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LAND SUITABILITY ANALYSIS USING GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR SUSTAINABLE LAND DEVELOPMENT IN JELI, KELANTAN, MALAYSIA

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Abstract

Three (3) satellite images (2004, 2014, and 2022) were processed and analysed using a Geographic Information System (GIS) to obtain the land use types. The land suitability parameters were chosen based on population density and landscape factors such as slope, land use, elevation, and distance from rivers. The weights of each evaluation factor were determined using Analytical Hierarchical Analysis (AHP). Additionally, weighted overlay analysis, available in ArcGIS 10.8 software, was used to integrate all the parameters. This study found that Jeli's build-up area increased from 1.9% in 2004 to 24.5% in 2022. The suitability map for Jeli's land development has been reclassified into three (3) highly suitable categories (42.43%), moderately suitable (53.32%), and highly not suitable (4.25%). The area of land suitability for land use increases along with the population density. The findings of this study will help policymakers develop better strategic urban expansion policies.

Keywords: Land Suitability Analysis, Analytical Hierarchical Analysis (AHP), Weighted Overlay, Geographic Information System (GIS)

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INTRODUCTION

Urbanisation, migrating from rural to urban areas, necessitates thoughtful land use planning for sustainable development and economic growth. Efficient urban land assessment is crucial for optimal resource allocation, promoting intensive land use while considering environmental impact. The suitability of land units plays a pivotal role in determining urban use (Ge & Liu, 2021). Built-up activities in urban areas contribute to environmental issues like traffic congestion, pollution, and reduced open spaces. Slums, often located on vulnerable slopes and riverbanks, pose challenges for the urban poor, demanding sustainable land management for environmental health and well-being. Sustainable land management involves accommodating human needs while preserving the land's social, economic, and ecological functions (Al-Taani et al., 2021, Pirdaus Yusoh, 2022). Integrating GIS, Remote Sensing, and landscape ecology, spatial analysis explores the potential of interoperable databases for informed decision-making (Jamru et al., 2023). Landscape ecology focuses on ecological processes and spatial heterogeneity, aiming to understand ecosystem patterns and interactions within a region. The study aims to develop a land suitability map in Jeli, Kelantan, Malaysia, considering landscape factors and population density for informed urban planning (Nizeyimana, 2020).

LITERATURE REVIEW

Urban Development Impact on Landscape Structure

Exposing built-up areas has detrimental environmental consequences, causing traffic congestion, pollution, unsustainable land development, reduced public spaces, and increased strain on public services (Shao et al., 2021). As urbanisation progresses, impermeable surfaces increase, impacting stormwater infiltration and increasing direct runoff, altering urban hydrologic processes. This elevation in runoff raises the risk and severity of flooding, potentially causing substantial property damage. Land use and cover types, encompassing water bodies, built-up areas, vegetation, agriculture, roads, and cleared land, are essential components of the urban landscape (Table 1).

Table 1: Landscape Factor

Landscape Factor	Justification of criteria	Reclassification of maps
Land use	Vegetation cover sustaining natural and aesthetic values of a particular landscape	1. Forest 2. Agriculture 3. Built-up area 4. Cleared land (Schirpke et al., 2021)

Landscape Factor	Justification of criteria	Reclassification of maps
Elevation	Forest areas in lowlands are easier to access compared to those at higher elevations	1. 0-300m 2. 300-750m 3. 750-1200m 4. 1200-1500m 5. >1500m (Whitmore 1986)
Slope	Recreational development will be located in areas with gentle slope	1. 15° 2. 15-25 ° 3. 25-30 ° 4. 30-35 ° (Zhao et al., 2021)
Distance from river	river traces and some arithmetic to determine river distance (or "river mile") from point A to point B.	1. < 500m 2. 500 – 1500m 3. 1500 – 3000m 4. 3000 – 4500m 5. >5000m (Mihalevich et al., 2020)

Land Suitability Analysis for Sustainable Land Development

Land suitability analysis is crucial for determining suitable land uses, addressing environmental concerns arising from rapid urbanisation (Yang et al., 2021), and detecting deforestation, as Latip et al. (2022) mention. Furthermore, Pimid et al. (2020) highlighted the importance of forest management in achieving sustainable land development in forest areas. The study utilised a descriptive quantitative method, employing three land suitability classes (low, medium, and high) based on landscape factors and population density. One model suitability method discussed is the weighted overlay approach, which is implemented in ArcGIS. This method involves assigning weights to each raster layer, reclassifying values using a standard suitability scale, and creating a suitability value by layering and summing results. The values are the basis for the output layer's symbology, enabling control over how different factors interact in the suitability model. The Analytical Hierarchy Process (AHP) was employed to assign numerical weights to factors through pairwise comparisons. These weights, crucial for the weighted overlay method, were determined based on expert opinions using a pairwise comparison matrix (Hassan et al., 2020).

RESEARCH METHODOLOGY

Study Area

Jeli, located in Kelantan, is a crucial gateway to the state and a convenient stopover for travellers on the East-West highway from the East Coast to the West Coast. The Jeli - Dabong road connects the district to South Kelantan. Strategically bordered by Thailand to the north, Tanah Merah District to the east, Kuala Krai and Gua Musang District to the south, and Perak State to the west, Jeli is deemed a strategic area with significant development potential (Figure 1). The selection of Jeli as a study area is attributed to its status as a developing district in Kelantan that is experiencing urban expansion. The study focuses on the geographical coordinates of Jeli, Kelantan, situated at 5.7007° N and 101.8432° E.

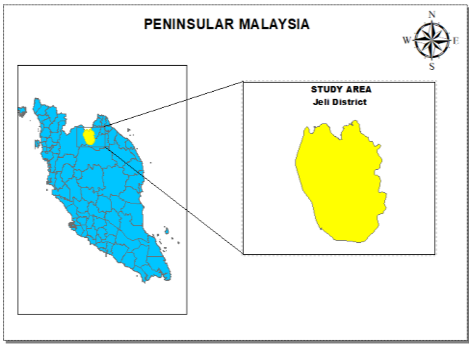

Figure 1: Map of the study area

Data Collection

This study adopted a case study approach, involving three key steps: data collection, processing, and analysis. Satellite imagery interpretation was used to create land use maps, recorded in both soft copy and hard copy formats. The research emphasised the importance of land suitability analysis for long-term reclamation planning, considering various land use alternatives such as agricultural, industrial, recreational, and residential areas (Wang et al., 2017). Satellite images from the United States Geological Survey (USGS) were obtained for selected study areas to develop Land Use Land Cover (LULC) data maps, which included land use, slope, and elevation maps (Table 2).

Table 2: Satellite Images

Year	Type of satellite image	Path/Row Resolution	Coordinate
2004	Landsat 8-9 OLI/TIRS C2 L1	127/056 30m resolution	Lat: 05° 42’ 02” N, Lon: 101° 50’ 35” E
2014	Landsat 8-9 OLI/TIRS C2 L1	127/056 30m resolution	Lat: 05° 42’ 02” N, Lon: 101° 50’ 35” E
2022	Landsat 8-9 OLI/TIRS C2 L1	127/056 30m resolution	Lat: 05° 42’ 02” N, Lon: 101° 50’ 35” E

Image Processing
Three geocoded satellite images were processed with ArcGIS to create Land Use Land Cover (LULC) maps for the Jeli district in 2004, 2014, and 2022. The satellite images were then subset using the boundary of Jeli that was downloaded from Global Administrative Areas (https://earthexplorer.usgs.gov/) to extract the area of interest from the image. For all three selected years, 2004, 2014, and 2022, the satellite images must be of good quality and have less cloud coverage around them to produce more accurate results. Supervised classification in remote sensing analysis involves collecting representative samples for each land cover class, known as "training sites", in ArcGIS (Richards, 2022). Initially focusing on specific features like urban areas, these training samples are progressively added across the entire image until appropriate samples for each class are obtained. The spectral data of these samples is compiled into a signature file, utilised for image classification.

Accuracy Assessment
Google Earth serves as a reference in the classification process, and various accuracy assessment methods, particularly using ground truth data, have been developed for classes with distinct boundaries (Maxwell & Warner, 2020). The comparison involves creating random points from ground truth data and assessing their accuracy against the classified data, a widely adopted method. Base maps and Google Earth aid in comparing outcomes of different classification methods, and ArcGIS is used to convert raster data to vector format. The resulting land use and land cover (LULC) maps are analysed to study the spatial pattern evolution in land suitability analysis.

Land Suitability Analysis
Use a weighted overlay to conduct a comprehensive analysis of land suitability based on a single factor's result. High, medium, and low suitability were assigned to the city's land use, and these integer numbers ranging from 1 to 5 were assigned to each category (Zhang et al., 2010). GIS-based land suitability mapping divides the urban and agricultural areas into zones, each with a different likelihood, or risk, of encountering specific land-use processes (Othman et al., 2021). To determine land class, numerical marks are granted as a weightage to various soil, land characteristics, and natural hazards, and the sum of this weightage determines the class obtained by that land, which is classified accordingly. The distribution of land use suitability for highly, moderately, and lowly suitable land use was shown using the weightage approach (Yang et al., 2021). After processing and classifying land use, elevation, and slope maps downloaded from the USGS, the next step involves categorising slope and elevation using the ArcGIS slope tool and adjusting colours through classification. Following this,

each map is ranked for high, medium, and low suitability on a scale of 1 to 5. To create a land suitability map using the weighted overlay tool in ArcGIS, the weightage of factors like land use, elevation, and slope must be calculated. These calculated results are input into the weighted overlay tool, where the overall sum of weightings is used to classify land. The Analytic Hierarchy Process (AHP) determines the weightage, ranking the significance of factors influencing urban land use changes at the system level through quantitative and qualitative analysis (Zhang et al., 2010). The AHP involves defining criteria weight, normalising pairwise comparison matrices, and creating a weighted matrix, with each criterion's weight influencing the weighted overlay.

Statistical Analysis

A correlation analysis was used to explain the landscape factors and population density by using Pearson's correlation (Abas et al., 2020). The researchers used Microsoft Excel to get the regression and correlation data using the landscape factors and population density data. The correlation coefficients are calculated using land suitability area as the dependent variable and population density as the independent variable.

> H_0: There is no significant relationship between landscape factors and population density.

RESULTS AND DISCUSSION

Image Classification

Figures 2, 3, and 4 represent the land use map for Jeli and Kelantan in 2004, 2014, and 2022, respectively. Each figure contains a land use map with the following class categories: waterbody, cleared land, agriculture, build-up area, and forest. The various uses of land were coded with different colours, and the legend for the map shows which colours correspond to which categories. The weighted overlay mapping results that produced land suitability results are shown in Figure 8 based on three categories for land suitability: highly suitable, moderately suitable, and highly not suitable.

Accuracy Assessment

Remote sensing imaging, using process data, was employed to identify physical factors accurately. Image enhancement assessed the quality of the satellite image, and a validation dataset with similar characteristics was used for accuracy analysis. The precision of the remote sensing-produced map was evaluated by comparing it to a reference map, often derived from different data sets, known as "ground truth." This ground truth could be obtained from high-resolution imagery, existing classified imagery, or GIS data layers. Classification accuracy was assessed after data image processing, typically reported as a percentage success rate. Random points were selected to create a land use map, and the classification of these points provided a nuanced evaluation of the map's accuracy. Table 3 summarises the data, indicating accuracy rates of 91.33% in 2004, 88.20% in 2014, and 89.53% in 2022. This evaluation method helped gauge precision between the randomly selected points and the resulting land use map.

Table 3: Accuracy Assessment and Kappa Statistic for 2004, 2014 and 2022 using Landsat 8 OLI/TIRS C1

Year	2004	2014	2022
Overall accuracy (%)	91.33	88.20	89.53
Kappa Statistic	0.8538	0.8165	0.8378

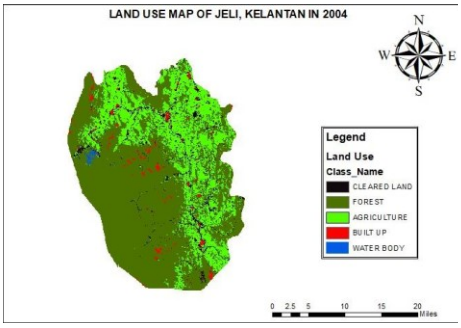

Figure 2: Land Use Map of Jeli, Kelantan in 2004

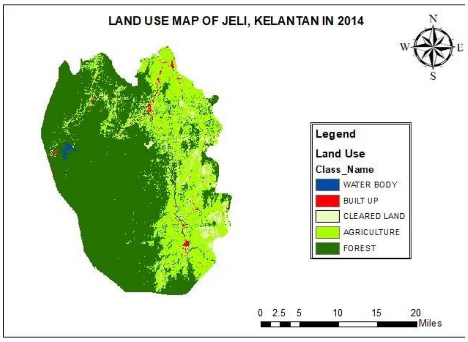

Figure 3: Land Use Map of Jeli, Kelantan in 2014

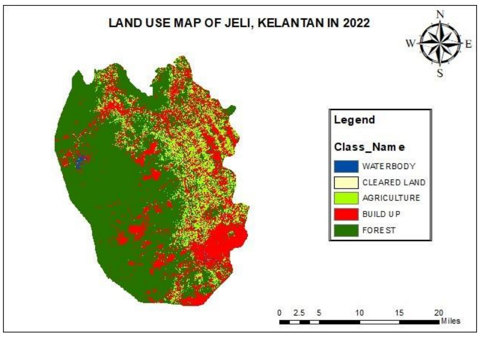

Figure 4: Land Use Map of Jeli, Kelantan in 2022

Land Changes Transition

In 2004, Jeli, Kelantan, had 4.8% cleared land, decreasing to 4.5% in 2014 and projected to be 0.5% in 2022 (Figure 5). The built-up area was 1.6% in 2004, decreasing to 0.9% in 2014 (likely due to the 2014 floods) and rising to 24.5% in 2022. The 2014 floods in Jeli caused substantial destruction to the built-up area. The study indicates urbanisation in Jeli, with open space transforming into built-up areas. Urbanisation involves clearing land for new development after deforestation, indirectly contributing to urban establishment. The research offers insights into land suitability for development, changes in green spaces over time, and the sequences of these changes in the ongoing urbanisation of a specific area.

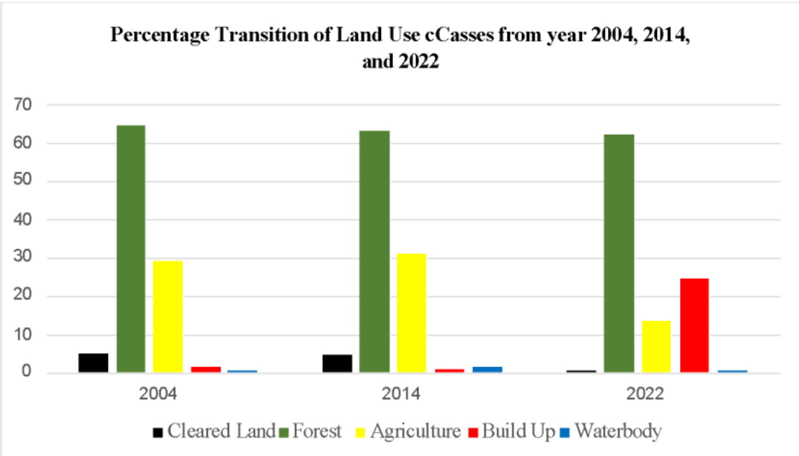

Figure 5: The graph of the transition of the classes from years 2004, 2014, and 2022

Land Suitability Analysis

This study developed a land suitability map for Jeli, Kelantan, in 2004, 2014, and 2022 based on landscape factors and population density. Figures 6 and 7 show the map considering factors like low elevation (prone to floods), high slope (prone to landslides), and land use. For land development, sustainability levels are classified as low, medium, or high. The study highlights the relationship between landscape factors and population density, offering valuable insights for urban planners to evaluate existing policies and develop sustainable development strategies (Rahman et al., 2021). USGS satellite imagery data from 2004, 2014, and 2022, along with Digital Elevation Model (DEM) data from the USGS, were used for image processing and land classification. The Analytic Hierarchy Process (AHP) was employed to assess factors influencing urban land use changes, determining weightage values for land suitability factors like land use, slope, elevation, and distance from the river (Table 4). The resulting land suitability map categorises areas into highly suitable, moderately suitable, and highly unsuitable for sustainable development (Figure 8). The weighted overlay feature in ArcGIS was utilised for the land suitability analysis, calculating the percentage of each suitability class. Results indicate the spatial distribution of land suitability classes, providing crucial information for sustainable development planning in Jeli, Kelantan (Table 5).

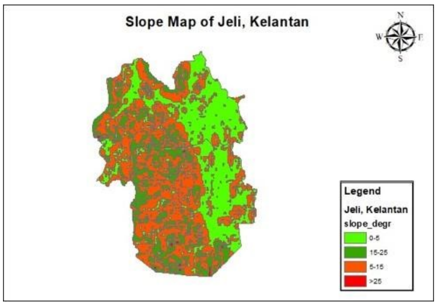

Figure 6: Slope map of Jeli, Kelantan

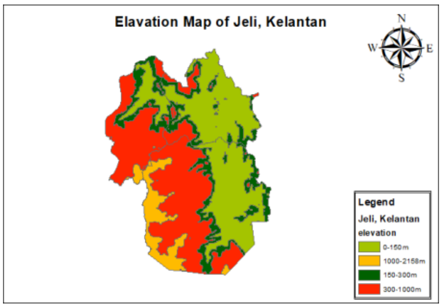

Figure 7: Elevation map of Jeli, Kelantan

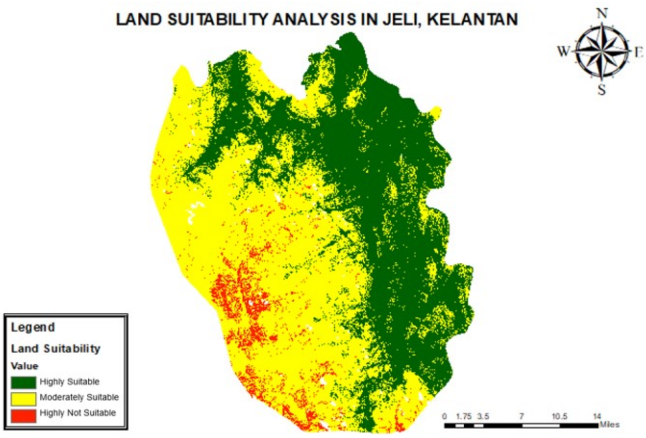

Figure 8: Land Suitability Analysis in Jeli, Kelantan

Table 4: Pairwise Comparison Matrix and Normalised Pairwise Matrix

Pairwise Comparison Matrix	E	S	LU	D
Elevation	1	2	2	4
Slope	1/2	1	2	4
Land use/ land cover	1/4	1/3	1	3
Distance from river	1/3	1/4	1/4	1
Total	2.08	3.58	5.25	12
Normalised Pairwise Matrix	E	S	LU	D
Elevation	0.48	0.56	0.38	0.33
Slope	0.24	0.28	0.38	0.33
Land use/land cover	0.12	0.09	0.19	0.25
Distance from river	0.16	0.07	0.05	0.08
Total	1	1	1	1
Note: E: Elevation, S: Slope, LU: Land use/Land cover, D: Distance from river				

Table 5 also shows that most of the land in Jeli is suitable for moderate, sustainable development. This category covered 75,565 hectares (ha) more land than the other categories combined. With a total area of 60,126 hectares, 42.43 per cent of Jeli's land is highly suitable for sustainable development.

Table 5: Results of Land Suitability Analysis in Jeli, Kelantan

Class	Area (Ha)	Percentage (%)
Highly Suitable	60,126	42.43
Moderately Suitable	75,565	53.32
Highly Not Suitable	6,019	4.25

This could be due to the land, slope, elevation, and distance from the river, which became perfectly suitable for sustainable development. In contrast, Jeli has 6,019 Ha with 4.25% land, which is highly unsuitable for any development. The findings make it abundantly clear that the Jeli have limited suitable land for cultivation.

Relationship between Landscape Factors, Population Density and Level of Suitability Analysis

Table 6 shows that the correlation coefficient is 0.551, indicating a robust positive correlation between the two variables. Because the p-value for the significance test is 0.000, which is less than any reasonable level of significance, the null hypothesis is rejected. Most of the land suitability area can be explained in terms of population density, according to the high value of R square, which is 0.303 for the relationship between population density and land suitability area.

Table 6: Pearson Correlation between Population Density and Land Suitability Area

	Population Density	**Land Suitability Area**
Population Density	1	0.551
Land Suitability Area	0.551	1

However, other factors like urbanisation and landscape may also affect population density.

CONCLUSION

This research focused on classifying land use in Jeli for 2004, 2014, and 2022. The study revealed a significant shift towards urban residential and built-up land, impacting non-land and inappropriate land, agricultural areas, and green spaces. Land suitability analysis based on landscape factors and population density indicated that most of Jeli's land is suitable for moderate development. The research highlighted a strong relationship between population density and land suitability, suggesting that the area of suitable land for development also rises as population density increases. The study underscores the potential influence on future sustainable development practices, aiding in preserving ecological networks and guiding policymakers in strategic urban expansion policies. It provides valuable reference data for city planners, facilitating improved urban planning and development plans, and enhancing the reasonable utilisation of limited urban land resources. The suitability evaluations contribute to informed decision-making for urban improvement.

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