Geographical Information System For Mapping Of Settlements Land Potential Index

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***Abstract*— Rapid population growth is a problem for all regions, especially in big cities. Because uncontrolled population growth will result in an increase in the need for housing, the amount of land needed for settlements will also increase. This paper presents spatial data modeling to determine the suitability of settlements on land with the land suitability potential index (LSPI) approach based on geographic information system (GIS) technology. Mapping the suitability of residential land using the LSPI approach is based on multi-criteria parameters of topography/relief, lithology, type of soil, hydrology, and disaster vulnerability. The private dataset from the Department of Regional Development Planning Agency of Jepara district, is the subject of our analysis. The results show that the superiority of the area that will produce a layer of information on mapping land suitability for settlements has a good land suitability classification category value with a land suitability potential index value of 25. The results of this trial state that this method can produce settlement land suitability maps, which are classified into three types, namely non-suitable, low-suitable, and suitable.**

Keywords—Spatial data modeling, geoprocessing, layer, land suitability potential index, GIS

I. INTRODUCTION

Rapid population growth and massive migration demand land availability as one of the most important indicators, especially in big cities [1]. Meanwhile, the limited availability of settlement land creates new problems [2]. An unbalanced comparison between the volume of population growth and the limited availability of settlement land causes land conversion problems or changes in the function of the land area from its initial function. This is due to the uneven distribution of land for appropriate settlements. In addition, the development of unsuitable settlements is one of the factors that increases the number of slum settlements.

Wei et al (2013) stated several environmental suitability criteria for settlements, such as: slope, aspect, degree of land surface relief, land use, vegetation index, hydrology, and climate, as a model of the human settlements environmental index (HEI) [3][4]. Meanwhile, Wilhelm (1992) states the need for environmental planning specifically, by mentioning aspects such as air and water pollution, waste disposal, degradation and lack of green areas [5]. However, often more territory was occupied through the informal occupation process than was formally planned [6]. Meanwhile, the need for natural resources such as forests, grasslands, wetlands and agricultural land has been converted into settlements. This is an important basis for determining the spatial distribution pattern of the population in a particular area [7].

Decision problems involving geographic data are referred to as geographic or spatial decision problems [8]. The spatial data of settlements land is the basis for studying the evolution of the spatial pattern of settlements and is therefore important for obtaining accurate results [9]. Thus, understanding the extent of spatial data and the geographic distribution of human settlements is fundamentally important for landscape management [10]. The use of spatial data that is processed into information can be used to analyze the needs of geospatial data as a decision-making system [8]. Spatial decision problems often require many feasible alternatives that can be evaluated based on several criteria [11].

Decision making and problem solving rely on information and communication technologies as well as the exchange of ideas and information, which are necessary to address a particular decision problem. Spatial decision problems often require a large number of alternatives to be evaluated against several criteria. Spatial decisions are multi-criteria [12]. Geographic information systems (GIS) are designed to address this problem. It has the ability to map and analyze spatial data with spatial analysis as well as time analysis (temporal analysis), which results in an integrated analysis covering all aspects [12][13][14]. Spatial decision problems often require many feasible alternatives that can be evaluated against several criteria [15]. Spatial analysis is easier with maps because it can produce deeper studies [16].

Spatial data modeling is the process of using data resulting from spatial analysis to determine decisions. The resulting process includes geocoding and mapping to produce a decision-making system. Accroding to Goirán et al (2012), detected vegetation changes associated with land-use with the spectral vegetation index SATVI (soil adjusted total vegetation index), which were not detected with the normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI) [17]. Analyzing land availability and suitable land suitability using multicriteria analysis (MCA) [18]. Mapping of agricultural land availability using fuzzy logic modeling taking into account climate and land classification [19]. analysis of site selection with GIS based Multi-criteria decision analysis (MCDA) [12]. An integrated land suitability potential (LSP) index was computed considering the contribution of various parameters of land suitability, and was categorized as good, fair, moderate, average, poor, and not suitable by adopting the logical criteria [20]. Presented an approach to calculate the theoretical and realistic potential of rural settlement consolidation (RSC) [21]. Spatial metrics combined with spectral information extracted from very high resolution (VHR) imagery allow quantification of general spatial characteristics of urban areas, as well as specific morphological features (i.e., density, size, and pattern) of unplanned settlements using the unplanned settlement index (USI) [22].

Based on previous research, the use of geographic information system technology through spatial analysis to identify the suitability of settlement land. Multicriteria spatial decision support systems have been used in a large number of disciplines, such as site planning, urban and rural planning, and distribution of limited resources [23][24]. Meanwhile, Niekerk et al (2016), combined multi-criteria decision making, GIS and planning support systems to generate a number of growth scenarios for settlements using ArcGIS software [25]. Our study will analyze spatial data using the land suitability potential index (LSPI) approach to assessing the suitability of settlements land to determine the weight value of each criterion based on topography/relief, lithology, type of soil, hydrology and disaster vulnerability parameters [3][4][20]. Before using this method, we assigned a weight to each criterion. Furthermore, the calculation process is carried out using the LSPI method. This study contributes to providing information related to mapping the suitability of settlement land, which will result in layers of information on settlement land that is non-suitable, low-suitable, and suitable. Then the results of the spatial map information are entered into the ArcGIS server-based Web map software.

II. Research Methodology

The application of the LSPI approach that is integrated with GIS technology is used as a decision maker in determining or selecting the feasibility of a location. The use of spatial data to analyze the need for geospatial data as a decision-making system [8]. Whereas, the ultimate goal of GIS is to provide support for spatial decisions with multi-criteria decision making [15]. Spatial data analysis in our study was used for mapping settlement land to produce information related to the suitability of settlement land. This process must input all the data that will be needed, with the aim of defining spatial data and layer attributes in the form of a spatial shapefile (*.shp). This dataset includes a map of the district of Jepara, Indonesia for each sub-district. The dataset contains attributes, such as: topography/relief parameters, lithology, type of soil, hydrology, and disaster vulnerability [3][4][5]. This spatial data modeling process uses the LSPI method to determine the suitability of settlements land. Before performing calculations on each criterion using this method. First, we determine the weight for each criterion.

A. *Analysis Parameter*

Spatial data will be applied in the form of layers and tables by assigning a weighting value to each parameter criterion that will be used for analysis using the LSPI method [4][20]. In the initial stage, we will analyze map information on settlements land areas. After the data is poured into layers and tables, the next step is to use the LSPI approach to calculate the weights for each parameter criterion in order to provide an analysis of the suitability of settlements land. In determining the weight vector, this model also allows the author to describe variations or uncertainties in the judgment of experts and the Regional Development Planning Agency of Jepara district. The first step is to examine the map data on the suitability of settlement land. The determination of the weight value for each criterion of suitability of settlements land is entered as in Table I, to calculate the parameters of this analysis. In the table, it can be explained that there are several criteria in each attribute with a weighted value between 0 to 10 [4]. The parameters of this analysis are determined by entering the weight value for each criteria for the suitability of settlement land as shown in Table I.

TABLE I. THE CRITERIA WEIGHT OF SETTLEMENTS LAND [4]

Criteria	Weight
Topography/Relief	
I (0-5%) / (flat-sloping)	5
II (5-15%) / (wavy)	4
III (15-25%) / (low hilly)	3
IV (25-45%) / (hilly)	2
V (>45%) / (mountainous)	1
Lithology	
Lb (massive igneous stone)	5
Lp (pyroclastic stone)	8
Lk (Coarse grained clastic sediment)	5
Lh (fine-grained clastic sediment)	2
Lg (limestone and metamorphic sediments)	3
Ll (limestone)	5
La (Aluvium / Coluvium)	10
Type of soil	
S1 (Crude: Regosol, Litosol, Organosol)	1
S2 (Rather roughly: Podsolik, Andosol)	4
S3 (Medium: Alluvial chocolate, Mediteran)	5
S4 (Somewhat subtle: Gley humus, Rensina, Podsol)	3
S5 (Refined: Grumosol, Latosol, Alluvial Gray)	2
Hydrology	
A1 (High productivity, wide spread)	5
A2 (Medium productivity, wide spread)	4
A3 (Medium productivity- high local (local))	3
A4 (Small productivity- medium local (local))	2
A5 (Rare groundwater)	0
Disaster vulnerability	
E1 (Very heavy)	0.5
E2 (Heavy)	0.6
E3 (Moderate)	0.7
E4 (Light)	0.8
E5 (Without)	1.0

B. *Geoprocessing Layer*

After determining the weighting value for each criterion, the next step is to perform the geoprocessing layer process. In this process, it functions to digitize analog maps by inputting all data attributes, parameters, and criteria in the form of a form file (*.shp) which will become a layer. The next stage will carry out the buffer process, which will be carried out after the layer is formed, with the aim of creating polygons from the area layer. After this process is formed, the union process will be carried out to unite the main data layer with the area layer. In this process, we will remove layers using the intersecting process, this is because this process produces several layers that are outside the range of the actual layer. So, in detail the process of analyzing settlements land can be explained in Fig. 1, while Fig. 2 is the process of analyzing the level of suitability of settlement land.

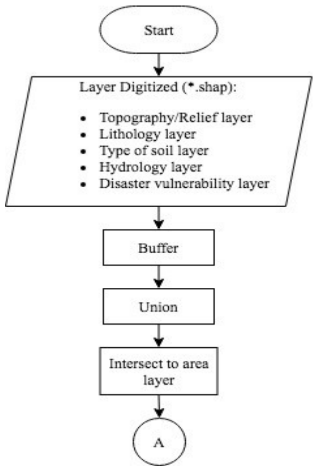


Fig. 1. Geoprocessing layer of settlements land

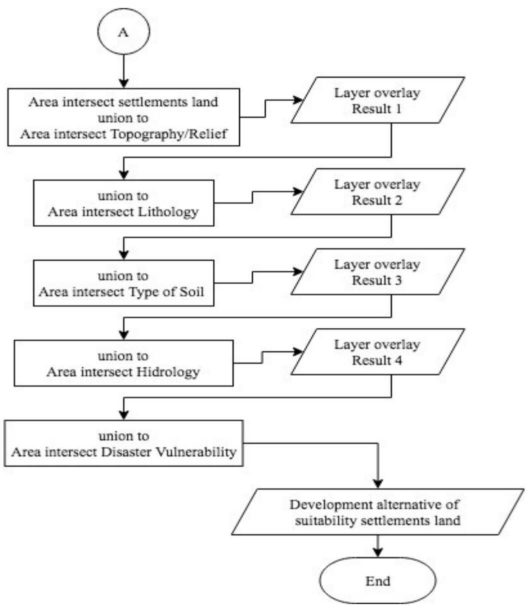


Fig. 2. Overlay result of development alternative of settlements land as a suitability settlement land

In the figure, we analyze the data from the initial data to make a decision. Layers of topography/relief, lithology, type of soil, hydrology, and disaster vulnerability in unity. From the union results, the overlay stage is carried out so that the 5 layers on the map are combined. Then, from the results of the overlay, the results of data analysis are formed from 5 layers into 1 main layer.

C. Framework Spatial Using Land Suitability Potential Index

The LSPI method is a quantitative comparison method that combines several different measurement criteria. Where, each of the existing criteria can provide several alternatives that are used for decision making as a solution to a problem. The use of this method is a way to determine the carrying capacity of land with numbers, the higher the number/value, the land has a high ability. In the preparation of the LSPI, the parameters that affect the value of the land suitability potential index are used, namely: topography/relief (T), lithology (L), type of soil (S), hydrology (H), and disaster vulnerability (D). In preparation for determining the land suitability potential index using equation [4].

$$LSPI = (T + L + S + H)*D \tag{1}$$

From the calculation results according to equation (1) described in Figure 3, which is a sequence of steps in calculating LSPI.

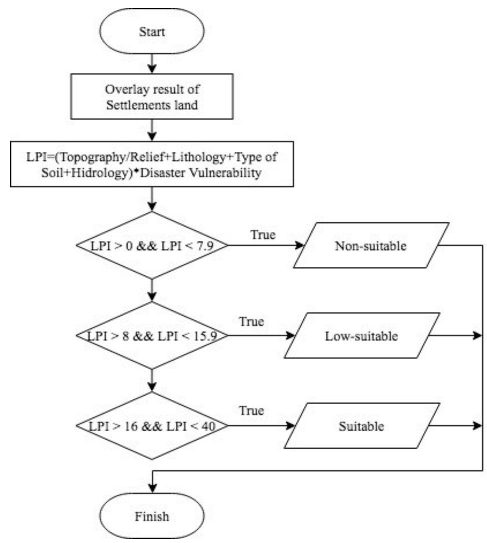


Fig. 3. Geoprocessing layer flow of overlay layer on suitability settlements land

The Land Suitability Potential Index (LSPI) states the relative potential of land for general uses. The higher the LSPI value, the higher the ability of the land if it is used for land processing activities so that it can provide optimal results. Land potential can be classified relatively into 5 classes, namely very high, high, Moderate, low, and very low. In this study, the land potential index method is used to determine the suitability of residential land in Jepara district with the parameters of topography/relief, lithology, type of soil, hydrology and disaster vulnerability as limiting factors, presented in Table II.

TABLE II. CLASS OF LAND SUITABILITY POTENTIAL INDEX

Class	Land Potential Class	Value Range
I	Very high	32 – 40
II	High	24 – 31.9
III	Moderate	16 – 23.9
IV	Low	8– 15.9
V	Very low	0 – 7.9

After being analyzed based on the LSPI formula, a value is obtained, thus the same process will occur for each existing parameter, the final value will then appear in each part of the layer map. Determine the smallest and largest values of all these calculations. The higher the LSPI value, the higher the ability of the land to be used for land processing activities so that it can provide optimal results. Thus, the obtained land potential values can be classified into 5 classes, namely: 32 – 40 (very high), 24 – 31.9 (high), 16 – 23.9 (moderate), 8 – 15.9 (low), and 0 – 7.9 (very low).

Next, overlay so that one map is obtained with variables from each map that is overlaid. The last step is to add up the scores from each map on each variable using the LSPI formula based on (1), then from the results of calculations and then classification according to the total value of the land potential index, the area is obtained based on the land potential index in Jepara district, which is presented in Table III.

TABLE III. AREA BASED ON LAND POTENTIAL INDEX

Land Potential Index Criteria	Wide (Ha)	Procentase (%)
Very high	2.0901	7.626
High	16.2630	59.342
Low	7.000	25.542
Very low	2.0527	7.49

From the weight values on the parameters in the Jepara sub-district, the system will analyze using the land suitability potential index method and the analysis results in the form of numbers that will determine the area map that is suitable or low-suitable or non-suitable for the suitability of settlements land in Jepara district. Then the classification process is based on class, divided into 3 classes, namely: class I (red area class which indicates non-suitable), class II (yellow area class that is low-suitable), and class III (green area class which indicates suitable). From this class coloring, can get information about land in a location or settlement area that is in accordance with the capabilities of the land and which land has the potential to be used as a settlement location or area, presented in Table IV.

TABLE IV. CLASSIFICATION OF CLASS

Class	Suitability	Value Range
I	Non-suitable	0 – 7.9
II	Low-suitable	8 – 15.9
III	Suitable	16 – 40

III. Result and Discussion

In the geoprocessing layer, the sample used is private data from the Department of Regional Development Planning Agency of Jepara district, Indonesia. Geoprocessing layer to determine the suitability of settlement land mapping in Jepara districts which is a base map of sub-district boundaries in Jepara districts with different colors and there are 16 sub-districts based on spatial data weighting analysis using a web-map based on ArcGIS server, as presented in Fig. 4.

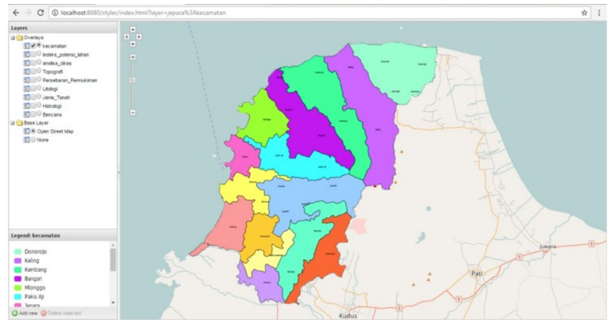
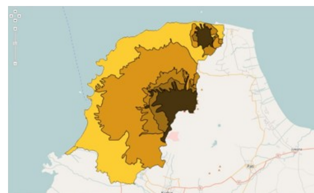
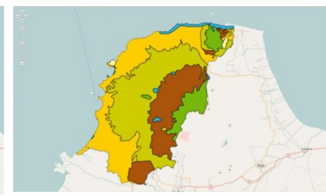


Fig. 4. Sub-District Base Map

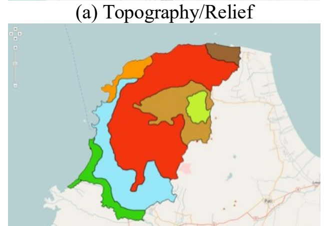
Where the results of this mapping can display an analysis of five conditions of settlement land based on each criterion, as presented in Fig. 5.



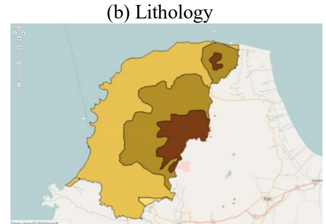
(a) Topography/Relief



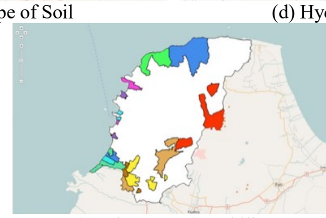
(b) Lithology



(c) Type of Soil



(d) Hydrology



(e) Disaster vulnerability

Fig. 5. Base Map of each criterion on settlements land

In Fig. 5(a) to determine the suitability of settlements land on the topographic/relief base map. The orange color is a topography/relief that is very suitable for the development of settlement land designations with a slope of 0 - 5%, the light brown color is a topography/relief suitable for the development of settlement land designations with a slope of 5 - 15%, the brown color is a topography/relief sufficiently suitable for the development of settlement land designations with a slope of 15 - 25%, The dark brown color is a topography/relief that is non-suitable for the development of settlement land designations with a slope of 25-40% and the black color with a slope of more than 40% is a topography/relief that is non-suitable for the development of settlements land use. While in Fig. 5(b) to determine the suitability of settlements land on the lithology base map. In the types of La alluvium/coluvium stone with orange color markings, Lp pyroclastic stone with light green markings, Lh fine-grained clastic sediment with blue markings, Lb massive igneous stone with dark green markings, Ll limestone with yellow markings, and LK coarse grained clastic sediment with brown markings.

Meanwhile, to determine the suitability of settlement land presented in Fig. 5(c) based on the basic map of soil types. The soil types are alluvial with orange markings, regosol brown soils with brown markings, latosol brown soils with light brown markings, andosol brown soils with light green markings, litosol red soils with red markings, mediteran association soils with light blue markings, and alluvial gray soil with green markings. Fig. 5(d), suitability of settlement land based on a hydrology base map. The hydrology base map describes the distribution of groundwater in the Jepara district. Using a gradient color that shows the darker the color on the map layer means that groundwater is decreasing or groundwater is getting scarce. Also, Fig. 5(e), to determine the suitability of settlements land based on a disaster vulnerability base map. The white color is a non-disaster-prone area, the red color is a landslide-prone area, the flood-prone area is marked in yellow, the brown color indicates a flood and drought-prone area, the light blue color is prone to flooding and tidal waves, while the dark blue color indicates prone to floods, tidal waves, and droughts. The dark green color indicates tidal waves and drought, light brown color indicates prone to drought disasters, the purple and pink colors indicate prone to abrasion and hurricane disasters, while the green color indicates prone to tidal wave and abrasion disasters.

After all parameters are entered, the calculation process is carried out using the LSPI method, which refers to equation (1) where the weight value of the parameters refers to Table I. Thus, the weighting value for each criterion is obtained, as follows: topography/relief has a weight value of 5, lithology of 10, soil type of 5, hydrology of 5 and disaster vulnerability of 1. Then calculate the LSPI value, thus a value of 25 is obtained with a land suitability potential index categorized as having a very good land classification (see Table IV). Layer analysis is based on the parameters used to analyze the suitability of settlements land in the Jepara district.

Thus, the results of determining the suitability of settlements land on the base map of the land suitability potential index are presented in Fig. 6. From the union results, the overlay stage is carried out so that the 5 layers on the map are combined. Then, from the results of the overlay, the results of data analysis are formed from 5 layers into 1 main layer. Where, the green color is an area that has the potency for development of settlements land designation, the yellow color is an area that is low-potency for development of settlements land designation development and red is an area that is non-potency for the development of settlement land designation in Jepara districts.

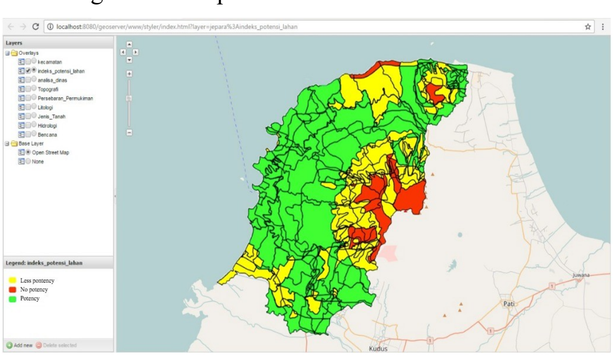


Fig. 6. Base Map of Land suitability Potential Index

An important factor in the accessibility of research and methods is the availability of tools that implement them, for example the ArcGIS product suite for implementing LSPI methods including weighting overlays and map algebra. The final result of this paper is recommendations for further actions for decision makers which are presented in the form of a suitability map. In Figure 7, a map of the suitability of raster and vector output is presented for mapping the distribution and knowing the distribution of suitable settlement areas in the Jepara area generated in ArcGIS using the LSPI method plugin.

Testing the application of land suitability mapping for settlements in Jepara district based on GIS technology calculates the success rate of calculating settlement land suitability analysis using the LSPI approach. The results of the calculation of the LSPI value with a land potential index categorized as having a good land classification [4].

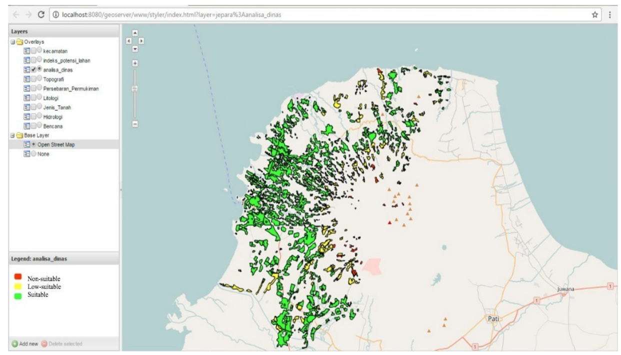


Fig. 7. Base Map for Settlement Evaluation

IV. Conclusion

Based on the results obtained in the geoprocessing layer based on the calculation of the LSPI method, in determining the weighting of the criteria for the suitability of settlements land which is classified relatively into 5 classes, namely very high, high, moderate, low, and very low. Spatial data modeling for land suitability mapping for settlements uses a GIS-based LSPI approach. The use of this method shows the advantages of mapping the suitability of settlements land which will produce a layer of area information in the form of non-suitable, low-suitable and suitable. There is a clear need for models such as decision support systems, which might help solve complex problems such as mapping the suitability of settlements land.

V. Further Works

Despite these developmental achievements, there are still many things that need to be improved from the analysis of spatial data using the methods in our paper. It is hoped that further research will develop the use of the model by collaborating with the multi-attribute decision making method and the classification method. The aim is to compare the results of the classification of settlement land suitability for each type of method used.

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References

[1] H. Akinci, A. Y. Özalp, and B. Turgut, "Agricultural land use suitability analysis using GIS and AHP technique," *Comput. Electron. Agric.*, vol. 97, pp. 71–82, 2013.

[2] A. Bjørn, M. Margni, P. O. Roy, C. Bulle, and M. Z. Hauschild, "A proposal to measure absolute environmental sustainability in life cycle assessment," *Ecol. Indic.*, vol. 63, no. April 2016, pp. 1–13, 2016.

[3] W. Wei, P. Shi, J. Zhou, H. Feng, X. Wang, and X. Wang, "Environmental suitability evaluation for human settlements in an arid inland river basin: A case study of the Shiyang River Basin," *J. Geogr. Sci.*, vol. 23, no. 2, pp. 331–343, 2013.

[4] Suharsono, *Identifikasi Bentuk Lahan dan Interpretasi Citra Penginderaan Jauh. Fakultas Geografi*. Universitas Gadjah Mada. Yogyakarta, 1995.

[5] J. Wilheim, "Urban planning in Brazil. The case of an Ill-developed though modern country," *Habitat Int.*, vol. 16, no. 2, pp. 65–71, 1992.

[6] P. Zeilhofer and V. P. Topanotti, "GIS and ordination techniques for evaluation of environmental impacts in informal settlements: A case study from Cuiabá, central Brazil," *Appl. Geogr.*, vol. 28, no. 1, pp. 1–15, 2008.

[7] X. Ke, J. van Vliet, T. Zhou, P. H. Verburg, W. Zheng, and X. Liu, "Direct and indirect loss of natural habitat due to built-up area expansion: A model-based analysis for the city of Wuhan, China," *Land use policy*, vol. 74, no. November, pp. 231–239, 2018.

[8] J. Malczewski, "GIS-based multicriteria decision analysis: A survey of the literature," *Int. J. Geogr. Inf. Sci.*, vol. 20, no. 7, pp. 703–726, 2006.

[9] W. Song and H. Li, "A new method for acquiring long-term high-precision spatial data on rural settlements," *MethodsX*, vol. 8, p. 101249, 2021.

[10] Y. Zhang *et al.*, "Landscape pattern and transition under natural and anthropogenic disturbance in an arid region of northwestern China," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 44, pp. 1–10, 2016.

[11] V. M. Salem Chakhar, "Spatial multicriteria decision making," in *Encyclopedia of GIS*, Springer, Boston, MA, 2008.

[12] A. Rikalovic, I. Cosic, and D. Lazarevic, "GIS based multi-criteria analysis for industrial site selection," *Procedia Eng.*, vol. 69, pp. 1054–1063, 2014.

[13] K. Eldrandaly, "A GEP-based spatial decision support system for multisite land use allocation," *Appl. Soft Comput. J.*, vol. 10, no. 3, pp. 694–702, 2010.

[14] P. B. Keenan and P. Jankowski, "Spatial Decision Support Systems: Three decades on," *Decis. Support Syst.*, vol. 116, no. October 2018, pp. 64–76, 2019.

[15] P. Nijkamp and P. Rietveld, "Multiple objective decision analysis in regional economics," in *Handbook of regional and urban economics. Vol. 1: regional economics*, vol. 1, ©Elsevier Science Publishers BV, 1986, pp. 493–541.

[16] S. Revitalizing, P. Of, and B. By, "Slum revitalizing plan of baghdadiyah by spatial re-modeling configuration," *J. Geomatics Plan.*, vol. 4, no. 2, pp. 69–80, 2017.

[17] S. B. Goirán, J. N. Aranibar, and M. L. Gomez, "Heterogeneous spatial distribution of traditional livestock settlements and their effects on vegetation cover in arid groundwater coupled ecosystems in the Monte Desert (Argentina)," *J. Arid Environ.*, vol. 87, pp. 188–197, 2012.

[18] Widiatmaka, W. Ambarwulan, Y. Setiawan, and C. Walter, "Assessing the suitability and availability of land for agriculture in tuban regency, East Java, Indonesia," *Appl. Environ. Soil Sci.*, vol. 2016, pp. 1–13, 2016.

[19] X. Zhang and X. Cai, "Climate change impacts on global agricultural land availability," *Environ. Res. Lett.*, vol. 6, no. 1, 2011.

[20] S. Bandyopadhyay, R. K. Jaiswal, V. S. Hegde, and V. Jayaraman, "Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach," *Int. J. Remote Sens.*, vol. 30, no. 4, pp. 879–895, 2009.

[21] X. Zhao, X. Huang, L. Li, and J. Fan, "Potential calculation of rural settlements consolidation: a case study of Tianchang City in Anhui Province," *PIAGENG 2010 Photonics Imaging Agric. Eng.*, vol. 7752, no. 1, 2011.

[22] M. Kuffer, J. Barros, and R. V. Sliuzas, "The development of a morphological unplanned settlement index using very-high-resolution (VHR) imagery," *Comput. Environ. Urban Syst.*, vol. 48, pp. 138–152, 2014.

[23] J. Malczewski and M. Jackson, "Multicriteria spatial allocation of educational resources: An overview," *Socioecon. Plann. Sci.*, vol. 34, no. 3, pp. 219–235, 2000.

[24] V. R. Sumathi, U. Natesan, and C. Sarkar, "GIS-based approach for optimized siting of municipal solid waste landfill," *Waste Manag.*, vol. 28, no. 11, pp. 2146–2160, 2008.

[25] A. Van Niekerk *et al.*, "Development of a multi-criteria spatial planning support system for growth potential modelling in the Western Cape, South Africa," *Land use policy*, vol. 50, pp. 179–193, 2016.