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A GIS-BASED SUSTAINABILITY AND HIGHEST-BEST USE (SHBU) FOR FELDA LANDS DEVELOPMENT PLANNING DECISION-MAKING

Mohd Fadzil Abdul Rashid[1], Salbiah Mokhtar[2], Siti Mazwin Kamaruddin[3], Muhamad Asri Abdullah Kamar[4], Suzanah Abdullah[5], and Mohamad Azal Fikry Ali[6]

[1,2,4,5,6]*Department of Built Environment Studies and Technology,*
College of Built Environment,
UNIVERSITI TEKNOLOGI MARA, PERAK BRANCH, MALAYSIA
[3]*Centre of Studies for Town and Regional Planning,*
College of Built Environment,
UNIVERSITI TEKNOLOGI MARA, PUNCAK ALAM, MALAYSIA

Abstract

FELDA is enforcing a new direction of sustainable FELDA development in the future. It has timely developed a Sustainability and Highest and Best-use (SHBU) framework based on a GIS-based Multicriteria Decision Analysis (MCDA) approach for optimising FELDA lands, particularly crops, and other possible developments. This paper attempts to demonstrate the application of the GIS-based SHBU for FELDA Bukit Rokan discovering its capabilities. It includes generating criterion maps and sub-criterion maps, weighting criterion maps, and creating outcomes – composite maps of cropland suitability and future-physical development. The geospatial analyses for a Bukit Rokan confirmed that the SHBU model could provide the needed information for crop and settlement area developments. The production of the composite crop and physical land development maps significantly helps FELDA management or crop plantation planners optimise lands for crop plantation and future physical development. Hence, its application provides valuable information about the areas and support attributes enhancing FELDA lands development planning decision-making.

Keyword: FELDA, Sustainability & highest and best use, GIS, MCDA, UAV

[1] Associate Professor at Universiti Teknologi MARA Perak Branch. Email: mohdf032@uitm.edu.my

INTRODUCTION

A FELDA blueprint, the so-called report of Kertas Putih, aims at enforcing a new direction of sustainable FELDA development in the future through two catalyst projects, namely: (a) the Settlers Development Programme (SDP); and (b) the Smart farming initiative via Smart Plantation Management System (SPMS). By working on it, Rashid et al. (2022) have developed a sustainability and highest and best use (SHBU) framework as a missing link approach to the SDP and SPMS to oversee the optimisation of FELDA lands for crops and other possible developments comprehensively. It is timely to address FELDA's fundamental issues, such as unproductive or abandoned lands, limited housing schemes for second and third generations, low-income settlers, and so on (Government of Malaysia, 2019). More importantly, it aligns with the sustainable development goals, remarkably reducing inequalities between rural and urban areas and enhancing recent work and economic growth (UNDP, 2023).

The current paper attempts to demonstrate the application of the GIS-based SHBU for FELDA Bukit Rokan discovering its capabilities in optimising FELDA lands, particularly crops, and for other possible developments. FELDA Bukit Rokan located in Mukim of Gemencheh, District of Tampin, Negeri Sembilan. The selection is based on the developed criteria (i.e., strategic issues of land development and residents' economic activities) and consent from representative FELDA officers.

SHBU MODEL FOR FELDA LANDS DEVELOPMENT PLANNING

The SHBU framework (Figure 1) developed by Rashid et al. (2022) is tailored to the prospects and fundamental issues in the FLEDA settlements.

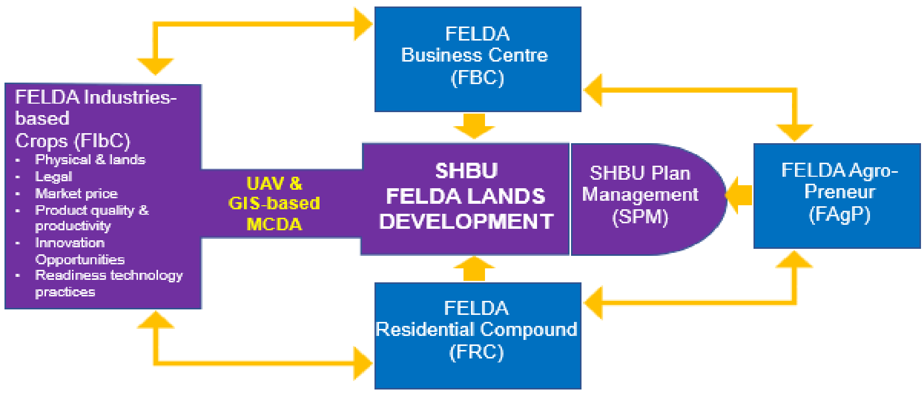

Figure 1. Five-Dimension-Objectives Measure-based SHBU Framework for FELDA Lands Development
Source: Rashid et al. (2022)

The SHBU measure is aimed at synergising FELDA transformation towards diversifying economic catalysts in the settlement schemes by five-dimension-objectives measure: FELDA industries-based crops (FIbC) and SHBU plan management (SPM) from the highest-best use (HBU) domain; and the remaining FELDA business centre (FBC), FELDA residential compound (FRC) and FELDA agro-preneur (FAgP) are from the sustainability domain. It is a strategic and comprehensive approach to realising the FELDA lands development by integrating with a GIS-based Multicriteria Decision Analysis (MCDA) approach. Furthermore, an Unmanned Aerial Vehicle (UAV) would be embedded as a tool for obtaining real spatial data and their attributes on-site, as well as enhancing SHBU geospatial analysis and results. Further discussion of the SHBU model can be obtain from Rashid et al. (2022).

METHODOLOGY

A Detailed Process of A GIS-MCDA Application

Figure 1 depicts the overall process of generating the SHBU's FELDA lands development at the execution stage using a GIS-based MCDA approach.

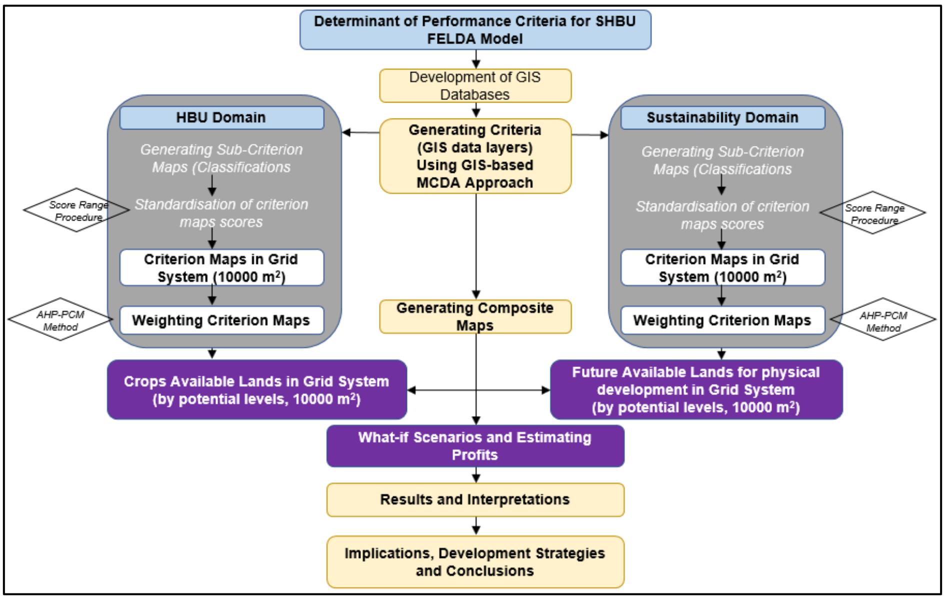

Figure 01: An entire process of executing the SHBU model based on a GIS-based MCDA approach

A GIS-based MCDA approach is an excellent analysis tool for dealing with and managing spatial decision problems (Prieto-Amparán et al., 2021), such as FELDA lands development planning decision-making. It includes identifying the suitability of lands for crops and future-physical potential projects such as a business centre, residential compound and agro-preneur centre. The process then involves three main stages in order to accomplish the execution of the SHBU model: (a) Generating criterion maps and sub-criterion maps, (b) Weighting criterion maps, and (c) Creating outcomes – composite maps of cropland suitability and future-physical development.

The SHBU outcomes can be breakdown into three main stages so as to provide planning scenarios, intervention strategies, and profit estimations. These anticipated outcomes include: (a) Stage 1 – Assessment for crops available lands by potential levels, (b) Stage 2 - Assessment of available areas for future-physical development, and (c) Stage 3: What-if scenarios for feasible FELDA lands development and estimating profits. However, stage 3 will not be included in this paper due to the complex process and shall be presented in other publications. Additionally, only areas within 2km from centric points of the case study have been delineated for the SHBU model execution due to cost constraints to capture Unmanned Aerial Vehicle (UAV) images and generate GIS data layers.

Stage 1: Assessment for Crops Available Lands by Potential Levels
*(a)*Generating the criterion maps
The croplands suitability assessment will be executed on the five determined performance criteria. These performance criteria, with their sub-criteria and standardised scores, are described in detail in Table 1.

Table 1: Five selected performance criteria and classifications with the standardised scores for crops lands potential levels

	Criterion Maps with Weights	**Sub-Criterion Map in Raster System (Classifications by 10000 m^2)**	**Justifications**	**Raw Score**	**Standardisation of Scores**
1	Crops map	Productive areas	Areas with healthy (productive) oil palm trees	2	1.0
	(W=0.402)	Productive areas but require replanting	Areas with unproductive oil palm trees (trees above 25 years old)	1	0.5
		Non-productive areas with constraint (or merged with constraint areas)	Constraint areas due to a higher slope level and difficult to access	0	0.0
2	Slope levels	Suitable areas for crops (slope level 0-12 degree)	Acceptable slope levels for oil palm and others (multiple interim crops)	3	1.0
	(W=0.273)	Suitable areas for crops (slope level 13-20 degree)	Acceptable slope levels for oil palm and others (short term crops)	2	0.7
		Suitable areas for crops (slope level 21-25 degree)	Acceptable slope levels for oil palm and others (medium-long term crops)	1	0.3
		Constraint areas (slope level above 25 degree)	Constraint slope levels for oil palm	0	0.0

3	Access to estate (Estate access network) (W=0.110)	Areas within radius (buffer) 100m	Areas with a higher accessibility (for crops management)	1	1.0
		Areas outside radius (buffer) 100m	Areas with a lower or no accessibility (for crops management)	0	0.0
4	Fertile areas (W=0.146)	Vacant estate lands (with no existing crops)	Areas that can take into consideration for crops planting (based on the current physical features)	1	1.0
		Vacant estate lands with constraint (or merged with constraint areas)	Constraint areas due to a higher slope level and difficult to access	0	0.0
5	River/water bodies (water resources) (W=0.068)	Areas within radius (buffer) 50m	Areas with a higher accessibility to water resources (for crops management)	2	1.0
		Areas outside radius (buffer) 50m	Areas with a lower accessibility to water resources (for crops management)	1	0.5
		The existing river/water bodies (as constraint)	Constraint area (no development on river/water bodies)	0	0.0

Table 1 shows that each criterion has gone through two important processes in order to be ready for generating a composite map of cropland suitability, namely, (1) classification, and (2) criterion scores standardisation. Each classification process involves various geospatial analyses in the ArcGIS environment, such as buffers, clips, merges, vector to raster conversion, and so on. The crop criterion map, for instance, is classified into three sub-criterion maps. Each sub-criterion map has an unequal importance (or effect) on the cropland suitability. They were evaluated by giving 'raw' scores by their magnitude of effect. The more effects on the cropland suitability, the higher score will be given.

To reduce all the raw scores in the direct comparable format, all the sub-criterion maps need to be transformed into one common measurement unit, through implementation of the standardisation of the criterion scores. At this extent, the score range procedure method has been applied with an equation, as follows:

$$z_j = \frac{x_j - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (1)$$

where zj is the standardised score for jth sub criterion (attributes), xj is the raw score for jth sub criterion, and xj min and xj max are the minimum and maximum score for the jth sub criterion, respectively. The numerator measures the range of the jth value from the minimum. Meanwhile, the denominator measures the range of the data (i.e. the variability). Thus, zj is a standardised value. The value of the standardised scores ranges from 0 to 1, where the worst standardised score is always equal to 0, and the best score equal to 1 (Table 1). Then, all the criterion maps are converted into a grid system in the value of 10000m^2 to complete the process of generating the criterion maps of the cropland suitability assessment (Figure 2).

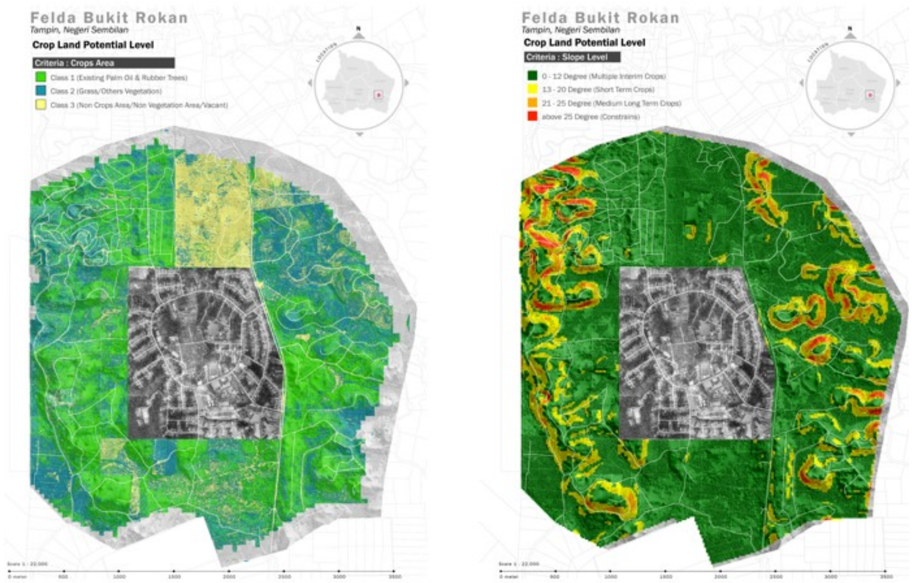

Figure 02: Examples of criterion maps (with classifications and standardization of scores) for cropland suitability assessment (Bukit Rokan)

*(b)*Weighting the criterion map

One more important step, that is required for generating the composite map of cropland suitability is the weighting criteria. It is due to the five criterion maps of the cropland suitability assessment have different extents of importance in the overall assessment. Hence, relative importance exercises are needed. This issue was then handled by an MCDA-based Analytic Hierarchy Process based Pairwise Comparison Matrix (PCM) to strengthen the decision-making process (Saaty, 1980; Saaty & Kearns, 1985). The AHP-based PCM is a relatively easy and effective approach to handle the spatially related problems of development strategies (Malczewski, 2004). The PCM dealing with positive reciprocal matrices in which each matrix table is determined by the equation,

$$\frac{n(n-1)}{2} \quad (2)$$

where n is the total number of performance criteria (criterion maps) being compared. So that, the size of pairwise comparison table for the assessment is calculated as *n* = 5 (performance criteria), so 5 × (5-1) ÷ 2 = 10, by means that only 10 comparative judgements were needed to accomplish the weighting task.

Table 2 shows that the values (scores) in the upper right corner (shaded values) were derived from pairwise comparisons of the relative importance among the five performance criteria. This exercise was accomplished through the researcher's group discussion. The other values were derived using logic (reciprocal), where C1 > C2 = 2; thus, C2 < C1 = 0.5 and C1 > C3 = 3; thus, C3 < C1 = 0.33. When comparing a dimension to itself, the evaluation scale (ratio) must equal one, which indicates "equal importance." A similar procedure was applied to the balance judgment process.

Table 2: Three results (shaded scores) croplands potential levels

Criterion Maps	**Judgment Process**					**Weights**
	C1	C2	C3	C4	C5	
C1	1	2	3	3	5	0.402
C2	0.5	1	2	3	4	0.273
C3	0.33	0.5	1	0.5	2	0.110
C4	0.33	0.33	2	1	2	0.146
C5	0.2	0.25	0.5	0.50	1	0.068
					Total	**1.000**
					Consistency ratio (CR)	**0.012**

Note: C1=Crops map, C2=Slope levels, C3=Access to estate (Estate access network), C4=Fertile Areas map, and C5=River/water bodies (water resources)

Accordingly, C1 was weighted at 0.402, C2 (0.273), C3 (0.110) with a low value compared to C4 (which is 0.146), and the last is C5 with 0.068. The judgment process confirmed that when the Consistency Ratios (CR) were less than 0.10. This would portray each area in its best light for the crops according to their criteria' performances.

*(c)*Generating the composite map

The final stage is generating the composite map by applying the standardised scores for each sub-criterion of the five criterion maps (in the GIS raster system), and the weights for each criterion map. This process is a weighted linear combination (WLC) or scoring method that is based on the concept of a weighted average. The WLC uses the following formula (Malzewski, 2004):

$$A_i = \sum_{j=1}^{n} w_j \, x_{ij} \quad (3)$$

where x_{ij} is the score of the ith alternative (pixel of lands in the grid system) with respect to the jth attribute (criterion maps), and the weight w_j is a normalised weight, so that $\sum_{i=1}^{n} w_i = 1.$ The weights represent the relative importance of the criterion maps. The most preferred alternative (very potential of land) is selected by identifying the maximum value of A_i (i = 1,2,...,m). In the case of the cropland availability problems, alternatives can be the whole pixel of lands of the study area but different in their degree (potential levels).

Stage 2: Assessment of Available Areas for Future-physical Development
This assessment follows a similar procedure to the first, but with a different set of data (Table 3).

Table 3: Five selected performance criteria and classifications with the standardised scores for a Business Centre and Residential lands potential levels

	Criterion Maps with Weights	Sub-Criterion Map in Grid System (Classifications by 10000 m^2)	Justifications	Raw Score	Standardisation of Scores
1	Reserve/ alternative development lands (W=0.433)	Reserve/ vacant lands within 100m from the existing residential areas	Potential areas for physical-future developments	3	1.0
		Reserve/ vacant lands within 100m from the existing settlement service centre	Potential areas for a business centre	2	0.7
		Reserve/ vacant lands outside 100m from the existing residential areas and settlement service centre, and 100m within the existing PPP projects.	Areas that could consider for any possible physical-future developments (including PPP projects)	1	0.3
		Existing residential, public facilities, other land use activities (built-up areas)	Built-up areas that constricted for a new development	0	0.0
2	Access to settlement (Settlement access network) (W=0.280)	Areas within radius (buffer) 100m	Areas with a higher accessibility (for physical-future land development)	1	1.0
		Areas outside radius (buffer) 100m	Areas with a lower or no accessibility (for physical-future land development)	0	0.0
3	Slope levels (W=0.110)	Suitable areas for physical-future land development (slope level 0-10 degree)	Higher potential slope levels for physical-future land development	2	1.0
		Suitable areas for physical-future land development (slope level 11-17 degree)	Acceptable potential slope levels for physical-future land development	1	0.5
		Constraint areas for physical-future land development (slope level >17 degree)	Least or Constraint slope levels for physical-future land development	0	0.0

	Criterion Maps with Weights	Sub-Criterion Map in Grid System (Classifications by 10000 m^2)	Justifications	Raw Score	Standardisation of Scores
4	River/water bodies	Areas outside radius (buffer) 50m	Areas with a potential for physical-future land development	1	1.0
	(W=0.110)	Areas within radius (buffer) 50m (as constraint)	Constraint area (no development on river/water bodies)	0	0.0
5	Legal (if applicable)	No restricted areas for development	Areas that allow for any potential possible development	1	1.0
	(W=0.066)	Restricted areas for development	No development is allowed due to restrictions by legal	0	0.0

Aforementioned, the classification of sub-criterion maps and the standardisation of scores in Table 3 follows the same process as in Stage 1. For the weighting exercise, Table 4 shows the judgment process for each criterion map to another and weights for each criterion map.

Table 4: Three results (shaded scores) for a Business Centre and Residential lands potential levels

Criterion Maps	Judgment Process					Weights
	C1	C2	C3	C4	C5	
C1	1	2	4	4	5	0.433
C2	0.5	1	3	3	4	0.280
C3	0.25	0.33	1	1	2	0.110
C4	0.25	0.33	1	1	2	0.110
C5	0.2	0.25	0.5	0.5	1	0.066
					Total	**1.000**
					Consistency ratio (CR)	**0.012**

Note: C1= Reserve/ alternative development lands, C2= Access to settlement (Settlement access network), C3= Slope levels, C4= River/water bodies, and C5= Legal (if applicable)

Accordingly, as shown in Table 4, C1 was weighted at 0.433, C2 (0.280), C3 and C4 got the same weight values which is 0.110, and the last is C5 with 0.066. The judgment process also confirmed that the Consistency Ratios (CR) were less than 0.10 which is 0.012. This would portray each area in its best light for the expected projects according to their indicators' performances.

RESULTS AND DISCUSSIONS

Croplands Available by Potential Levels

The expected results from this assessment can be classified into three main outputs: (a) Areas that have the potential for the main crop (palm oil trees), (b) Areas that have potential for interim crops/ integrated agricultural, and (c) Constraint areas for crops.

Moreover, to complete the application of the SHBU's croplands suitability for generating a composite map using a weighted linear combination

(WLC) - the weighted average of the five performance criteria. The WLC for the SHBU's croplands suitability was defined as the following:

$$FCLands_{ij} = \sum_{j=1}^{n} w_j \, \chi_{ij} \quad (4)$$

Where $(FCLands)_{ij}$ is FELDA croplands suitability at the coordinate *i*th row and *j*th column, i = 1, 2,…, nk, j = 1, 2,…, mk; *Wj* is normalised weights for the *j*th criterion map so that $\sum wj = 1$, j = 1, 2,…,n; x_{ij} is the standardised score of the *j*th criterion map concerning the destination at coordinate *i*th row, *j*th column, i = 1, 2,…,nk, j = 1, 2,…,mk. nk is the number of rows in the *j*th criterion map, and mk is the number of columns in the *j*th criterion map. The values of x*ij* and W*j*, where k = 1, 2,…,5, are shown in Table 1.

Figure 3 shows the result of cropland suitability by potential levels for Bukit Rokan. Four potential levels (or areas) were generated to demonstrate the croplands' suitability, namely: (a) the most potential, (b) potential, (c) less potential, and (d) the areas with constraints. The results were then transformed into size and distribution (Table 5).

Figure 03: Croplands suitability by potential levels in Bukit Rokan

Table 5: The generated size of crop areas by their potential levels and intervention strategy for Bukit Rokan

The Existing Crop Planted Area (H)	The Generated Size by Potential Levels		Crop Areas - Potential Intervention Strategy
	Potential Levels	Size (H)	
860.50	The most potential	526.10	It is the most productive area that remains for the oil palm trees and adds on with interim crops (e.g., cili merah, cili hijau, jagung manis) planted within the oil palm trees, particularly in replanting areas.
	Potential	139.20	This area also remains for oil palm plantation with mitigation to better manage the trees, production and harvesting support.
	Less Potential	115.20	This area also remains for oil palm plantation with all the needed mitigations to better manage the trees, production, and harvesting support.
	Constraint areas	91.58	The highly land area has potential to be created for plantation tourism-based recreation and extreme sports for adventure and fun such as mountain biking, ATV off-roading, etc.
Total		872.10	

Table 5 shows the existing size of crop plantation areas compared to the generated size by their potential levels. It shows that approximately 525 hectares (60%) of the total areas were identified as the most potential areas for crops based on performance criteria, such as existing productive lands, suitable slopes, higher accessibility for crop management, and nearby sources of water. It is followed by potential and less potential levels with 139.20 hectares (16%) and 115.20 hectares (13%), respectively. The remaining (92 hectares or 11%) is identified as a constraint area due to its steep slope. As such information, the potential crops and any other development activities could be suggested for each respective area according to FELDA aspirations, settlers' needs, locations and geographical features such as high land areas suitable for recreational activities. More importantly, the results shall provide a solution room to the issue of less diversification of crops at the farm level, as highlighted by Khazanah Research Institute (2020).

It is worth noting that the results of the SHBU composite crop map generation can also indicate cropland optimisation in comparison to existing plantation areas. This can be seen in increasing and optimising the potential cropland areas instead of planting on the total with constraints. Mitigation plans can be properly designed to cater to the areas with less potential while avoiding the constraint areas for crop planting. In this case, only 780.5 hectares of cropland are suitable for crop planting. Subsequently, the SHBU results can significantly increase crop production and quality, and generate more profits. It reflects the concept of the HBU, that is, dedicated the measurable results with physically, reasonably and financially feasible (Utomo et at., 2018), and offers an approach for resilience in cropland and rural areas (Knickel et al., 2018). So, this attempt gives a value-addition to croplands development and crop plantation literature as well.

Future-physical Land Availability
This stage is the SHBU model application for identifying the suitable locations (lands) for future-physical development in the FELDA residential/settlement areas, especially for a business centre and residential units. As such, as aforementioned, the two expected outcomes to be produced from a composite map of future-physical development are: (a) Areas that have the potential for residential units, a business centre (mini-RTC including FELDA Agro-Preneur centre), and (b) Other areas with no potential.

Then, the SHBU's future-physical development lands suitability is generated in the GIS environment to produce a composite map using a weighted linear combination (WLC) - the weighted average of the five performance criteria. The WLC for the SHBU's future-physical development lands suitability was defined as the following:

$$FFLands_{ij} = \sum_{j=1}^{n} w_j \, x_{ij} \quad (5)$$

Where $(FFLands)_{ij}$ is FELDA future-physical development lands suitability at the coordinate *i*th row and *j*th column, i = 1, 2,…, nk, j = 1, 2,…, mk; Wj is normalised weights for the *j*th criterion map so that $\sum wj = 1$, j = 1, 2,…,n; x_{ij} is the standardised score of the *j*th criterion map concerning the destination at coordinate *i*th row, *j*th column, i = 1, 2,…,nk, j = 1, 2,…,mk. nk is the number of rows in the *j*th criterion map, and mk is the number of columns in the *j*th criterion map. The values of xij and Wj, where k = 1, 2,…,5, are shown in Table 3.

Figure 4 shows the result of future-physical development lands suitability by potential levels for Bukit Rokan. Four potential levels were generated to demonstrate the future-physical development lands' suitability, namely: (a) the most suitable areas, (b) potential, (c) less potential, and (c) constraint areas. Out of those four, only the areas with the most potential and potential levels will be considered for future development. The result indicates the capability of the SHBU measure in producing a composite map of future-physical development land potential, which significantly helps FELDA management to optimise the uses of lands for future needed development.

Additionally, the SHBU measure provides some information (attributes), such as the size and distribution of the best areas and scenario planning that is relevant to consider in making decisions for future land development.

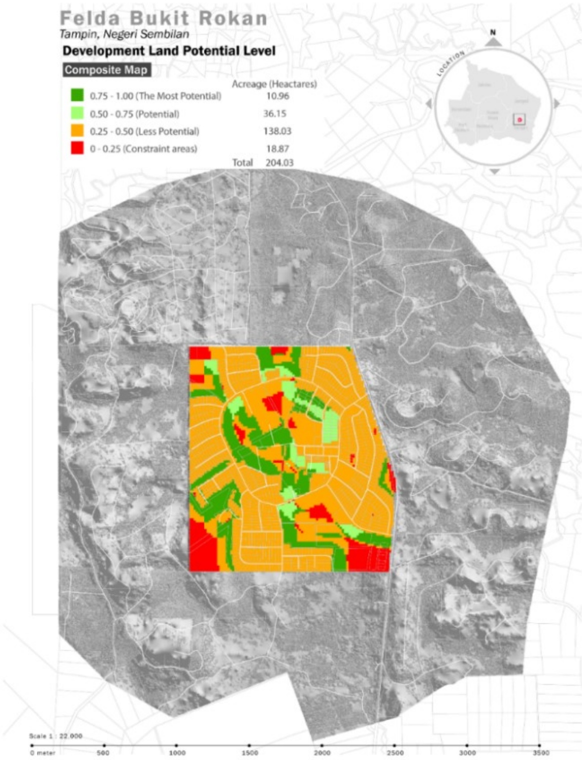

Figure 04: Future-physical development lands by potential levels in Bukit Rokan

Therefore, it indicates only the alternative areas of approximately 10.95 hectares suitable for physical development focusing on the three elements of the SHBU, which are a business centre, a residential compound and an agro-preneur hub. With the suitable areas, the determinant physical projects are based on the current needs of the residents incorporating the study area background (i.e., demographic profiles), the surrounding development (i.e., population threshold), and the size and distribution of the suitable lands as well.

Considering all the above matters, the future development projects in FELDA Bukit Rokan are a small-scale residential compound and agro-entrepreneur hub to cater to the resident's needs, particularly the youth generation. They are the most needed people to sustain FELDA lands for crops yielding the FELDA contribution to the nation. To that extent, as highlighted in Rashid et al.

(2021), the youth is the driven people to bring rural transformation towards a modern rural engaging technology in their livelihood, economic activities, and enhancement of rural solutions.

CONCLUSIONS

The geospatial analyses for a Bukit Rokan confirmed that the SHBU model could provide the needed information for crop and settlement area development decisions. The production of the composite crop and physical land development maps significantly helps FELDA management or crop plantation planners optimise lands for crop plantation and future physical development. That is, through generating the required information (spatial map and their attributes), such as the size and distribution of areas that are relevant for crop plantation management and the best location of lands for physical development and cost or profit estimation as well. This attempt adds value to cropland development, and FELDA lands development literature as well. The performance criteria, processes, and methods or techniques involved in generating FELDA land composite maps are new contributions in this field and could be endorsed as a novelty.

All research would not be exempt from limitations. The implementation of the SHBU model for Bukit Rokan is only within 2 km of the centroid points. It is due to the time and budget constraints, especially in developing a GIS database ready for the intended analysis. There is also an unavailable dataset to meet all the 'SHBU's performance criteria, such as criteria for fertile areas, so it was done with a manipulation process. This limitation, however, was well-managed and maintained the reliability and quality of the research outcomes. So, the identified shortfall and weakness would be avoided in future research.

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