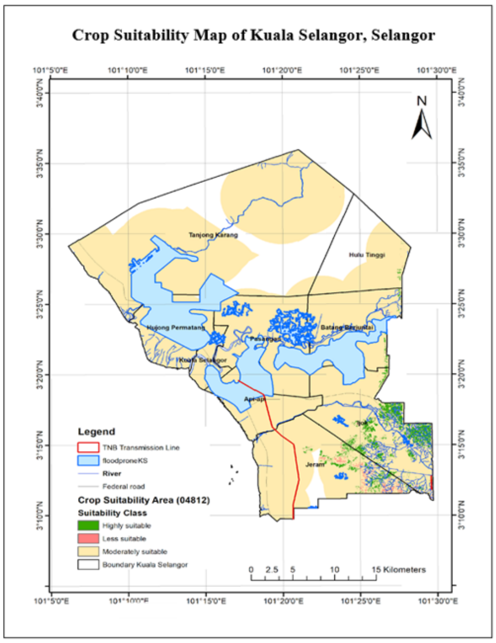
3.2 Crop Site Suitability Using Weighted Overlay GIS Technique and AHP Weightage

Fig. 3(a) shows the crop site suitability map area of Kuala Selangor using weighted overlay technique in ArcGIS and using Eq. (3). The overall area suitable for crop planting is shown in Table 5 and the area suitable for crop planting under-utilized land or each category also presented. The highly suitable (S4) area is located within the Ijok sub-district (mukim) at Saujana Utama area. Meanwhile for the moderately suitable (S3) crop area is located within the Api-api and Jeram sub-district. However, some parts of S3 consisted of flood prone areas (blue polygon area in map) within Api-api which indicate high risk for flooding and may affect crop planting in the future.

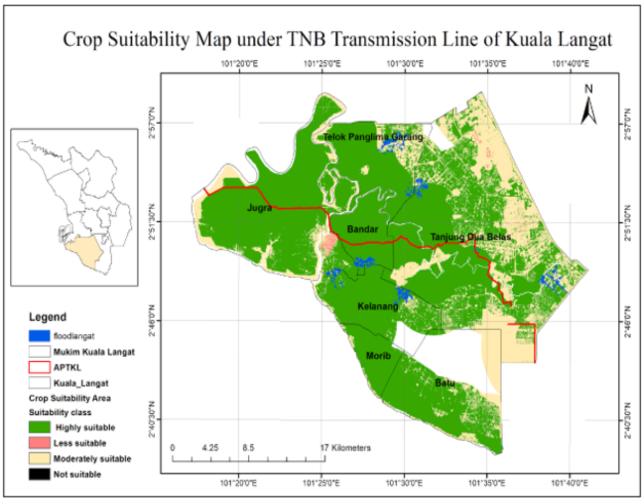
For the Kuala Selangor, crop suitability map contributed about 101,704.28 ha of area categorized as suitable for crop planting. In terms of percentage, S2, S3 and S4 contributed about 0.32%, 97.36% and 2.32% respectively. S3 or moderately suitable area is the highest category for Kuala Selangor district.

Table 5 *Overall crop site suitability area (in hectare) for the Kuala Selangor, Selangor*

		Kuala Selangor		Kuala Langat	
Suitable class	Code class	Area (Ha)	Percentage (%)	Area (Ha)	Percentage (%)
Not suitable	S1	-		2.76	0.004
Less suitable	S2	330.24	0.32	239.78	0.305
Moderately Suitable	S3	99,016.47	97.36	19,829.58	25.197
Highly Suitable	S4	2,357.57	2.32	58,625.19	74.495
Total		101, 704.28	100	78,697.31	100



(a)



(b)

Fig. 3 *Crop site suitability map using Weighted Overlay for (a) Kuala Selangor; and (b) Kuala Langat with flood prone area (in blue color)*

Fig. 3(b) shows the crop site suitability map area of Kuala Langat using weighted overlay technique in ArcGIS. Three categories of suitable area were produced for Kuala Langat with Less Suitable (S2), Moderately suitable (S3) and Highly suitable (S4). The overall area is suitable for crop planting as shown in Fig. 5 for crop planting under for the Kuala Langat. The S4 area is mostly located within all sub-district of Telok Panglima Garang, Jugra, Bandar, Tanjung Dua Belas, Kelanang, Morib and Batu. The S3 category is also situated within these seven sub-district areas with lower values, mostly in Tanjung Dua Belas and Batu sub-districts. Only a small area categorized by the S1, mostly located at the Jugra. No transmission line falls under the flood prone area that may affect crop planting in the future.

For the overall district of Kuala Langat crop suitability map contributed about 78,697.31 ha of area categorized as suitable for crop planting. In terms of percentage, S1, S2, S3 and S4 contributed 0.004%, 0.305%, 25.197% and 74.495% respectively. S4 or highly suitable area is the largest category for the Kuala Langat district, followed by the S3 or moderately suitable area (Table 5).

The first stage of the analysis using GIS for crop site suitability assessment is able to provide an indicator of the four categories of crop site suitability within five Selangor's districts as listed in Table 5. The result indicated that the S3 or moderately suitable category contributed the highest suitable crop site with 97.36 and 25.19%, secondly by the S4 or highly suitable category with 2.32% and 74.49%, thirdly by the S2 or less suitable category with 0.32% and 0.31%. Meanwhile, the S1 or not suitable class only contributed about 0.004% from both study area of Kuala Selangor and Kuala Langat, Selangor. Similar technique was used by [3] in assessing organic farming plantation area within Sabak Bernam, Selangor. The study found that majority of the area falls under the moderately suitability area and followed by the highly suitable area between 92.6% and 2.44% respectively. A study by [17] outlined that weighted overlay GIS technique combined with AHP method able to estimate groundnut suitability area with suitable and moderately suitability highest percentage as opposed to not suitable area. The GIS-AHP method was used in assessing suitability of land for agriculture in Yen Khe commune, Con Cuong district, NgheAn province, Vietnam. The study found that larger area is not suitable for agriculture in the Con Cuong district due to natural forest land unsuitable to be allocated for agriculture plantation [21]. Most of the previous researches concluded that GIS integrated with MCDM analysis was found the best approach by including soil, climate and topographic parameters for land suitability evaluation. The criteria considered for land suitability assessment were mainly biophysical and incorporating socio-economic variables to provide comprehensive crop site suitability area [2], [21], [22], [23].

4. Conclusion

This research is conducted to analyse land criteria factors (i.e., physical, and socio-economic) to assess crop site suitability for under-utilized land in Kuala Selangor and Kuala Langat districts of the Selangor state. The findings show that the proposed method is able to outline the crop site suitability area in Selangor based on four different suitability categories of not suitable, less suitable, moderately suitable and highly suitable. The Kuala Selangor crop suitability area produce about 97.36% or moderately suitable as opposed to highly suitable area of 2.32%. Different category outlined for the Kuala Langat with highly suitable area contributed the highest percentage of 74.5% as opposed to moderately suitable with 25.2%. The less suitable or not suitable crop suitability area is very minimum with the value lower than 0.32% for both study area. The research manages to address that the integration between GIS and AHP significantly provides an effective approach in assessing crop site suitability for better land use/land cover and agriculture management and production. The assessment methods from this research is in line with the Sustainable Development Goals (SDG) for food security and promoting sustainable agriculture initiative thus can be explored further in assessing sites suitability to be planted with different crops in bigger scale.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nor Aizam Adnan, Aida Firdaus MN Azmi;* ***data collection:*** *Nor Aizam Adnan;* ***analysis and interpretation of results:*** *Nor Aizam Adnan, Ahmad Rosly Abbas, Nur Iffika Ruslan , Ainaa Suhardi;* ***draft manuscript preparation*** *Nor Aizam Adnan, Raseetha Vani Siva Manikam, Siti Maslizah Abdul Rahman, Ismail Rakibe, Wan Edura Wan Rashid.*

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