RESEARCH PAPER

ENHANCING AGRICULTURAL PROTECTION AREAS UNDER SPATIAL RESTRICTIONS: A CASE STUDY OF MAJALENGKA REGENCY, INDONESIA

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ABSTRACT. The escalating trend of urbanization in Indonesia, accompanied by the conversion of agricultural land into urbanized areas, necessitates the implementation of zoning regulations. These regulations are crucial to protect agricultural land and safeguard the finite land assets of the country. To ensure the preservation of scarce land resources and guarantee food security, it is paramount for the Indonesian government to establish agricultural land protection areas. This paper presents an innovative approach and integrated methods to define agricultural land protection zones in spatial form. Results of studies landscape structure classification; core farmland accounts for 33.59% of the study region, whereas edge farmland accounts for 36.43%. Furthermore, the corridor farmland area is 0.30%, the discrete farming area is 12.26%, the Edge-Patch area is 3.54%, and the Perforated area is 13.89%. Geographically, the primary agricultural land is stretched out as a continuous area located on the outskirts of Majalengka city. By integrating Geographic Information Systems (GIS), remote sensing, landscape structure, prime farmland identification, and agricultural «land interest» could have a conservationist bent. It can mean protecting specific areas for environmental reasons (reach calculated), the study aims to create optimal farmland protection areas. The techniques outlined here can aid in determining PFPA from a geographical science standpoint, and the research's findings will be helpful for PFPA planning.

KEYWORDS: prime farmland protection area (PFPA), landscape structure classification, Geographic Information System (GIS), remote sensing, reach calculation, UrbanSCAD

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INTRODUCTION

Agricultural land is crucial for sustaining life, ensuring national food security, safeguarding the environment, and enhancing the transition to renewable energy sources. Furthermore, it plays an important role in military and security activities (Bakker et al. 2011; Godfray et al. 2010; Qianwen et al. 2017; Sutherland et al. 2015). The ecological habitat surrounding urban areas tends to deteriorate due to socio-economic progress and the reduction of natural areas. Also, the conservation of regional ecological security increasingly relies on the ecological function of agricultural systems (Deslatte et al. 2017; Reid et al. 2010).

To safeguard agricultural land, policymakers, specifically the government, needs to consider its scope, quality, and ecological role. Also, the preservation of a unified agricultural landscape system can promote sustainable food production, especially lands dedicated to agricultural purposes (Sayer 2009; Sayer et al. 2013). The contradiction between farmland preservation and urban expansion poses a fundamental difficulty in planning the landscape systems. This is an important issue because it is the major link between agricultural scale, quality, and the ecosystem (Girvetz et al. 2008; Holmes 2014).

Disruptions to agricultural landscapes caused by non-agricultural activities, such as construction, and human development caused changes in the landscape configuration. These disturbances led to a deterioration in the overall quality of agricultural land usage (Jiang et al. 2018; Liang et al. 2015). Spatially, building activities related to urban expansion were observed to encroach upon agricultural land in a given area due to the increased demand for urban development and urbanization flows. The importance of striking a balance between protecting agricultural land and facilitating urban growth cannot be overstated, as these are basic conditions for driving sustainable economic growth and establishing resilient urban centre (Chen et al. 2019; Huang et al. 2019; T. Liu et al. 2015).

In Indonesia, particularly in Java, there has been a massive shift from farmland to urban development. The drastic reduction in the agricultural land area poses threat to regional food security, particularly in the Majalengka Regency. This situation arises from the on-ground changes in the conditions of agricultural land cover/use, in relation to development of infrastructure, such as the West Java International Airport Kertajati and the surrounding areas (Adrian et al. 2022).

The spatial regulation of agricultural land should safeguard sustainable agricultural land near urban areas while limiting the construction of buildings to accommodate urban expansion. Also, precise measures are imperative to demarcate critical agricultural land protection areas and outline clear-cut limits for urban development (Deng et al. 2015; Duan et al. 2019; Jiang et al. 2016). Establishing sustainable food agricultural land protection zones necessitates optimizing agricultural land spatial planning to facilitate the proximity of agricultural land, whether in a dense or concentrated arrangement. Furthermore, encouraging agricultural mechanization is essential for increasing output and quality (Deng et al. 2015; Qianwen et al. 2017).

According to (Jiang et al. 2018), the integration of farmland landscape structure could directly enhance the function of the agricultural system, with the agricultural land protection strategy gradually shifting from a quantity-based perspective to a landscape reorganization perspective. Therefore, protecting agricultural land in the suburbs through new forms of administration and maintaining the spatial continuity of landscapes are important considerations that have been discussed (Duan et al. 2019; Perrin et al. 2018). This study takes into account management difficulties and landscape structure in depth to establish sustainable food agricultural land protection zones in Majalengka Regency.

This study addressed a gap in the existing literature by examining the tension between protecting farmland and creating new economic zones in the Majalengka District. Also, leading agricultural land protected zones and the prime property were identified near the Special Economic Zones development region using a landscape structure categorization model for agricultural land. Specific limits for urban development were drawn to prevent unchecked urban encroachment into farmland. Policy guidance for managing the connection between building, agricultural land conservation, and sustainable agricultural food land protection was also determined. This was achieved by integrating urban development boundaries with key agricultural land conservation zones to establish spatial control boundaries for cultivated land.

MATERIALS AND METHODS

Study Area

This study was conducted in Majalengka Regency, located in West Java Province. Majalengka is comprised of 26 Districts, and geographically situated between 108°03′ and 108°25′ East Longitude and 6°36′ and 6°58′ South Latitude. It shares borders with Indramayu to the north, Garut, Tasikmalaya, and Ciamis to the south, Sumedang to the west, and Cirebon and Kuningan to the east, (see Fig. 1).

This study was inspired by the fact that the agricultural sector remains a vital aspect of the welfare and economic growth for the people of Majalengka Regency, where the sector's domestic revenue still holds the first position in the province (BPS 2018). (Sari and Kushardono 2019) showed a massive change in the use of agricultural land in Majalengka. This transformation was driven by the construction of Airport BIJB infrastructure in the Regency, which was part of the Rebana Special Economic Zone. The area occupied by the West Java International Airport expanded from

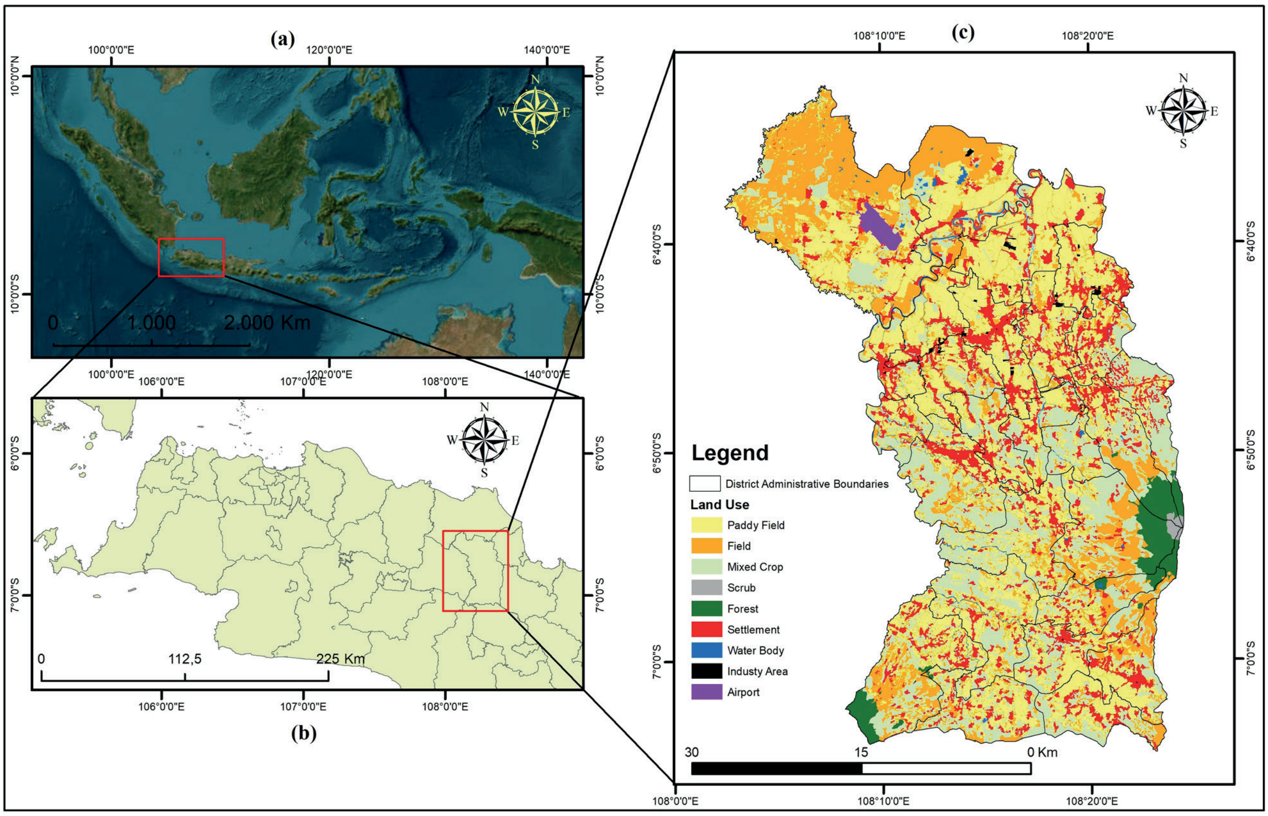

Fig. 1. Study Area

10.10 Ha in 2013 to 546.70 Ha in 2018. Furthermore, the area of paddy fields underwent a conversion of 413.30 Ha. This indicated the Rebana economic area in Majalengka Regency had a negative physical impact on land use change, primarily agricultural land on a large scale. It also significantly threatened regional food security, specifically in the area.

Data

This study utilized both primary and secondary data sources. The primary data included land use survey in the form of image interpretation in the field (using the results of field surveys), enabling the structural classifications of agricultural landscapes and providing essential data for planning agricultural land spatial regulations. The classification and gradation data on the quality of agricultural land served as the standard for evaluating high-quality agricultural land. In addition, secondary data comprised of several maps sourced from various regional and central agencies, as presented in Table 1.

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Methodology

Agricultural land protection zoning model

Zoning protected farmland is one example of a more general problem known as land use planning, a series of questions on how to optimize space utilization. The study flow presented in (Fig.2) illustrates the procedure for agricultural land protection zoning. Remote sensing enables the acquisition of land use and urban development information, while GIS (Geographic Information System) provides spatial data analysis tools. Also, land interest was used to classify agricultural land based on factors like accessibility and proximity to public social facilities. It provided a probability of change, which helped to determine potential future changes to built-up land. This model was intended to protect agricultural land based on suitability and growth potential maps. The subsequent sections will delve into models for solving zoning protection problems.

This study proposes a method for protecting agricultural land, namely by using three sub-models: (a) the farmland landscape sub-model, namely the use of land landscape characteristic factors, which delineate the functional landscape of agricultural land based on the agricultural landscape structure classification model (b) the farmland quality sub-model, the quality of agricultural land is more comprehensive, then an integrated quality assessment of regional agricultural land is carried out using spatial analysis; (c) reach calculation sub-model, namely Proximity analysis, often used in spatial analysis and geographic information systems (GIS), involving assessing the relationship and distance between spatial features. In the context of calculating range in proximity analysis, in this case, the value of interest is to determine how far a particular feature is from a particular location or set of locations; (d) delineate protection zones of prime agricultural land, Interactions between protected areas and prime agricultural land often involve considerations related to land use planning, conservation, and sustainable development, the specific processes are described (see Fig. 2).

Land suitability map data and land use surveys (Table 1), were used to carry out structural classification of agricultural land landscapes and gather primary data for planning spatial regulations. This process enabled the classification and gradation of agricultural land quality, facilitating the assessments for selecting high-quality agricultural land (Jiang et al. 2018; Qianwen et al. 2017). Also, the configuration of the landscape was directly associated with agricultural land. Core farmlands had the most contiguous distribution, the most minor interference from non-farm activity, and the best agricultural productivity of all categories; Furthermore, edge farmland serves as an ecological transition zone between core farmlands and nonfarm ecosystems; it aids in the isolation of ecological interference and the ecological buffering of nonfarm habitats and nonfarm activities occurring on prime farmlands; Edge farmlands buffer and protect core farmland production functions, and the two farmland kinds complement each other; Corridor farmlands, on the other hand, are canals that connect farmlands and serve as barriers between farmlands and nonfarm habitats. We combined the core farmlands as contiguous farmlands and the edge patches of farmland, discrete patches of farmland, and perforation farmlands as discrete farmlands using the landscape structure classification results, functional segmentation, and pixel attribute reclassification, and defined corridor farmlands as connecting channels. Contiguous farmlands and linked canals were chosen as the ideal prime farmland conservation patches to provide consistency among farmland landscapes, based on the definitions of different farmland landscape types, the details of the farmland landscape structure classification process described (see Fig. 3).

Table 1. Data-collection used in the study

No	Data Name	Data Type	Data Source	Scale
1	Landuse Map	Vector	Classification of Spot 7 2021	1: 25k
2	Local Government Regulation Map	Vector	Local Government Majalengka Regency 2021	1: 25k
3	Cultivation intensity map	Vector	Local Government Majalengka Regency 2021	1: 25k
4	Land area map	Vector	Local Government Majalengka Regency 2021	1: 25k
5	land suitability for paddy map in Majalengka Regency	Vector	(Adrian et al. 2022)	1: 25k
6	Administrative map	Vector	Landuse Plan (RTRW) of Majalengka Regency 2021	1: 25k
7	Points Of Interest	Vector	Google (Gmaps Leads Generator)	1: 25k
8	Map of building geometries	Vector	Open Street map and vectorization from Spot 7	1: 25k
9	Location of Paddy Field	Point	Ground Truth Data 2022	-

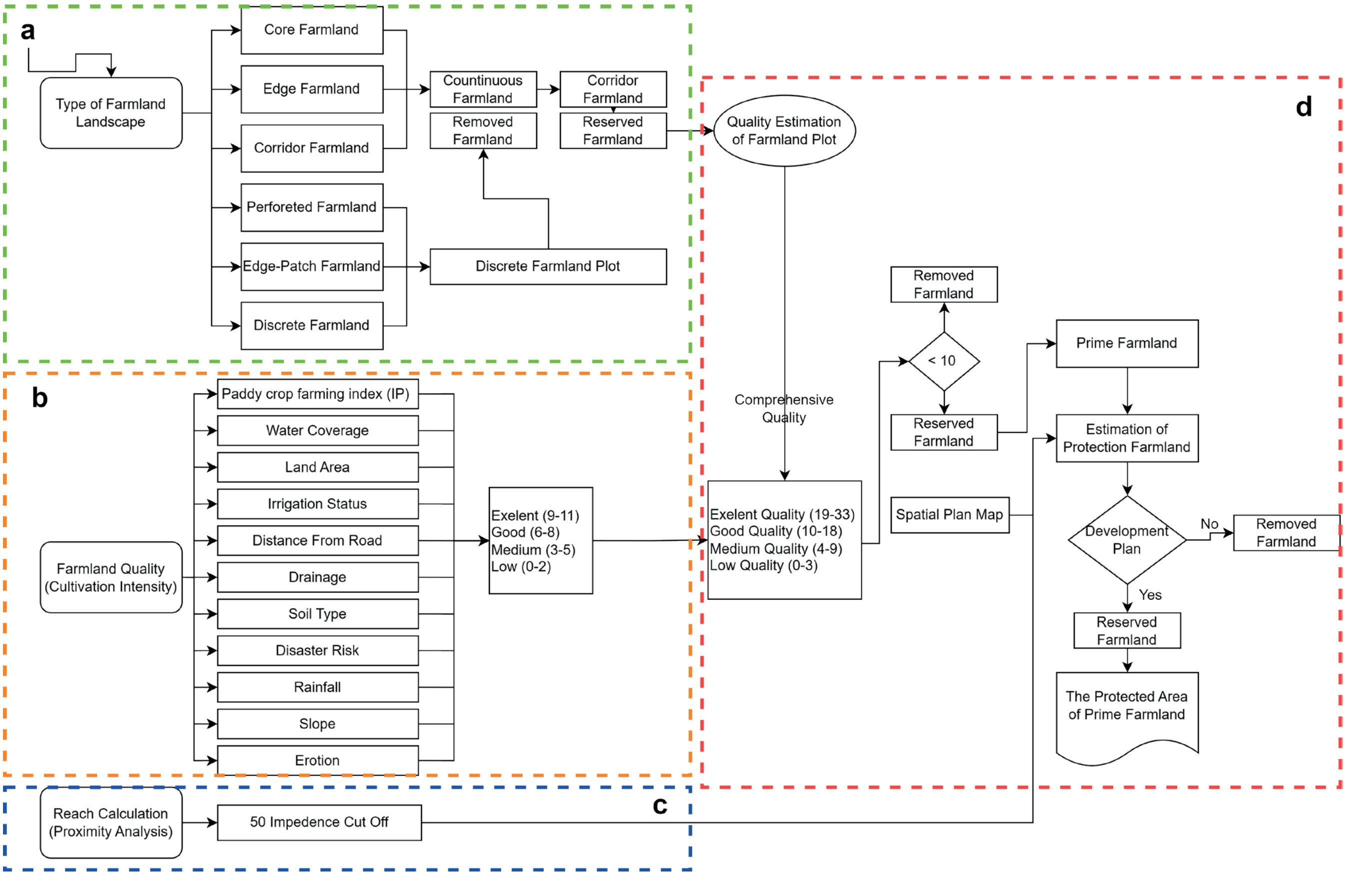


Fig. 2. Single-factor layer-by-layer exclusion procedure for identifying prime agricultural protection zones

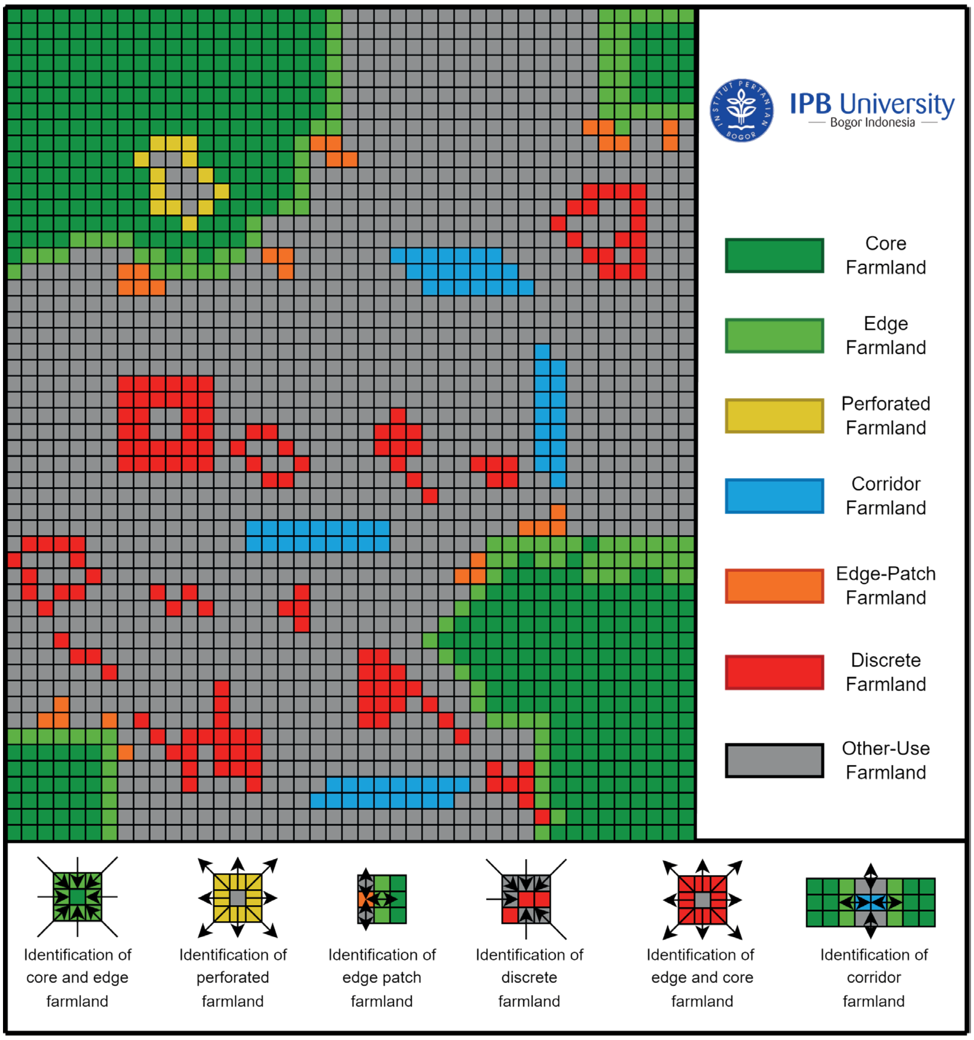


Fig. 3. Farmland landscape structure sketch map and farmland landscape categorization design

Excessive fragmentation necessitated greater precision in verifying the ecological role of agricultural land as a constituent of the landscape. It also led to noticeable mis-segmentation, focusing on the shared confusion among patches, edges, perforations, and corridors of agricultural land cartographic representation of a spatial plan (Jiang et al. 2020). Prime farmland (PF) protection area is described as high-quality farmland, A prime farmland protection area (PFPA) is a territory designated for the particular protection of PF, including accompanying roads, rivers, and facilities. The GIS spatial analysis process presented in (Fig.3) is as follows (1) Simplifying the polygonal form to delineate PF, (2) performing buffer analysis for each PF patch, and (3) conducting aggregation analysis to determine the boundaries of the PFPA.

The core farmlands were merged with adjacent ones, as well as edge and discrete patches, and perforated farmlands to form discrete using landscape structure classification, functional segmentation, and pixel attribute reclassification results. Corridor farmlands were selected to connect waterways. The adjacency of farmlands and connecting canals was considered to identify optimal farmland preservation patches and maintain the continuity of farmland landscapes.

Maximize Farmland Quality

Farmland quality refers to a piece of land's usefulness for agricultural purposes. Several factors influence farmland quality, and these factors have a significant impact on the success and productivity of agricultural activities. Data related to farmland quality include the paddy crop farming index (IP), land area, irrigation status, drainage, and soil type, which are data sourced from the Department of Agriculture of Majalengka Regency and processed in previous research (Adrian et al. 2022). The next step is to determine the weight of each driving factor in evaluating suitability and producing farmland quality classes (excellent, medium, good and low). The weighting of each attribute utilizes the calculation results of the AHP method, which involves six government stakeholders in the Majalengka Regency. In assessing the weighting of each farmland quality factor using the results of the AHP method calculation involving six government stakeholders in Majalengka Regency.

The analytic hierarchy process was used to rank the importance of different considerations. Furthermore, pairwise comparisons and expert opinions were used in this metric theory to establish ranking systems (T. L. Saaty 2003). Table 2 presents the weights assigned to various factors for assessing agricultural suitability and development potential. The suitability analysis process entailed considering numerous spatial variables or factors to assess the suitability score. A total of eleven variables were selected to analyze agricultural suitability. The incorporation of spatial factors into raster-based GIS software enabled the execution of spatial analysis using an overlay technique with a map algebra approach.

The primary objective of this endeavour was to safeguard valuable agricultural land. Agricultural fit can be determined through various geographic features obtained from *remote sensing data* (RS) combined with *Geographic Information System Data* (GIS). This integration proved invaluable in zoning agricultural land for protection. The Farmland Quality (Cultivation Intensity) method was based on the above spatial factors and the formula of the farming land quality conditions. The LS analysis incorporated criteria and subcriteria, as shown in (Fig.5):

The accuracy and availability of data have a significant impact on the results of this research. Therefore, extensive efforts are required to ensure a thorough review of important GIS datasets. This method is an integration of AHP and GIS-based farmland quality methods for paddy fields, as well as identification of suitable agricultural land. The AHP provided mathematical means to assess the consistency of judgment matrix. An accuracy ratio can be calculated based on the structure of the matrix, where the number of rows or columns is always greater than or equal to the number of rows or columns with the highest eigenvalue (max). The consistency index, which measures how well comparisons between two things match up, can be written as follows (T. Saaty, 1977; T. L. Saaty, 1988).

$$Ci = \frac{\lambda max - n}{n - 1} \quad (1)$$

Where *CI* is the consistency index, n is the number of elements in the compared matrix, and max is the largest or main eigenvalue. A random index table can be used to verify the consistency judgment for the right number of n to ensure the accuracy of the pairwise comparison matrix (T. L. Saaty, 1990).

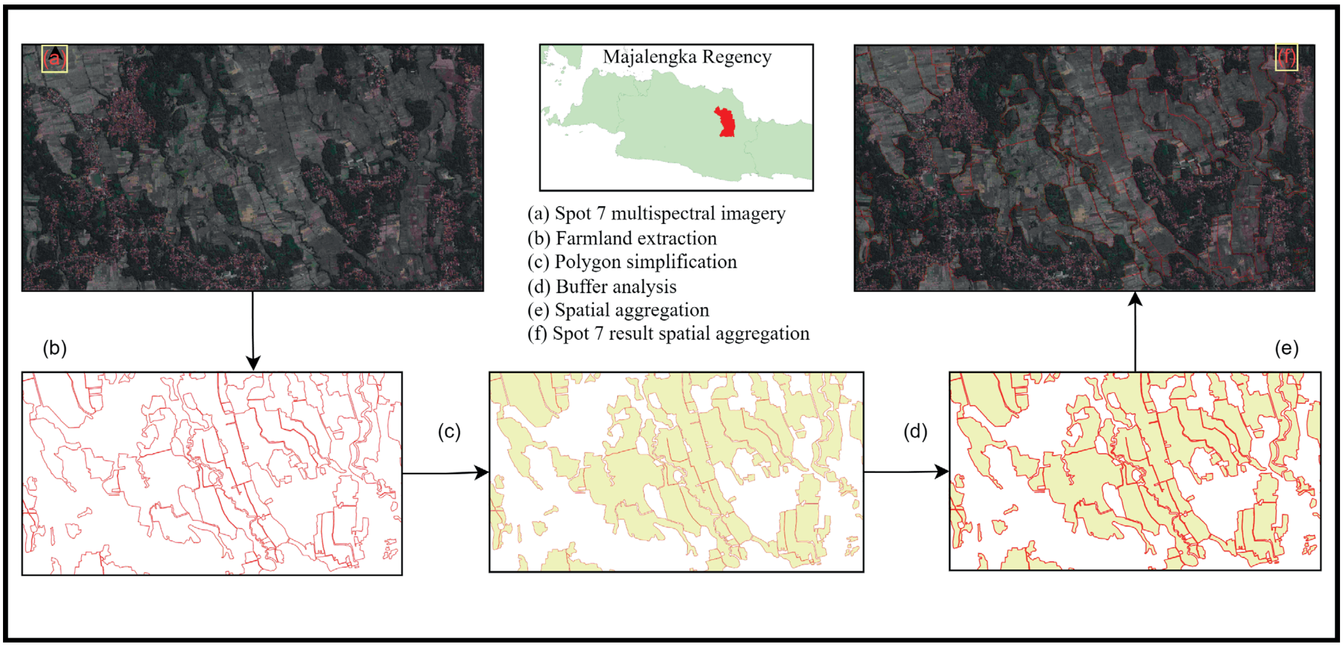


Fig. 4. Analysis Process GIS for Prime Farmland Protection Area

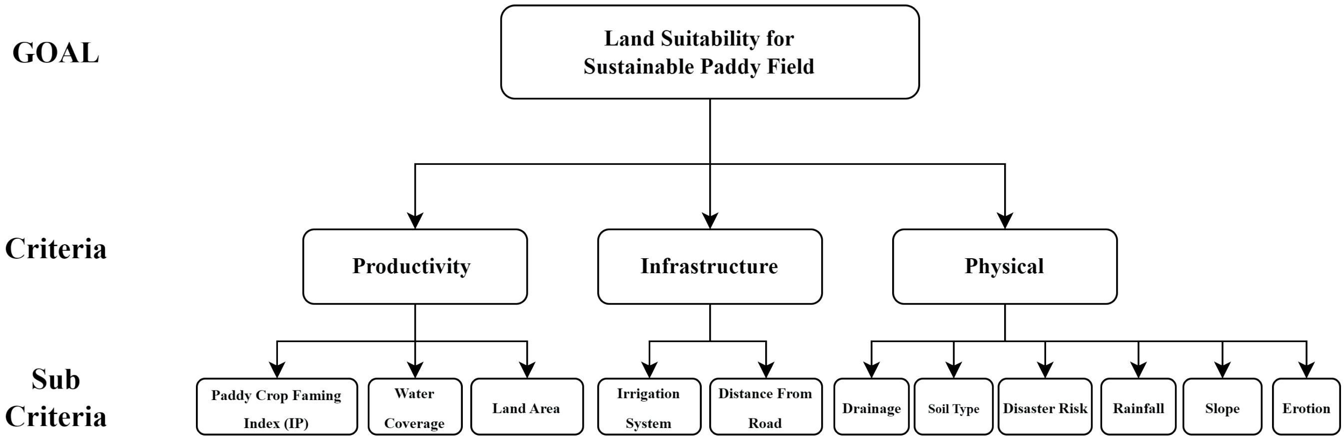


Fig. 5. Hierarchical Structure of Land Suitability

$$CR = \frac{CI}{RI} \quad (2)$$

Where *CR* is the consistency ratio, *CI* represents the consistency index, and *RI* denotes the randomness index. A consistency ratio below 0.1 indicates sufficient information to make an informed decision.

The aforementioned spatial factors are used to assess agricultural suitability using the Multicriteria Evaluation (MCE) approach (Eastman et al. 1995). Before the estimation, the factors should be standardized within the range of [0, 1]. A linear weighted combination approach generates the overall appropriateness score. The linear weighted combination method adopted the following equation to calculate the total fit score:

$$\begin{aligned} FQ\,(LS) &= W_1 XPcf + W_2 XWc + W_3 XLa + \\ &+ W_4 XIs + W_5 XDfr + W_6 XDr + W_7 XSt + \\ &+ W_8 XDis + W_9 XRf + W_{10} XSl + W_{11} XErt \end{aligned} \quad (3)$$

where FQ(LS) is farm quality (*land suitability*), which represents land suitability, was calculated using the equation below, where (**Pcf**) paddy crop farming index, (**Wc**) water coverage, (**La**) land area, (**Is**) irrigation system, (**Dfr**) distance from road, (**Dr**) drainage, (**St**) soil type, (**Dis**) disaster risk, (**Rf**) rainfall, (**Sl**) slope and (**Ert**) Erosion. w_1, $w_2 w_3$, w_4, w_5, w_6, w_7, w_8, w_9, w_{10} *and* w_{11}, These are the weights for each factor, the sum of all the criterion weights is 1.

Reach Calculation

Reach and centrality are standard network analysis terms for transportation, social, and other interrelated systems. These notions are crucial for attractiveness analysis, which examines how network aspects affect attraction. Reach is the measure of the extent or range that something covers inside a network. Within the framework of attractiveness analysis, it frequently denotes the capacity of a particular node or element within the network to attract and engage the target audience, exert influence, or facilitate accessibility. Reach is crucial for understanding how far the influence of a particular element extends within a network. For example, in marketing, reach indicates the potential number points of interest who may be exposed to a paddy field persil.

Centrality analysis is a method used to discover the most essential pieces in a network that significantly impact connecting other nodes. These key aspects are frequently more appealing, be it in terms of social impact, transit hubs, or other variables. Utilize the Kernel Density Estimation (KDE) method on your spatial data to produce a smooth surface representing the estimated density of points throughout the study area. Utilize visualizations to analyze the data and create contour maps or heat maps that depict regions with varying levels of point density. The regions with higher KDE values imply areas of greater point concentration, suggesting a more significant "reach."

Table 2. Pairwise comparisons to score land suitability

	Normalization											Total Weight
Responden	Pcf	Wc	La	Is	Dfr	Dr	St	Dis	Rf	Sl	Er	
Bappeda	0,283	0,050	0,041	0,216	0,077	0,097	0,101	0,062	0,047	0,026	0,283	
Distan	0,051	0,282	0,021	0,224	0,088	0,042	0,158	0,033	0,026	0,074	0,051	
Distan	0,289	0,044	0,021	0,224	0,088	0,031	0,158	0,033	0,036	0,076	0,289	
PUTR	0,089	0,244	0,024	0,216	0,093	0,030	0,152	0,038	0,039	0,075	0,089	1.000
Setda	0,215	0,119	0,029	0,223	0,081	0,030	0,153	0,036	0,040	0,074	0,215	
BPN	0,188	0,146	0,018	0,218	0,097	0,036	0,155	0,023	0,031	0,088	0,188	
Weight	0,157	0,117	0,025	0,220	0,087	0,040	0,144	0,036	0,036	0,065	0,157	

W: Water Body R: Rock OutCrop,
(ymax) Max eigenvalue = 9,118 n = 9
(Ci) Consistency index = (ymax - n)/(n - 1) = 0,012
(Ri) Random index = 0,580
(Cr) Consistency ratio = Ci/Ri = 0,0210451
CR score = 0,0210451 less than 10% (CR<0.1), confirmed

Method of Kernel Density Estimation (KDE)

Kernel density estimation (KDE) was used to interpolate the POI distribution for food retail outlets and the three indices of road network centrality. Points represent service centers, reach zones could indicate areas with better service coverage, KDE results to make informed decisions about resource allocation, marketing strategies, or other relevant considerations. This reflected their spatial clustering characteristics within the study area. Furthermore, KDE facilitated the transformation of different spatial elements into the same spatial unit and enabled the study of their relationship. This technique was widely used in previous studies to investigate micro-spatial distributions (Evangelista and Beskow 2019; Zhang et al. 2021).

KDE uses data1, data2…, as independent, identically distributed samples of the population with the distribution density function f. f (x) can be defined as follows:

$$fn(y) = \frac{1}{nh}\sum_{i=1}^{n} p\left(\frac{c-ci}{q}\right) \quad (4)$$

where p (.) is the kernel function, q denotes the bandwidth, and c - ci represents the distance from estimation point c to sample ci. Also, the POI data for the location of public and social facilities were assessed for centrality in relation to the road network when conducting the analysis with ArcGIS software. Subsequently, the data were stored using KDE, considering 100 m polyline elements and a 100 m bandwidth, to transform the two data layers into spatial units, facilitating correlation analysis between them.

Network Approach (Reach Calculation)

Generally, the concept of a network was based on the relationship between entities, such as organizations or people. The network properties previously studied were related to the structure of relationships. According to (Knoke et al. 1996), the assumptions underlying the network emphasized structural relationships, which aligned with what (Scott 2020) discussed about relationships. In "Analyzing Social Networks," (Teshale 2016) presented at least three types of "basic" network analysis that can be used for measuring network analysis, namely centrality, subgraphs, and equivalence. Centrality refers to the "most important" actor often located strategically within a social network (Uitermark and van Meeteren 2021).

A referral model and regionalization approach was used in this study, considering spatial aspects, such as the distributions of settlement population, village office facilities, road data, travel time to facilities, and scoring results. These factors contributed to the spatial patterns of paddy field distribution in Majalengka Regency based on the probability of interest. The first step was to identify distribution patterns of activity and business centre locations using a network analysis technique (Zheng et al. 2020). Reach centrality refers to "the proportion of network nodes the focal node can reach in a given number of steps" (Henneberg et al. 2007). This metric is an alternative method for determining an actor's proximity to other actors in a network. The extent to which an actor can access information from other members can be determined by identifying the reachable portion of all other actors in one step, two steps, three steps, etc (Robins et al. 2007).

A *Reach'[i]* centrality approach is used for determining the importance of an entity in a link chart based on a knowledge graph. The centrality score ranks entities based on their position in the graph represented by the link diagram. This score identifies the link chart entities that play an essential role in the link chart. For instance, it can identify the most influential people in a social network, events contributing to the spread of disease, critical infrastructure nodes in an urban network, among others. The formula for this approach is as follows:

$$Reach^{r}[i]=f(x)=\sum_{j\in G-\{i\};d[i,j]\le r} W[j] \quad (5)$$

Where *d[i,j]* is the shortest path distance between nodes *i* and *j* in *G* the graph containing nodes and edges, and *W[j]* denotes the weight of the destination node *j*. The weights can represent any quantitative quality of the target structures, such as their total square footage or the number of residents. By incorporating weights, an analyst can determine how many of these features (paddy fields and public facilities) are accessible from each building within a specific network radius (Porta et al. 2012).

The reach centrality visually demonstrated how it operates. Starting from the paddy field of interest *i*, an accessibility buffer was extended in all directions along the street network until the limiting radius r was reached. The Reach index was subsequently calculated by counting the number of destinations within the radius. The aggregate of weights, rather than the number of destinations was considered when weights were specified. In (Fig.5), the radius of location encompassed twenty neighbouring locations. The output illustrated the surrounding built volume that could be accessed from each structure within a 50-meter radius. It was observed that areas with higher Reach values had more significant, densely spaced buildings and a denser street network.

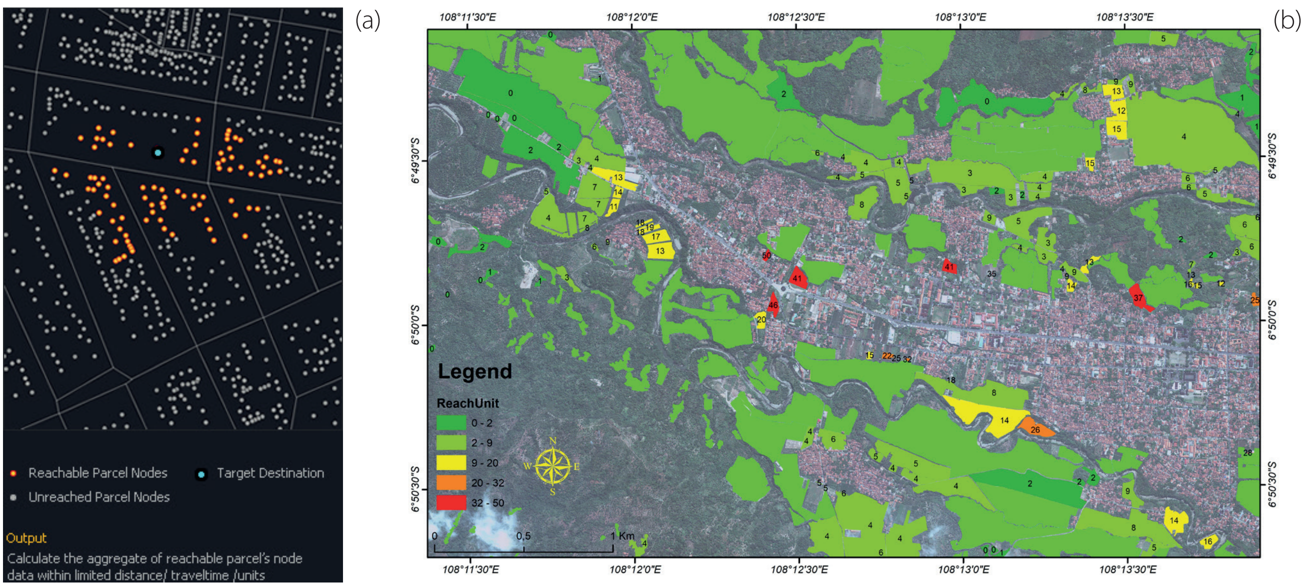


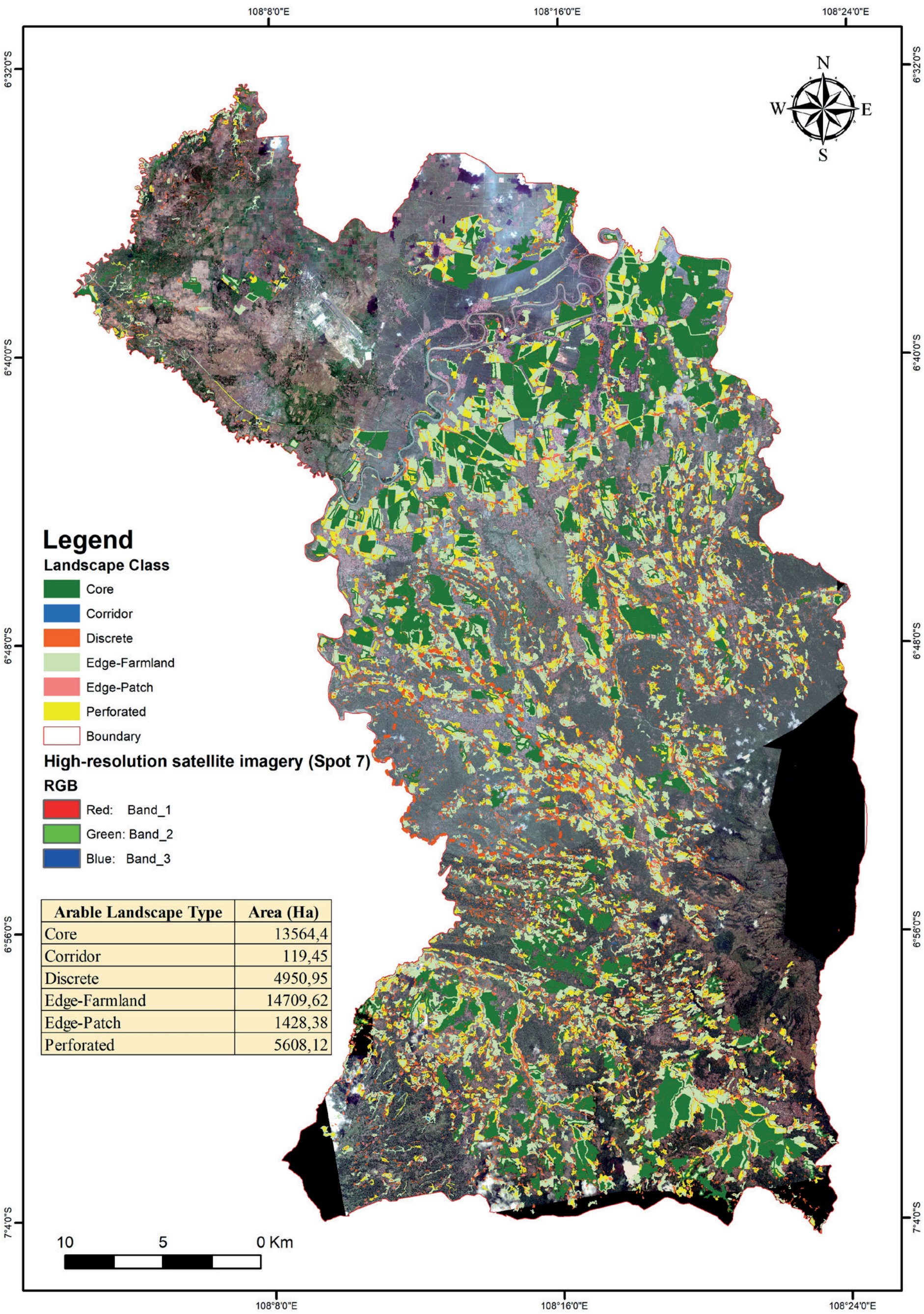
Fig. 6. (a) UrbanScad software tools, (b) Visual Illustration of The Reach Index

RESULTS AND DISCUSSION

Delineation of protection zones for precious farmland

The agriculturalfarmland landscape structure classification approach, as clearly shown in (Fig.6). In the study area, the core agricultural land occupied an area of 33.59%, while the Edge-Farmland covered 36.43 %. Furthermore, the Corridor area accounted for 0.30%, Discrete area of 12.26%, Edge-Patch area of 3.54%, and Perforated area of 13.89%. Spatially, the core agricultural land was predominantly distributed as a continuous area concentrated in the periphery outside the boundaries of the central urban area of Majalengka.

This peripheral area represented the historical agricultural land area in Majalengka Regency, which experienced a delay in urbanization and insignificant agricultural land segmentation due to road traffic, development areas, and other human activities. The agricultural land was segmented by other variables due to its dispersed nature on the outskirts of the city area, where regional development activities occurred daily, and non-agricultural activities encroached upon the limits of agricultural land. Most agricultural land was surrounded by built property, separating it as an ecological island in the heart of the city and reducing spatial proximity between different land uses. Compared to other land types, core farmlands exhibited superior functional qualities, such as strong connectedness, minimum disruption from non-agricultural activities, and optimal agricultural yield. This landscape was used for various agricultural purposes and significantly contributed to the quality of farmland landscapes. On the other hand, the edge farmland is a zone of ecological transition between core farmlands and non-farm ecosystems. Hence, implementing ecological conflict prevention methods enabled the coexistence of high-quality non-farm ecosystems and activities on arable lands while limiting their environmental impact. The peripheral agricultural lands functioned as a protective barrier, safeguarding the productive operations of central agricultural lands. The synergistic relationship between these two categories of agricultural land is noteworthy.



Arable Landscape Type	Area (Ha)
Core	13564,4
Corridor	119,45
Discrete	4950,95
Edge-Farmland	14709,62
Edge-Patch	1428,38
Perforated	5608,12

Fig. 7. Landscape class of agricultural land in Majalengka Regency

Corridor farmlands served as conduits linking agricultural lands, demarcating them from non-agricultural surroundings. The peripheries and fragments of agricultural land possessed diminutive habitats and exhibited mosaic patterns within non-agricultural landscapes. These factors frequently impacted the landscapes, potentially resulting in increased productivity. The objective of the aforementioned was akin to perforating farmlands, primarily exhibiting the temporal evolution of the spatial configuration of agricultural terrains. In the context of defining prime farmlands, it is imperative to consider both the peripheral and central farmlands as well as the continuity of the plot. The optimal utilization of prime farmlands can be achieved by adopting the core farmland as a prototype and demarcating the primary farming fields using the peripheries of the edge farmland.

Result Farmland Quality

Spatial variables were used to assess suitability scores during the analysis, it was important to categorize each variable based on the respective land suitability classification before applying the conformity overlay. The process of assessing and classifying a particular land region based on its intended purpose is called Land Suitability Classification (Fadlalla and Elsheikh 2016). The present study used the FAO (Food and Agriculture Organisation) land use suitability class to categorize agricultural land use. The classes in question were S1, S2, S3, and N1, denoting high suitability, sparse suitability, and unsuitability. This analysis utilized the values of each variable to ascertain the prospective land that could be used for sustainable food agriculture. The variables included physical factors that could be visually represented with spatial analysis. Some of the variables considered were agricultural index, water affordability and land area, irrigation system, drainage, soil type, disaster risk, rainfall, as well as slope and erosion hazard. Infrastructure sub-criteria, such as irrigation system analysis and road distance, were also considered. In addition, spatial analysis was carried out using the overlay technique.

As a result, the current study conducted a qualitative division of farmland by analyzing the quality of agricultural land at the block level in Majalengka Regency. Suitability analysis, which evaluated whether land properties were suitable for the intended use was a crucial part of the land use planning (Jayasinghe et al. 2019; Singha et al. 2019). The agricultural suitability study considered various spatial variables (factors) to determine the suitability score. A total of eleven parameters, including the water availability, land acreage, irrigation status, proximity to roads, drainage, soil type, disaster likelihood, precipitation, slope, and erosion, were selected, all of which contributed to the paddy crop farming index (IP). These spatial variables (factors) were incorporated into raster-based GIS software, and spatial analysis were performed using the overlay and map algebra methodology.

A land suitability calculation model and a modified algebra method raster analysis were used to create patterns of agricultural land protection. The estimated area required for protected agricultural land, based on strategic planning in the Majalengka district, was 40,380.92. This model offered alternative options for safeguarding agricultural land. The land suitability map was created using weighted spatial overlay analysis based on the AHP weights for 11 criteria, as shown in Fig. 8. The land quality grading for S1 (indicating high suitability for farming) was estimated to be 15,038.99 hectares, accounting for 11.31% of the total land area. Conversely, the estimated area of unsuitable land, mainly mountainous terrain and other land uses, was 80,764.05 hectares. The unsuitability of the land can be attributed to its current non-agricultural use and its lack of compliance with future suitability class requirements. In this case, the quality of farmland in Majalengka Regency was evaluated, encompassing a vast area of 39,190 hectares. The accessible land in Majalengka Regency was classified into two suitability ranges, namely S1 and S2. The total land area classified as *Highly Suitable* (S1) was 15,038.99 ha, while the *Suitable* (S2) group encompassed 23,745.42 ha, resulting in a total area of 38,784.41 hectares. The protection of this area against any change, particularly for development purposes is important to ensure its long-term viability.

Result Reach Calculation

Kernel Density *(Centrality Distributions Along Streets)*

The road network comprising 91,452 nodes (*intersections*) and 95,073 edges (*links between two intersections*), was obtained by merging the open street map data with Pleiades imagery. (Fig.9) shows the road length (*edge length*), while (Fig.10) illustrates the kernel density of the nodes, using kernel density estimation (KDE) on the street network, displaying the KDE of the nodes within a predetermined searching radius.

Point of Interest (POI)

The present investigation involved acquiring point-of-interest data in the Majalengka Regency from diverse sources, including Bappeda Majalengka. The data collection process was facilitated by utilizing G Map Scraper, which yielded 5,787 records. The Point of Interest (POI) was divided into 15 primary classifications, as illustrated in Fig. 9. The primary role of the urban center in the Majalengka District region was to furnish habitation and employment opportunities for its populace, alongside dispensing communal amenities. The most important land categories in terms of urban land functionality were commercial, residential, and industrial. Although the available POI dataset did not allow for a proper definition of industrial land within Majalengka Regency. Therefore, the POI data were classified into three, namely business facilities, commercial, residential locations, as well as public administration and services. The details of these categories are presented in (Fig. 11)

Reach Calculated

The reach analysis at each node was initially computed using the UrbanSCAD (https://circle.urbanesha.com/auth) urban network analysis tool. This study summarized the range analysis of edges by calculating the average centrality of the two connected nodes between points of interest (POI) and each paddy field (point). Furthermore, the paddy field data were processed from polygon data and converted into points using centroid tool in QGis software. The reach analysis was also computed to allocate point-of-interest amenities within a 50-meter constraint amidst the location markers of rice paddies. (Fig.12) shows the spatial distribution of the range analysis. Individuals may hold varying perspectives regarding the road network configuration as they traverse through. This study aimed to determine the effect of the road network index on the distribution of paddy fields and point of interest (POI) locations. In the study area, the reach estimates revealed

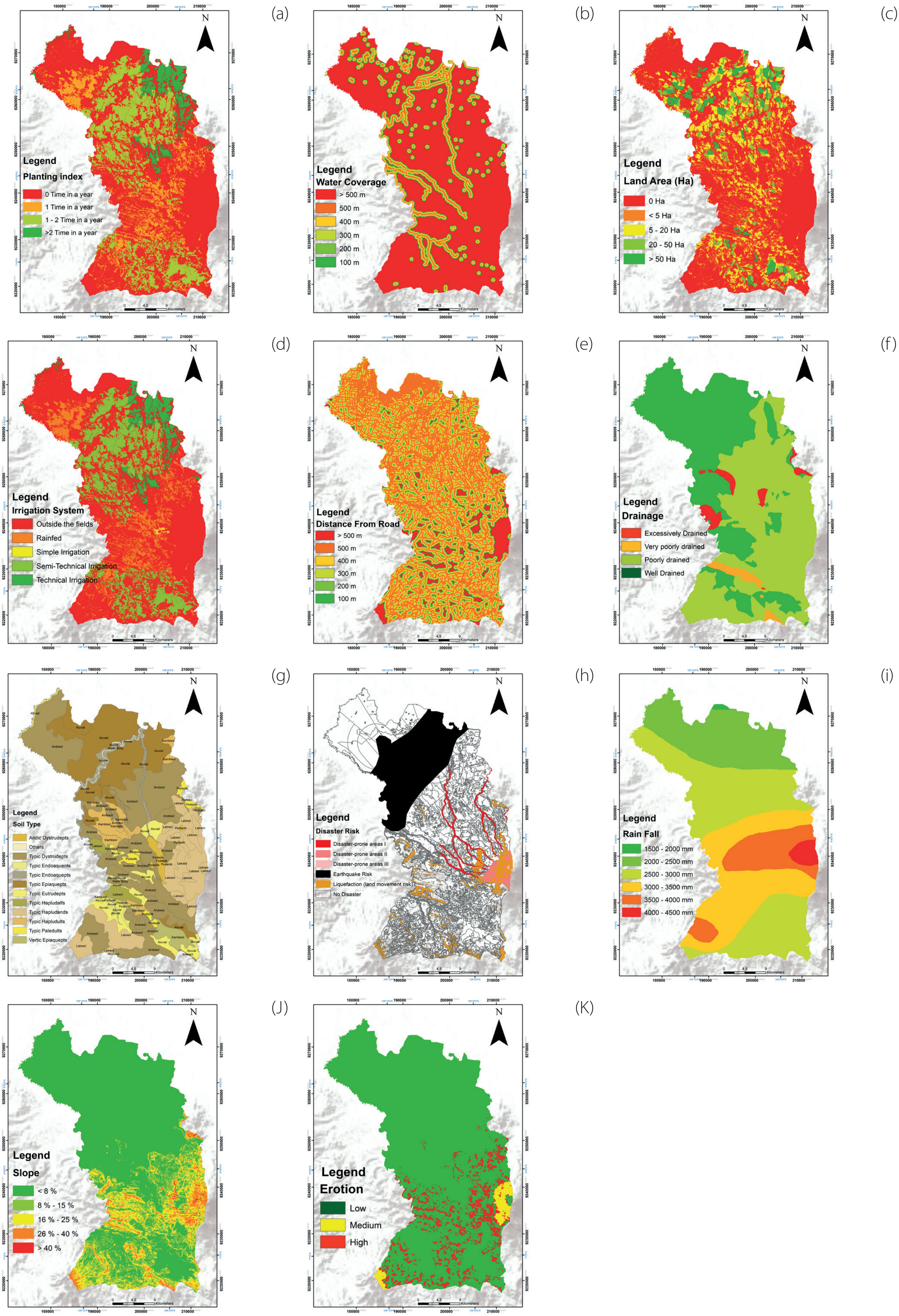


Fig. 8. Thematic Data Layer maps

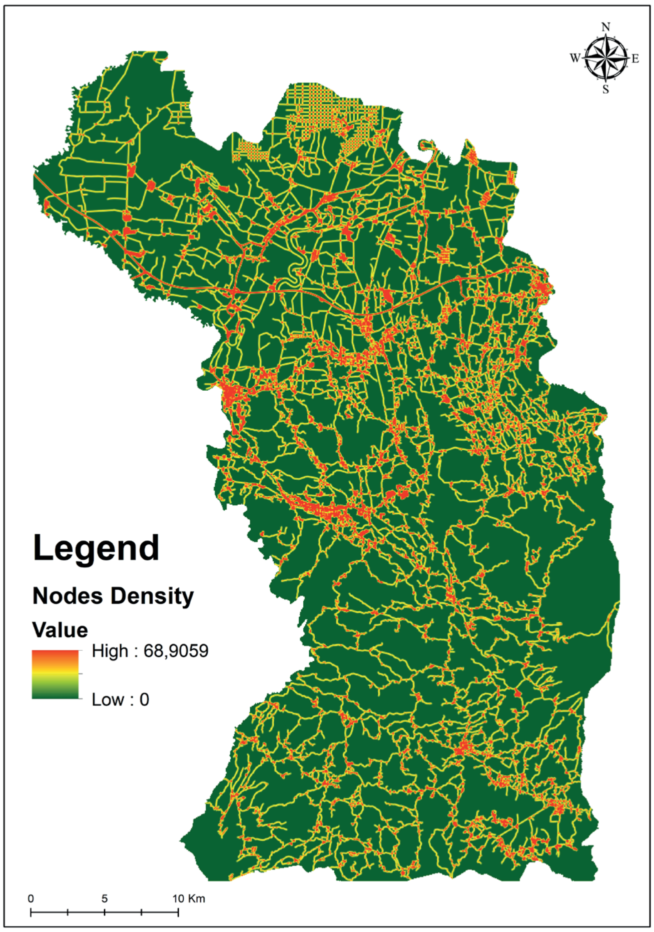
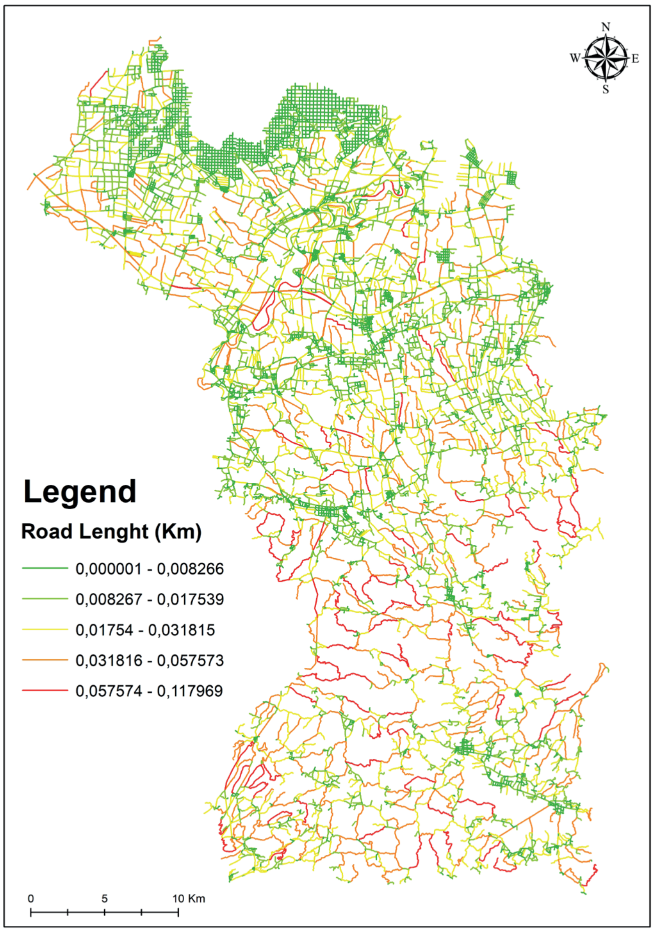


Fig. 9. Density of nodes in Majalengka Regency



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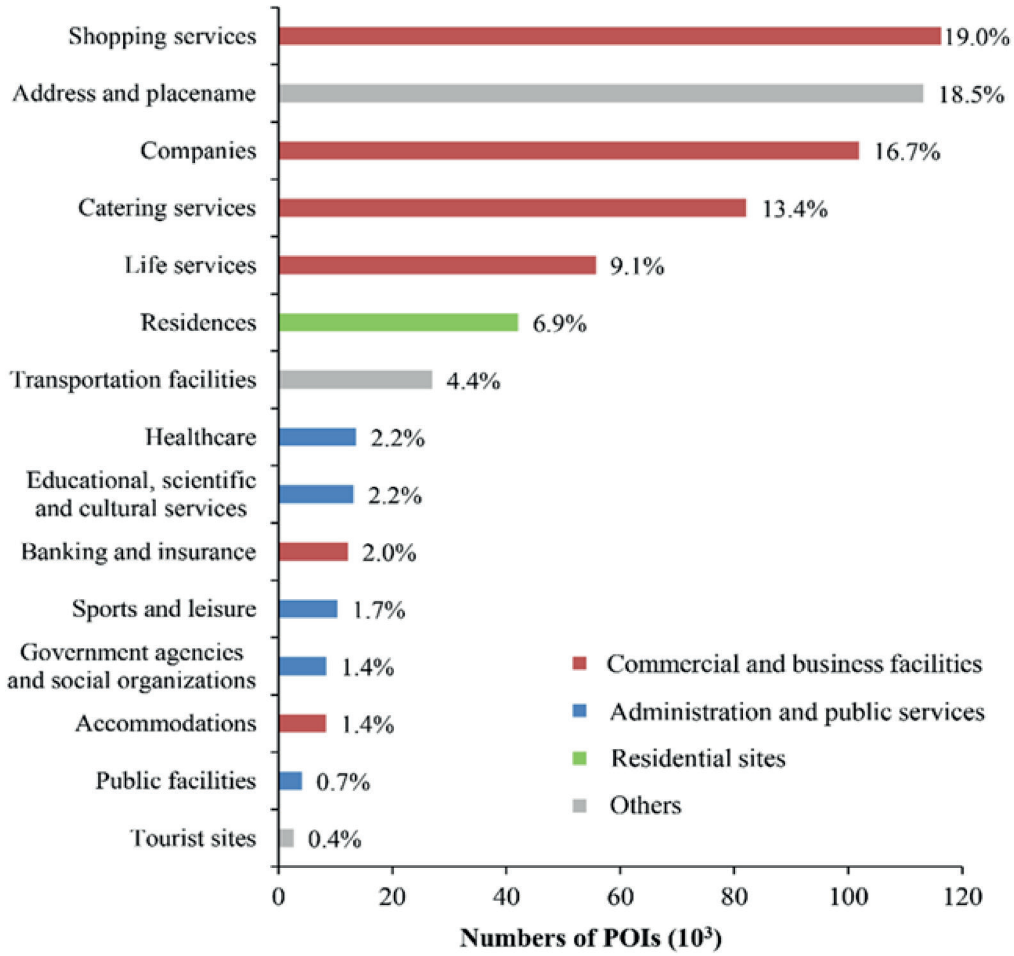

Fig. 11. Categories of Point of Interest (POI) in Majalengka Regency

varied spatial patterns, with a higher core concentration and a multipolar distribution in the suburbs. Also, the density of locations decreased from the downtown region to the outskirts. The proximity to geographical sites and the shorter average distance to the centre point implied easy accessibility (C. Liu et al. 2019; Van Duin et al. 2016).

Design of the spatial regulation of farmlands

This study developed a spatial arrangement structure for farmland, known as the 'two lanes, two zones' approach, based on the farmland protection principle. The approach aimed to manage and protect farmland while minimizing non-agricultural interference mechanisms. The term 'two lines' pertained to a pliant or inflexible boundary for urban development, while 'two zones' denoted a central zone for safeguarding agricultural land or an urban regulation zone with flexibility. The objective was to address spatial land use challenges arising from the tension between safeguarding agricultural land and accommodating urban growth. Results of the Reach Calculated calculation in (Fig.12) to implement this approach, Geographic Information Systems (GIS) spatial analysis technology was used to identify the factors that cause conflicts between agricultural land protection and urban expansion. A spatial diagnosis of land management policies was conducted using all available background information about the conflict areas. This step established the rules for the area, allowing for the definition of the final boundaries of the leading farmland protection zones, the flexible urban development boundaries, and the rigid urban development boundaries. This exclusion analysis from urban development boundaries identified areas that were flexible and adaptable to flexible or rigid urban development boundaries, also called urban spatial growth boundaries.

Delineation of the spatial regulation boundaries of farmlands

Establishing prime farmland conservation zones serves as the fundamental policy mechanism to mitigate the reduction of farmland due to urban expansion in the Majalengka Regency. The subject encompasses various components, including the structure of the storyline, the arrangement of physical spaces, the fertility of agricultural land, and the geographical characteristics of the location. Quantitative evaluations of landscape configuration indices are being conducted based on plot morphology and spatial layout, namely at the type, landscape, and patch scale. Quantitatively characterizing a single plot's spatial information and system functions is challenging. The assessment of farmland quality and regional geography mainly relies on extensive evaluations of multiple aspects and circumstances. The comprehensive review of regional farmlands' integrated productivity levels has some reference value; nonetheless, there needs to be clarity in determining the factors to be selected and weighted. Moreover, incorporating many elements tends to weaken the primary factor's significant impact on the quality of agricultural and environmental assessment, distorting the evaluation outcomes.

The conventional methodologies used in land-use planning and delineation in prime farmland preservation zones focus on the protected area's characteristics and the broader needs of regional socio-economic development (Qianwen et al. 2017; Xia et al. 2017). This approach creates numerous problems, such as a lowered quality of prime farmland protection zones, fragmented morphology, and high altitudes with highly gradient farmlands. Land morphology in the research area, namely Majalengka district, has an area of 400-2000 meters above sea level.

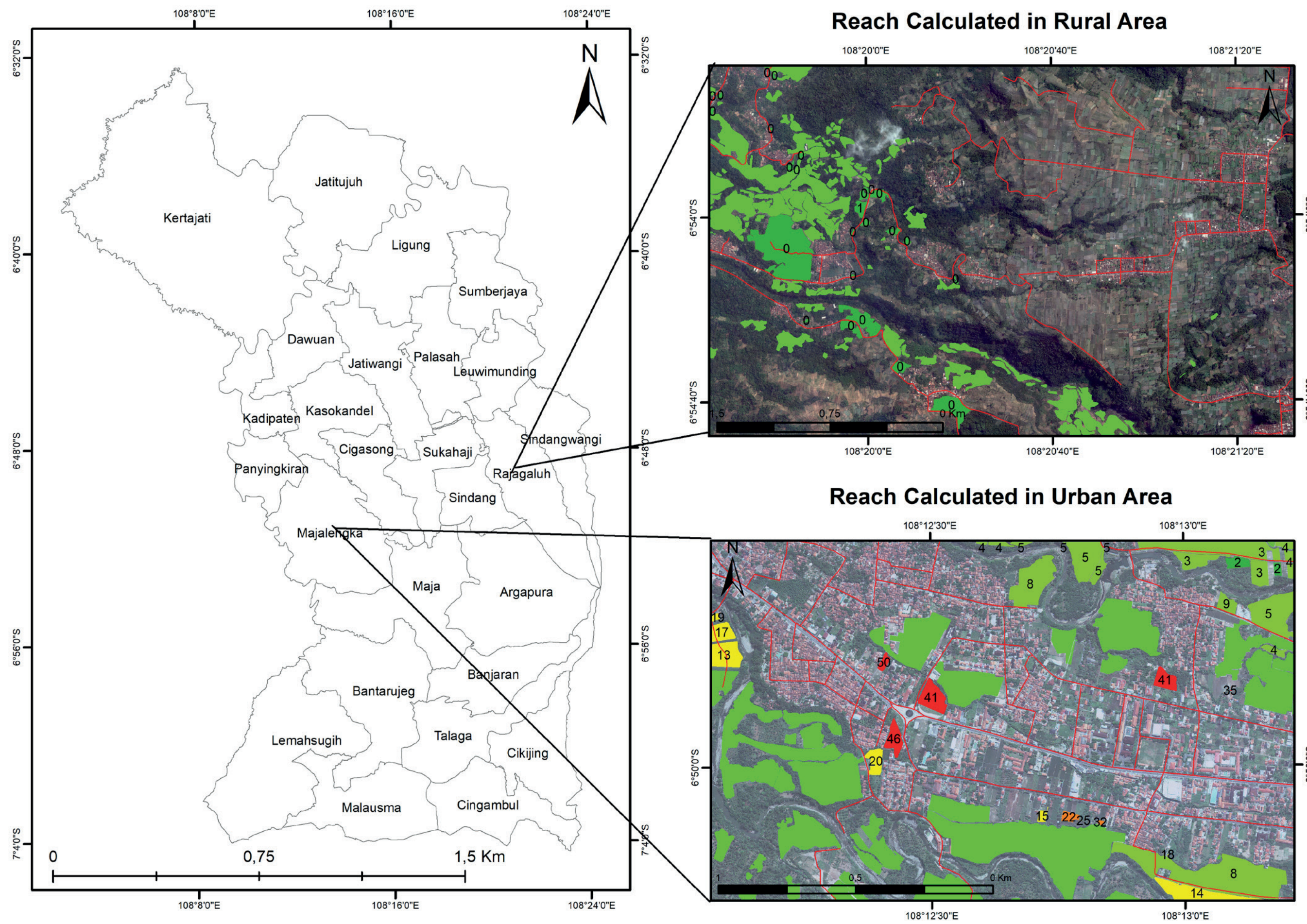

Fig. 12. Spatial Distribution of Paddy Field Reach Calculation to Point of Interest (POI)

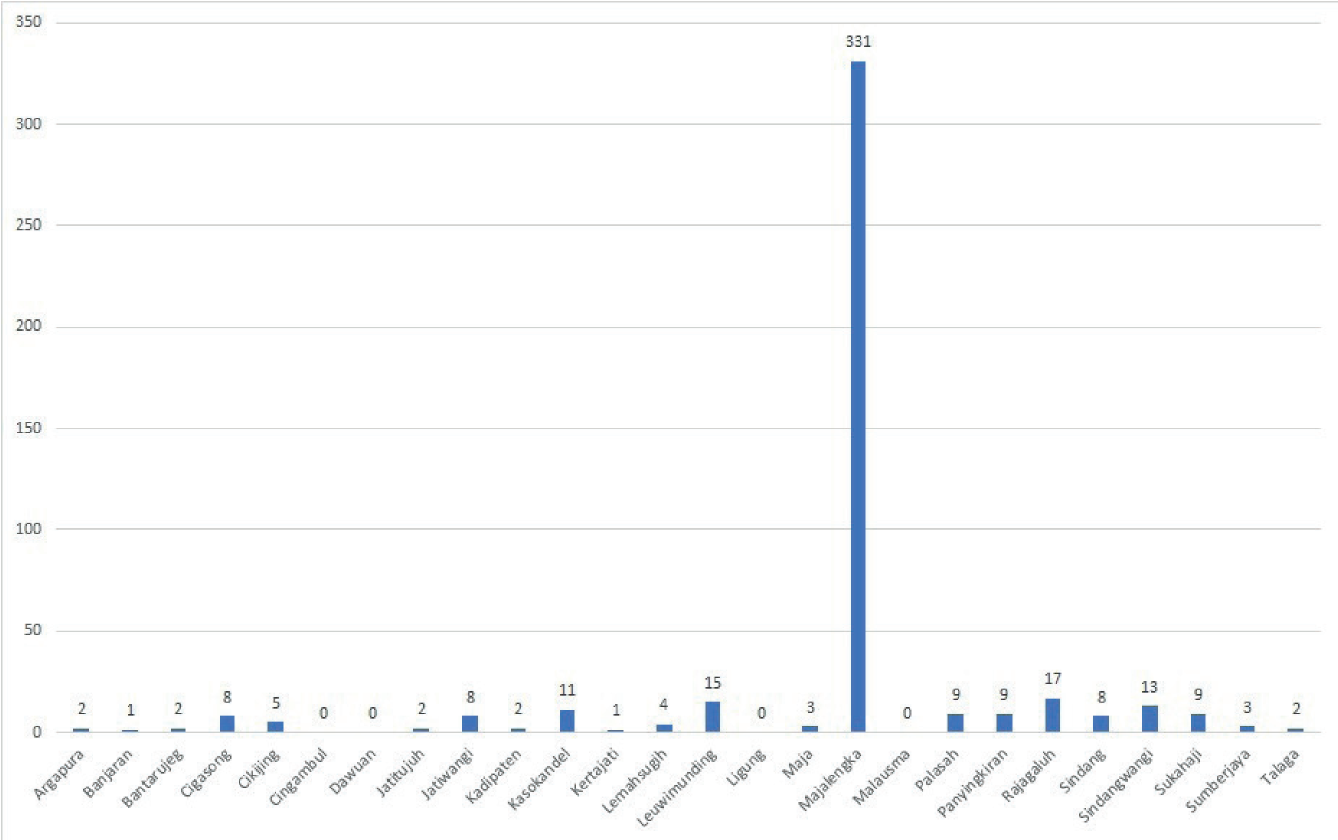

Fig. 13. Spatial Reach distribution data of district level

The total area of urban development boundaries, encompassing flexible and rigid boundaries, was 12,171.75 hectares. A flexible, adjustable zone of 998.22 hectares existed in this area. The demarcation resulted in the formation of two extensive areas, namely one situated north along the river and the other encompassing the majority of Majalengka Regency. The analysis, as depicted in (Fig.14), showed the protection zone covered a significant portion of the agricultural land, spanning an area of 13,564.39 hectares. This zone is situated in the northern region and comprised of two distinct patches in the central and eastern areas. The demarcation of the primary agricultural land conservation areas as well as the adaptable and inflexible urban expansion boundaries was established based on the outcomes of conflict resolution in these areas. The development of a two-lane, two-zone spatial regulation structure for agricultural land was informed by the range of flexible or rigid urban development boundary options and the identification of adaptable urban areas through spatial analysis. As previously mentioned, 'two lines' pertained to urban development boundaries that could either be flexible or rigid, while 'two zones' referred to zones primarily intended to protect agricultural land or regulate urban flexibility.

DISCUSSION

Due to the substantial overlap between agricultural land and urban development, Majalengka Regency has faced issues related to the widespread encroachment on valuable farmland caused by urban expansion. Agricultural land in Indonesia, particularly in Majalengka district, have diminished due to the following reasons (1) Agricultural lands were transformed into urban areas as people migrated and the number of people living in cities increased. The demand for homes, businesses, shopping centres and other urban infrastructure, necessitated more land, which often came at the expense of agricultural land. (2) Industries and Industrial Estates: The growth of industries and the establishment of industrial estates had also contributed to the reduction of agricultural land. Most factories, shops and other industrial buildings were constructed on land previously used for farming. (3) Infrastructural Development: Roads, bridges, airports, seaports and other infrastructure projects required land development, resulting in the conversion of agricultural land for other uses. (4) Improved Residential Land: Several agricultural lands were converted into residential areas to accommodate the growing population's housing needs.

Factors like threshold selection, data resolution, and landscape categorization size contribute to errors; future studies should investigate and resolve these issues. For instance, the regulations for gradation on agricultural land quality form the backbone of farmland quality classification in Indonesia. The regency-scale standard of farming, the land economic coefficient, and the land usage coefficient all play a role in determining this gradation. Setting up zones to protect good farmland was a primary policy tool for preventing shrinkage. This process involved various components, such as considering the shape of the rice field parcels, land layout, farming quality, and the geographical characteristics of the area. Landscape configuration indices were subjected to quantitative analysis based on factors, such as land type, landscape, and patch scale, to examine the shape and arrangement of parcels. Quantifying the spatial information and reach system functions of a single image required significant effort.

A comprehensive review can serve as a reference point for assessing the productivity of regional farmlands. However, determining which factors to use and how much weight to assign were sometimes unclear. Considering numerous factors tended to diminish the impact of the most pivotal factor on the quality of farmland and the assessment of the environment. This approach compromised the accuracy of evaluation results. Traditional techniques for safeguarding prime farmland through land-

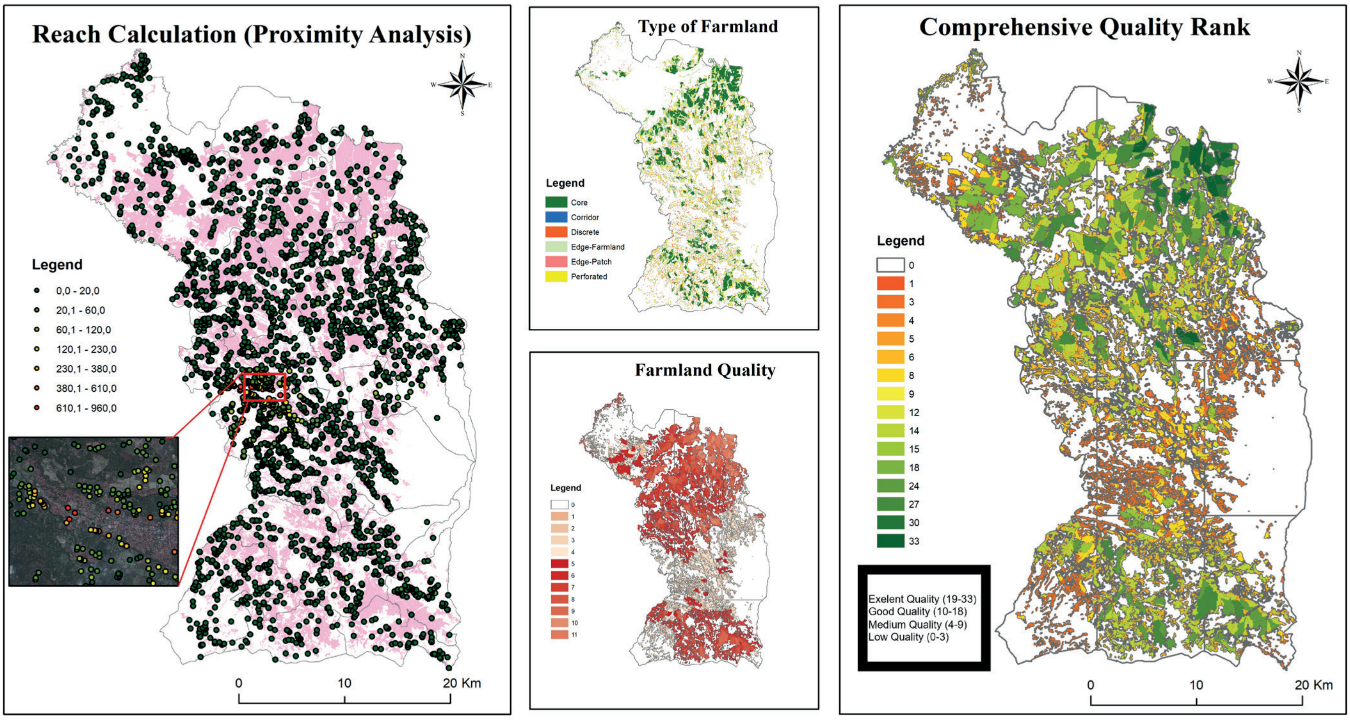

Fig. 14. Results of the Process of Optimizing Land Protection Patterns

use planning and delineation prioritized the characteristics of the preserved land and the broader requirements of socio-economic advancement in the region.

The present investigation employed a geographical spatial dimension deduction methodology, which entailed following a delineation sequence of "prime farmland protection plot, patch, and zone." Subsequently, spatial scaling and layer-by-layer aggregation were utilized to establish the prime farmland protection zones. The prime farmland protection patches were identified using a landscape structure classification model. This model used a proximity-based approach to identify clusters of plots and designated them as prime farmland protection patches. This study effectively screened prime farmland protection patches using a combination of quality grading of farmland plots, ownership information, and regional land development intensity. These patches were subsequently consolidated to form prime farmland protection areas, which were larger than patches but smaller than zones.

CONCLUSIONS

This study used the Landscape Structure Classification Model to analyze farmland and identify optimal areas for protection based on the functioning of different components. Furthermore, farmland quality grading and delineation were incorporated to determine the effectiveness of security patches on prime farms. This study used GIS spatial analytical techniques to investigate the causes of conflicts between farmland protection and urban development. A spatial diagnosis of the conflict areas was conducted, considering land-use spatial management policies and general background information. This step guided the regulatory direction of the conflict areas. The spatial boundaries of prime farmland protection zones, as well as the flexibility or rigidity of urban growth boundaries were also determined. implementing prime farmland protection zones was considered an effective strategy for managing and safeguarding farmland. The use of flexible buffer zones that could be modified as needed was the optimal approach for delineating farmland conservation areas within urbanized regions.

In the study area, core farmland has an area of 33.59%, while edge farmland has an area of 36.43%. Furthermore, the area of the corridor farmland is 0.30%, while the area of the discrete farmland is 12.26%, the Edge-Patch area is 3.54%, and the Perforated area is 13.89%. Spatially, the core agricultural land is mainly spread out as a continuous area concentrated on the outskirts outside the central area of Majalengka city. This study established a spatial regulatory framework for farmlands to reconcile the conflict between prime farmland protection zones and urban development boundaries. The establishment of this framework was aimed at addressing the construction and developmental requirements of the region, integrating spatial control of urbanized areas with the consolidation and protection of agricultural lands. This approach addressed the conflicts that arise from the need to preserve agricultural land while expanding urban areas. This has the potential to optimize the utilization of building land by enhancing both its spatial capacity and quality.

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