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Sustainable growth through transit-oriented development: Land suitability and planning along the Makassar-Parepare railway

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ABSTRACT

Transit-oriented development (TOD) integrates land use and transportation infrastructure to create sustainable, efficient, and accessible urban environments. This study evaluates the potential of greenfield areas surrounding the Maros, Pangkajene, Tanete Rilau, and Barru railway stations along the Makassar-Parepare railway corridor for TOD-based residential development. A land suitability assessment was conducted using the spatial multi-criteria analysis (SMCA) approach combined with a weighted overlay technique, with fuzzy analytic hierarchy process (AHP) results indicating proximity to stations (15.36%) and road access (12.76%) as the most influential factors for sustainable TOD implementation. The findings show that Tanete Rilau and Barru emerge as the most favorable locations, with the majority of their land classified as suitable or highly suitable. Tanete Rilau has 63.11% of its land categorized as suitable, making it highly viable for transit-integrated development, while Barru, with 10.72% of its land highly suitable, presents strong potential for greenfield-preserving TOD. Pangkajene also demonstrates TOD potential, with 50.86% of its land classified as suitable, while Maros faces greater constraints, with 46.44% moderately suitable and 31.62% unsuitable land. These findings highlight the importance of accessibility, infrastructure readiness, and land suitability in guiding TOD-based urban expansion, ensuring optimized land use and sustainable development along the railway corridor.

Keywords: transit oriented development, land suitability, greenfield areas, railway stations, SMCA, fuzzy AHP.

INTRODUCTION

Transit-oriented development (TOD) serves as an innovative urban planning strategy that integrates land use and transportation infrastructure to promote sustainable, efficient, and accessible urban growth. In Indonesia, where rapid urbanization poses challenges to sustainability, TOD principles offer a structured approach to optimizing land use around transportation nodes (Cervero & Arrington, 2008). This approach is particularly relevant for the Makassar–Parepare Railway Corridor, a key infrastructure project aimed at improving connectivity and economic integration in South Sulawesi (Adolphson & Fröidh, 2019).

Stretching 142 kilometers and linking major areas such as Maros, Pangkajene, Tanete Rilau, and Barru, the corridor traverses greenfield regions dominated by agricultural land, wetlands, and sparsely populated settlements (Zanaga et al., 2021). These characteristics provide unique opportunities for TOD-based urban expansion, emphasizing compact, pedestrian-friendly, and transit-accessible developments. By concentrating residential and mixed-use projects around transit hubs, TOD can decrease private vehicle dependence, enhance accessibility, and encourage sustainable regional development (Lyu et al., 2020).

Each station along this corridor – Maros, Pangkajene, Tanete Rilau, and Barru – exhibits distinct attributes that shape its TOD potential. Maros, due to its proximity to urban centers, holds promise for urban infill and enhanced (Huang et al., 2019). Pangkajene, with its diverse land use and strong connectivity, presents opportunities for balanced residential and commercial expansion (Olaru et al., 2011). Tanete Rilau, benefiting from high accessibility and well-developed infrastructure, emerges as a strong candidate for integrated urban development. Meanwhile, Barru's advantageous geographical and infrastructural conditions position it as an ideal site for compact, TOD-based communities (Renne et al., 2016b).

Nevertheless, unlocking the full potential of TOD in these areas necessitates addressing various challenges, such as regulating land-use changes, minimizing environmental impacts, and ensuring equitable access to resources (Bespalyy & Petrenko, 2022). A thorough land suitability analysis that integrates physical, environmental, and socio-economic factors is essential for guiding policymakers, planners, and developers in implementing TOD principles that align with local conditions (Weldu & Deribew, 2014).

This study assesses the potential of greenfield areas surrounding the four major railway stations for TOD-based residential development. Utilizing fuzzy analytic hierarchy process (AHP) and spatial multi-criteria analysis (SMCA), the research identifies both opportunities and constraints for sustainable urban growth (Alkharabsheh et al., 2022). The findings aim to facilitate TOD implementation, ensuring that future development enhances accessibility, maximizes land efficiency, and maintains ecological sustainability.

MATERIAL AND METHODS

This study employs a methodological framework designed to analyze the TOD potential of greenfield areas surrounding the Maros, Pangkajene, Tanete Rilau, and Barru railway stations along the Makassar–Parepare Railway Corridor. The approach integrates spatial analysis and multi-criteria decision-making to align development priorities with TOD principles.

Study area

The study focuses on four major railway stations along the Makassar–Parepare Railway Corridor: Maros, Pangkajene, Tanete Rilau, and Barru. Each station and its surrounding area within a radius of 1200 meters were selected as the primary study zones (Figure 1), which captures primary and transitional zones critical for TOD implementation. This range ensures the inclusion of compact, walkable, and transit-accessible areas that prioritize sustainable development. Each station's unique characteristics – from urban proximity to land use diversity – provide a rich basis for evaluating TOD potential.

Criteria for TOD potential

The selection of criteria in this study is based on a literature review of key factors driving the development of transit-oriented development (TOD)-based residential areas. TOD integrates land use and transportation to create sustainable, efficient, and accessible environments (Cervero & Arrington, 2008; Renne et al., 2016a). The selected criteria refer to previous studies highlighting essential elements in TOD-based residential development, particularly in greenfield areas.

Fuzzy AHP

The criteria used include accessibility, availability of public facilities, environmental conditions, and infrastructure (Table 1). Proximity to railway stations and road network accessibility are crucial in determining the affordability and connectivity of an area (Lund, 2006; Olaru et al., 2011). Public facilities, such as educational centers and healthcare services, support urban life oriented toward public transportation (Feizizadeh & Blaschke, 2013; Mees, 2014). Environmental factors, such as land slope, disaster risk, and ecosystem sustainability are primary considerations for ensuring residential sustainability and safety (Kapoor et al., 2020; Weldu & Deribew, 2014). Additionally, the availability of clean water and electricity is a crucial aspect in supporting the development of residential areas (Huang et al., 2019; Xu et al., 2011).

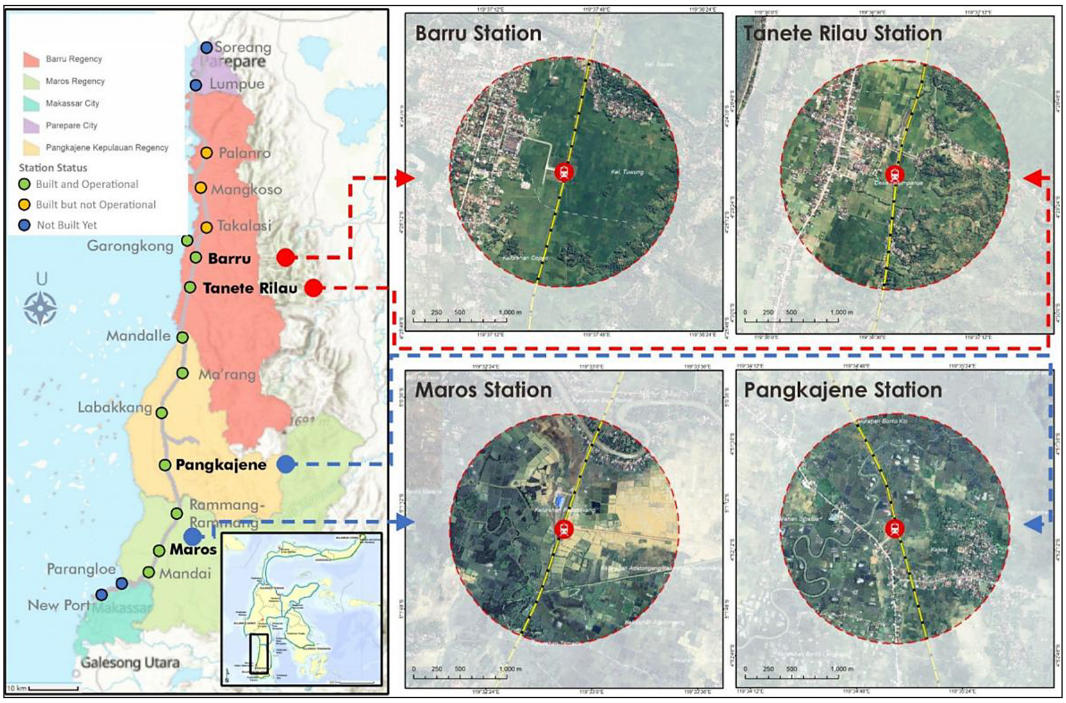

Figure 1. Research location

Table 1. Criterias of TOD-based development on the new developed area

No.	Criteria	Code	References
1.	Distance to the railway stasion	DS	(Cervero & Arrington, 2008; Hopkins, 2018; Lund, 2006; Shen et al., 2018; Yi et al., 2019)
2.	Distance to the road	DR	(Murseli & Isufi, 2014; Olaru et al., 2011; Park & Choi, 2020; Welch, 2013)
3.	Distance to the city center	DC	(Feizizadeh & Blaschke, 2013; Huang et al., 2019; Lyu et al., 2020; Seo & Nam, 2019; Terayama & Odani, 2017)
4.	Public facilities availability	FA	(Feizizadeh & Blaschke, 2013; Mees, 2014; Melchor & Lembcke, 2020; Renne, Hamidi, et al., 2016; Xu et al., 2011)
5.	Slope	SL	(Abbaspour et al., 2011; Akıncı et al., 2013; Park & Choi, 2020; Seo & Nam, 2019; Weldu, W. G., & Deribew, 2014)
6.	Disaster risk	RD	(Feizizadeh & Blaschke, 2013; Kapoor et al., 2020; Weldu, W. G., & Deribew, 2014; Xu et al., 2011)
7.	Land use	LU	(Feizizadeh & Blaschke, 2013; Liu et al., 2014; Park & Choi, 2020; Ustaoglu et al., 2021; Xu et al., 2011)
8.	Water supply	WS	(Akıncı et al., 2013; Feizizadeh & Blaschke, 2013; Huang et al., 2019; Weldu, W. G., & Deribew, 2014; Xu et al., 2011)
9.	Electricity supply	EN	(Akıncı et al., 2013; Feizizadeh & Blaschke, 2013; Huang et al., 2019; Weldu, W. G., & Deribew, 2014; Xu et al., 2011)
10.	Ecosystem sustainability (restricted areas)	EC	(Akıncı et al., 2013; Feizizadeh & Blaschke, 2013; Huang et al., 2019; Weldu, W. G., & Deribew, 2014; Xu et al., 2011)

Fuzzy analytic hierarchy process (AHP) was used to assign relative importance to each criterion. This method reduces uncertainty in expert judgments by employing triangular fuzzy numbers, providing reliable weights for decision-making. The criteria with the highest weights – proximity to stations and road access – align with TOD's emphasis on accessibility and connectivity (Alkharabsheh et al., 2022; Hamzeh & Alavipanah, 2014).

In the fuzzy AHP method, pairwise comparisons between elements are conducted using the AHP scale, which is converted into triangular fuzzy numbers (TFN). The distribution pattern

Table 2. Fuzzy AHP scale and corresponding triangular fuzzy numbers

Variable	AHP crisp value	TFN (*L*, *M*, *U*)
Both elements are equally important	1	(1, 1, 1)
Both elements are almost equally important	2	(1, 2, 3)
One element is slightly more important than the other	3	(2, 3, 4)
One element is moderately more important than the other	4	(3, 4, 5)
One element is more important than the other	5	(4, 5, 6)
One element is significantly more important than the other	6	(5, 6, 7)
One element is nearly absolutely more important than the other	7	(6, 7, 8)
One element is absolutely more important than the other	8	(7, 8, 9)
One element is entirely more important than the other	9	(8, 9, 9)

Note: *L* – represents the lower bound, *M* – represents the middle bound, *U* – represents the upper bound.

of TFN in Table 2 follows the standard approach in the fuzzy AHP to capture uncertainty in expert subjective assessments. The middle value (*M*) retains the crisp AHP scale, while the lower (*L*) and upper (*U*) bounds are defined as $L = M - 1$ and $U = M + 1$, except for the extreme values (1,1,1) and (8,9,9), which ensure scale stability (Alkharabsheh et al., 2022). This TFN distribution has been validated in various FAHP studies to ensure accuracy and avoid bias (Che Lah, 2019; Wang, 2021).

Each respondent produces a pairwise comparison matrix, and to obtain a more representative result across all respondents, the values are aggregated using the geometric mean (geomean) method. The geomean is calculated separately for each component of the triangular fuzzy number (TFN) as follows:

$$\tilde{L} = \left(\prod_{i=1}^{n} L_i\right),\ \tilde{M} = \left(\prod_{i=1}^{n} M_i\right),\ \tilde{U} = \left(\prod_{i=1}^{n} U_i\right) \quad (1)$$

where: $\tilde{L}$, $\tilde{M}$, $\tilde{U}$ are the aggregated lower, middle, and upper bounds of TFN, respectively; L_i, M_i, dan U_i are the fuzzy comparison values provided by the *i*-th respondent; *n* is the total number of respondents.

The geomean ensures that all fuzzy comparison values from respondents are proportionally considered, resulting in a combined fuzzy matrix that is more representative and stable. This method reflects a fair and accurate consensus among the respondents (Alkharabsheh et al., 2022).

Defuzzification and normalization are critical steps in converting fuzzy values into actionable crisp values for decision-making. Defuzzification transforms the fuzzy values obtained from pairwise comparisons into crisp values that are easier to interpret and compute. Normalization then adjusts the weights of each criterion to a uniform range, typically between 0 and 1, ensuring that all criteria have comparable influence in the analysis (Alkharabsheh et al., 2022; Hamzeh & Alavipanah, 2014). After defuzzification, the resulting crisp values are used to determine the weights for each criterion. These weights must be normalized to ensure comparability across criteria, allowing data from various sources to be combined effectively. Normalization adjusts the weights to a uniform range, typically between 0 and 1, ensuring that no criterion is overly dominant or underrepresented in the spatial analysis.

The normalized weight (w_i) for each criterion is calculated using the formula:

$$w_i = \frac{x_i}{\sum_{j=1}^{n} x_j} \quad (2)$$

where: w_i – normalized weight for criterion i; x_i – crisp value of criterion iii obtained from defuzzification; $\sum_{j=1}^{n} x_j$ – total sum of crisp values for all n criteria.

This normalization ensures that the sum of all weights equals 1:

$$\sum_{i=1}^{n} w_i = 1 \quad (3)$$

The normalized weights are then applied as weighted criteria in the spatial analysis using the weighted overlay method. This ensures proportional contributions from all criteria, facilitating a balanced and accurate evaluation of land suitability (Alkharabsheh et al., 2022).

Spatial multi-criteria analysis (SMCA)

Using geographic information systems (GIS), the study integrates weighted criteria into spatial layers to create a land suitability map. Key spatial tools include Euclidean distance for proximity analysis, Kernel density for public facility distribution, and slope analysis for terrain assessment. Each criterion was standardized into a 5-point scale, with higher scores indicating greater suitability (Feizizadeh & Blaschke, 2013).

Weighted overlay

The weighted overlay technique combines spatial layers to generate a composite suitability map. Land is categorized into four classes: highly suitable, suitable, moderately suitable, and unsuitable for TOD-based residential development. This classification highlights zones with optimal TOD potential, enabling targeted planning and investment (Weldu & Deribew, 2014).

The integration process involves assigning weights to these factors, reflecting their relative importance in influencing land suitability. These weights, derived from the fuzzy AHP method, are determined based on expert input and contextual priorities. For example, proximity to railway stations might receive a higher weight compared to ecosystem sustainability, depending on the focus of the analysis. The weighted overlay technique calibrates the raster layers of each factor using these weights, combining them into a single suitability score for each raster cell.

The suitability score (Si) for each raster cell is calculated using the formula:

$$S_i = \sum_{j=1}^{n} w_j \cdot X_{ij} \quad (4)$$

where: S_i – total suitability score for raster cell i; w_j – weight of factor j, as determined by fuzzy AHP; X_{ij} – ordinal value (5–1) for raster cell iii on factor j; n – total number of factors included in the analysis.

RESULTS

Land suitability factors

The successful development of any area is influenced by a variety of factors that shape its suitability for various purposes. Understanding the existing conditions of these factors is essential for effective planning and decision-making. This analysis explores key contributing factors such as proximity to transportation infrastructure, accessibility to essential services, land use patterns, and environmental considerations. By examining these elements, we can gain insights into the potential challenges and opportunities for development, ensuring that future growth aligns with sustainability, safety, and overall community well-being.

Distance to station

Proximity to railway stations plays a critical role in determining the potential for transit-oriented development (TOD). This study examines a 1,200-meter radius around four major stations – Maros, Pangkajene, Tanete Rilau, and Barru – divided into zones of 0–400 m, 400–800 m, 800–1,000 m, and 1,000–1,200 m. At Maros Station, the dominance of fishponds and agricultural land, with limited built-up areas along a collector road, highlights opportunities for transforming underutilized spaces into compact, transit-accessible developments. Pangkajene Station shows similar characteristics, though the presence of residential clusters in the 400–800 meter zone near Desa Kabba indicates potential for infill development. Tanete Rilau Station, with its mixed land use of rice fields, vegetation, and scattered residential areas, offers opportunities for balanced TOD-based growth. Barru Station, featuring higher densities of residential and commercial activity in its western section, particularly in the 400–800 meter zone, demonstrates strong TOD alignment. Overall, zones within 0–400 meters show the highest accessibility, while areas beyond 800 meters retain greenfield characteristics, offering gradual development potential in alignment with TOD principles.

Road network

The existing road network is a critical determinant of TOD potential as it facilitates connectivity and accessibility around railway stations. Roads serve as vital links between residential neighborhoods, public facilities, and transit hubs, thus shaping opportunities for compact, transit-oriented growth. By analyzing the distribution of road types – arterial, collector, and local roads – within a 1,200-meter radius of each station, this study uncovers key insights into development potential. Figure 2 summarizes the total road length and classification for the four major stations: Maros, Pangkajene, Tanete Rilau, and Barru.

The variation in road networks reflects differing levels of TOD readiness across stations. Maros, with its shortest road network and reliance on

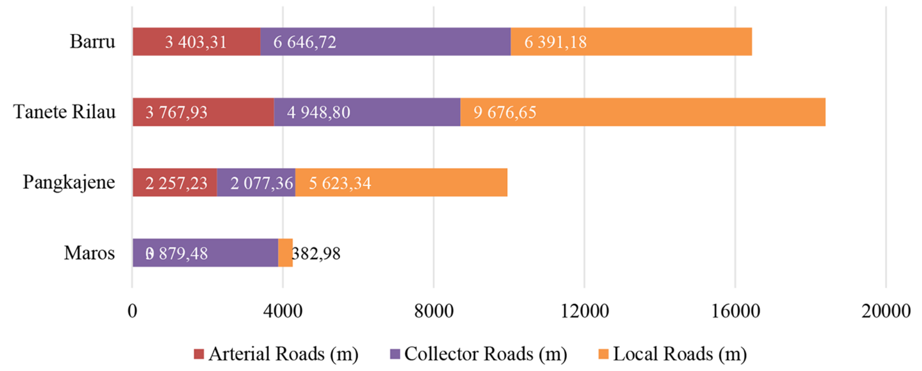

Figure 2. Distribution of road network types around major stations

collector roads, faces limited connectivity but offers potential for improved accessibility through targeted road development. Pangkajene exhibits a balanced road network, where the dominance of local roads near residential clusters supports gradual TOD-based infill development. Tanete Rilau stands out with the longest road network, characterized by a high density of local roads, which align well with TOD principles of walkability and mixed-use development. Barru, with a significant share of collector roads, demonstrates strong connectivity, particularly in areas near the station, enabling seamless integration with transit-oriented planning. These road network characteristics play a pivotal role in shaping the potential for compact, transit-accessible communities and guiding strategic TOD investments in south Sulawesi.

Distance to city center

Distance to city centers is a critical factor in assessing TOD potential, as it reflects the connectivity between railway stations and key hubs of government, economic, and social activity. In this study, city centers are defined as the regency offices within each district, and the distance to these centers is analyzed for four railway stations.

Maros Station is approximately 3,288 meters from the Maros Regency city center, offering strong connectivity to urban and governmental activities. Pangkajene Station, situated about 3,603 meters from the city center of Pangkajene and Kepulauan regency, benefits from an established road network that supports integration with transit-based developments. Tanete Rilau Station, though farther at 8,043 meters from the Barru Regency city center, is near a local activity hub in Tanete Rilau, presenting opportunities for decentralized TOD-based growth. Barru Station is the closest to its city center, located just 1,038 meters away, allowing for seamless integration with the urban core and a strong alignment with TOD principles. These variations in distance highlight diverse levels of accessibility and connectivity, with Barru and Maros demonstrating the strongest potential for central TOD integration. In contrast, Tanete Rilau and Pangkajene offer unique opportunities for localized, community-centered developments that align with TOD frameworks, supporting the creation of mixed-use, walkable neighborhoods.

Public facilites availability

The availability of public facilities significantly influences the potential for TOD by supporting the basic needs of residents and enabling compact, accessible urban growth. These facilities include economic, healthcare, educational, recreational, social, and transportation services, all of which contribute to integrated development (Figure 3). This study evaluates the distribution of public facilities within a 2,200-meter radius of four railway stations to understand their impact on TOD potential.

Maros Station has the lowest number of facilities, with 15 total, emphasizing education and social services but lacking sufficient economic and healthcare infrastructure, which limits its TOD potential. Pangkajene Station, with 20 facilities, shows moderate TOD potential due to its focus on recreation and social services, although it requires additional economic and healthcare facilities to fully align with TOD principles. Tanete Rilau and Barru Stations, both with 43 facilities, offer the greatest TOD potential. Tanete Rilau excels in economic and health services, supporting vibrant, mixed-use urban centers, while Barru's robust healthcare infrastructure and recreational services further strengthen its TOD alignment.

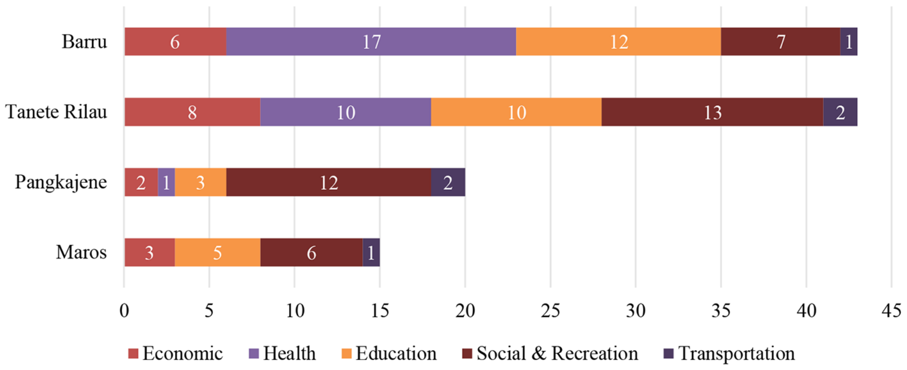

Figure 3. Availability of public facilities around major stations

The disparity in public facility availability underscores the varying levels of TOD readiness. Enhancing economic and healthcare services around Maros and Pangkajene would improve their TOD potential, while Tanete Rilau and Barru exemplify well-rounded, transit-supportive environments suitable for sustainable urban development.

Slope gradient

Slope is a critical factor in evaluating TOD potential, as it influences land stability, construction feasibility, and the overall suitability for urban development. Gently sloping areas (0–8%) are ideal for TOD due to their stability and minimal modification requirements, while steeper slopes pose challenges such as increased construction costs and risks of landslides. This study employed digital elevation model (DEM) data to classify slopes around four stations – Maros, Pangkajene, Tanete Rilau, and Barru – into five categories: flat (0–8%), moderate (8–15%), moderately steep (15–25%), steep (25–40%), and very steep (>40%) (Figure 4).

Flat to moderate slopes dominate the landscapes around Maros, Pangkajene, and Barru stations, making these areas highly suitable for TOD-oriented developments due to ease of construction and cost efficiency. Maros and Barru, with over 90% of their terrain classified as flat, are particularly well-positioned to accommodate compact, transit-centered urbanization. Conversely, Tanete Rilau presents a higher proportion of moderately steep to steep slopes, accounting for over 20% of its terrain. While this poses challenges for construction, it also offers opportunities for innovative architectural and engineering solutions tailored to hilly terrains, aligning with TOD principles. These findings emphasize the importance of terrain analysis in guiding sustainable, transit-accessible developments.

Disaster risk

Flood risk plays a crucial role in assessing TOD potential, as high flood-prone areas can disrupt transit infrastructure and reduce land suitability for compact, walkable developments. Areas with lower flood risks provide greater opportunities for sustainable TOD implementation. This study utilizes flood risk data from the GIS Service Inarisk by the National Disaster Management Agency (BNPB), classifying flood zones into low, medium, and high-risk categories. The flood risk distribution across the four major railway stations is presented in Figure 5.

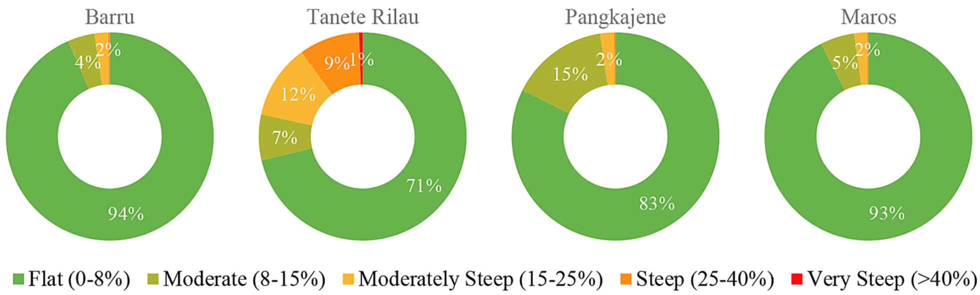

Figure 4. Slope distribution in areas surrounding each station

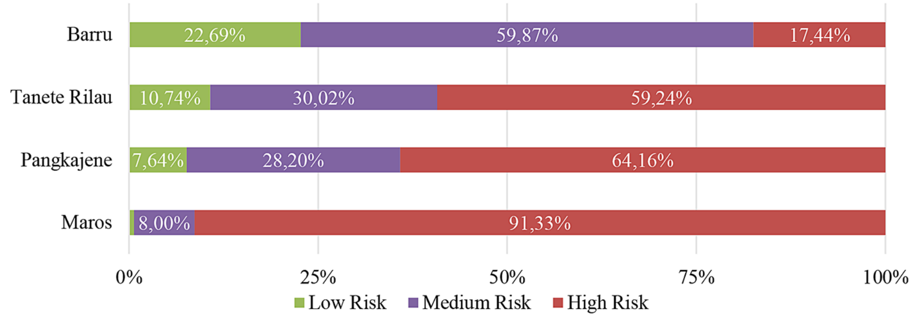

Figure 5. Flood risk per station

The flood risk assessment highlights varying levels of TOD feasibility across the stations. Maros presents the highest flood risk, with over 91% of its land classified as high risk, requiring significant flood mitigation strategies before TOD-based developments can be pursued. Pangkajene and Tanete Rilau exhibit a mix of medium and high-risk zones, suggesting that targeted planning is necessary to maximize TOD suitability in lower-risk areas.

In contrast, Barru stands out as the most favorable location for TOD, with only 17.44% of its land categorized as high risk and a majority of its area falling within low to medium-risk zones. This makes Barru particularly well-suited for sustainable transit-oriented development, with fewer challenges related to flooding. Strategic adaptation measures such as elevated infrastructure and flood-resistant building designs will be essential for optimizing TOD potential in higher-risk zones while ensuring resilience in transit-oriented communities.

Landuse

The existing land use surrounding the four major stations – Maros, Pangkajene, Tanete Rilau, and Barru – plays a crucial role in shaping TOD potential. The distribution of land use reflects varying degrees of agricultural activity, infrastructure availability, and residential development, impacting the feasibility of compact, mixed-use growth aligned with TOD principles. The spatial distribution of land use is illustrated in Figure 6, while detailed area measurements for each land use category are provided in Table 3.

The land surrounding the four stations reveals distinct land use patterns that directly impact TOD feasibility. Maros and Pangkajene are dominated by fishponds (48.43% and 52.10%, respectively) and paddy fields, limiting immediate residential growth but presenting long-term opportunities for sustainable, mixed-use development. The limited proportion of residential areas in Maros (2.03%) suggests a need for strategic land use conversion to align with TOD.

Tanete Rilau and Barru, on the other hand, exhibit stronger TOD potential due to their higher proportions of residential areas (16.08% and 21.60%, respectively) and well-distributed infrastructure. The presence of significant vegetation and vacant land in these areas suggests opportunities for TOD-compliant urban expansion while maintaining environmental sustainability.

Overall, Barru emerges as the most TOD-ready station, with the highest proportion of residential land and balanced land use distribution. Pangkajene and Tanete Rilau offer strong

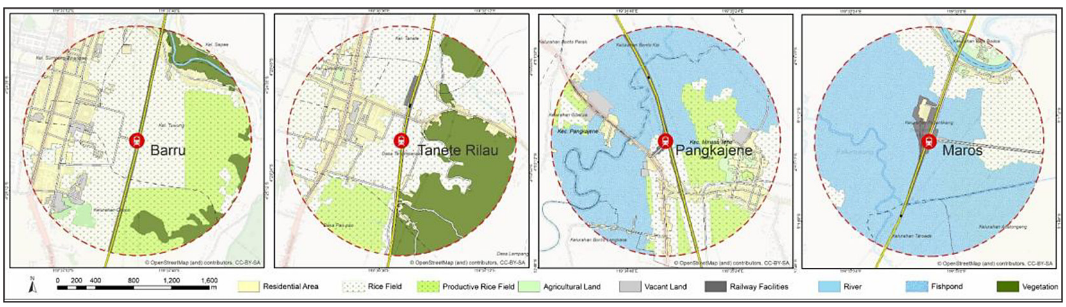

Figure 6. Land use classification maps around stations

Table 3. Land use areas per station

Land use	Maros		Pangkajene		Tanete Rilau		Barru	
	(km²)	(%)	(km²)	(%)	(km²)	(%)	(km²)	(%)
Agricultural land	74.28	1.14	69.36	1.53	4.07	0.09	67.86	1.50
Residential area	132.58	2.03	453.41	10.02	727.53	16.08	977.2	21.60
Rice field	2,871.21	44.02	676.82	14.96	2,029.38	44.85	1,838.61	40.63
Productive rice field	-	-	627.19	13.86	404.94	8.95	1,060.76	23.44
River	121.76	1.87	132.35	2.93	-	-	20.6	0.46
Fishpond	3,158.82	48.43	2,357.32	52.10	-	-	-	-
Vacant land	22.5	0.35	102.99	2.28	31.59	0.70	97.59	2.16
Vegetation	-	-	0.29	0.01	1,231.09	27.21	363.67	8.04
Railway facilities	140.96	2.16	104.73	2.31	96.07	2.12	98.48	2.18

opportunities for TOD but require strategic planning to integrate agricultural land into mixed-use developments. Maros, despite its current dominance in fishponds and paddy fields, holds potential for gradual TOD-based transformation, provided that infrastructure and residential zoning adjustments are implemented. These findings underscore the need for targeted land use planning to maximize TOD potential and create vibrant, transit-supportive communities around railway hubs.

Water supply network

The availability of a clean water supply network is a critical factor in supporting transit-oriented development (TOD), ensuring access to essential resources for sustainable urban growth. A well-developed water infrastructure enhances the feasibility of compact, high-density residential developments by providing reliable services to transit-adjacent communities. In this study, the clean water network is analyzed based on its coverage around the four railway stations, with distribution primarily following road networks to facilitate access. Maros Station has the most limited clean water network, spanning only 1,293.39 meters, which may constrain TOD implementation unless infrastructure improvements are made. Pangkajene Station demonstrates better readiness, with a network extending 6,642.19 meters, supporting a larger residential base. Tanete Rilau (11,067.10 meters) and Barru (13,337.79 meters) have the most extensive water supply networks, offering strong potential for TOD due to their capacity to sustain higher-density, mixed-use developments.

Barru stands out as the most infrastructure-ready location for TOD, given its extensive water network, which supports compact and sustainable residential growth. However, further evaluations on service efficiency and expansion potential are necessary to ensure equitable water distribution and to optimize TOD development in all station areas.

Electricity supply network

Reliable electricity infrastructure is fundamental to TOD, enabling efficient transit operations, economic activities, and high-density residential developments. This study focuses on the medium voltage overhead distribution network (SUTM), which supplies electricity directly to residential and commercial areas, typically following major road networks. The electricity supply network varies significantly across the four stations, influencing TOD feasibility. Maros Station has the shortest network coverage at 1,964 meters, potentially limiting large-scale TOD applications without significant infrastructure upgrades. Pangkajene Station is better equipped, with 9,957.95 meters of network coverage, supporting broader residential and commercial integration. Tanete Rilau (18,622.97 meters) and Barru (15,763.71 meters) feature the longest electricity networks, aligning well with TOD principles by facilitating transit-adjacent, mixed-use development. Tanete Rilau, with the most extensive electricity coverage, exhibits strong TOD potential by supporting transit-connected, mixed-use growth. Barru's well-established network further strengthens its suitability for transit-oriented urban expansion, ensuring reliable power distribution for higher-density developments. Infrastructure improvements in Maros and targeted expansions in Pangkajene would enhance their TOD readiness, supporting a more efficient and sustainable urban framework.

Restricted areas

Limited areas are designated to protect ecosystems and prevent unsuitable developments, such as residential zones. In this context, limited areas refer to regions identified in the regional spatial plan (RTRW), including forests, rivers, and river buffers, which are critical for environmental conservation and mitigating disasters like floods. Railway tracks are also classified as limited areas, although specific regulations for their management are lacking. These zones are generally non-residential due to safety considerations, accessibility, and the need for infrastructure maintenance. The Figure 7 provides an overview of restricted zones around each station.

This data illustrates the extensive limited areas surrounding each station, which restrict their use for residential development. For instance, the Maros Station area includes 75.17 km² of railway tracks and 611.71 km² of river and river buffer zones, while the cultivation area of 3837.31 km² remains available for development. Similarly, other stations like Pangkajene, Tanete Rilau, and Barru exhibit significant restricted zones near railways and water bodies, underscoring the importance of preserving these areas. The availability of cultivation area areas near these stations highlights their potential for TOD. TOD can optimize land use by integrating residential, commercial, and public facilities near transportation hubs, while ensuring sustainable growth and protecting ecological functions. By focusing development in cultivation area zones, TOD initiatives could enhance accessibility, reduce environmental impacts, and create vibrant, connected communities around the stations.

Fuzzy AHP

Pairwise comparison

The pairwise comparison questionnaire results, shown in Table 10, reflect the priority weights for each element based on responses from experts, including academics (AC), government officials (GO), and urban planning and transportation practitioners (PR). The process involved systematically comparing all element pairs to create a comparison matrix, which was then analyzed to determine the priority weights.

The consistency ratio (CR), also presented in Table 4 was used to assess the reliability of the

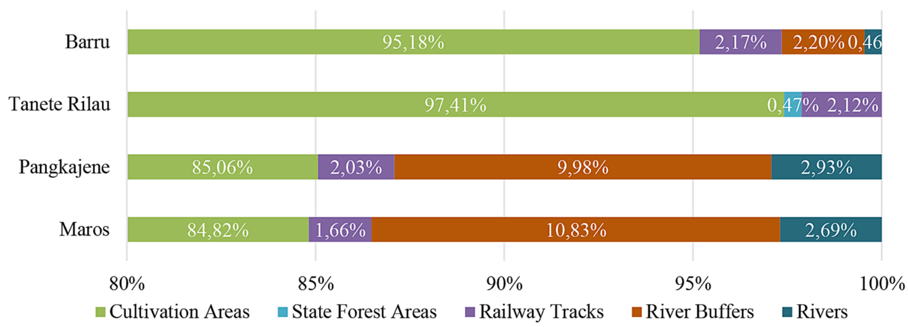

Figure 7. Distribution of restricted zones around stations

Table 4. Results of pairwise comparison ahp compilation

Respondent	DD	DR	DC	FA	SL	RD	LU	WS	ES	EC	CR
AC 1	0.15	0.05	0.05	0.09	0.08	0.09	0.13	0.09	0.09	0.20	0.10
AC 2	0.27	0.07	0.08	0.34	0.08	0.23	0.07	0.07	0.07	0.09	0.07
AC 3	0.35	0.11	0.04	0.35	0.02	0.11	0.15	0.15	0.18	0.10	0.08
GO 1	0.16	0.13	0.06	0.06	0.05	0.11	0.06	0.08	0.08	0.22	0.09
GO 2	0.09	0.07	0.06	0.09	0.04	0.10	0.19	0.19	0.12	0.17	0.10
GO 3	0.09	0.24	0.04	0.22	0.02	0.13	0.06	0.09	0.09	0.29	0.09
GO 4	0.26	0.24	0.26	0.10	0.03	0.09	0.13	0.17	0.10	0.06	0.06
PR 1	0.19	0.10	0.06	0.07	0.09	0.10	0.03	0.11	0.11	0.19	0.07
PR 2	0.06	0.22	0.20	0.08	0.03	0.20	0.06	0.09	0.09	0.19	0.08
PR 3	0.30	0.41	0.19	0.19	0.09	0.09	0.10	0.09	0.07	0.05	0.06

responses. CR values ranged from 0.06 to 0.10, indicating acceptable consistency and meeting the tolerance limit of CR ≤ 0.10. This confirms that the pairwise comparisons are reliable for further analysis using fuzzy values.

Deffuzifikasi

Fuzzy calculations involved separately tabulating the lower (L), middle (M), and upper (U) values for a systematic approach. After integrating these values, they were aggregated and defuzzified into crisp values. These values were then normalized to ensure the total weight summed to 1. The final priority weights, derived from this process, will be used in the weighted overlay.

The weighted results of various criteria based on the Fuzzy AHP method shown in Table 5. The proximity to the train station (DD) emerges as the most significant factor, with a fuzzy weight of 0.13 and a crisp value of 0.15, accounting for 15.36% of the total priority. This is followed by the distance to the road (DS) at 12.76%, and the factor of restricted areas (EC) at 12.39%. Public facilities availability (FA) also plays a notable role, contributing 11.79% to the overall weighting. Other important factors include disaster risk (RD) and basic infrastructure such as water supply (WS) and electricity supply (ES), which are ranked accordingly. Slope gradient (SL) is ranked the lowest, with the least influence on the land suitability analysis at 4.61%. The table's final column ranks the criteria from most to least influential, with proximity to the train station being the top priority for the development of sustainable areas.

The analysis highlights that accessibility, especially proximity to transportation hubs and roads, is crucial for sustainable development. Environmental factors, such as restricted areas and disaster risk, along with essential infrastructure like water and electricity, are also key to creating safe and suitable areas for development while preserving greenfield areas.

Land suitability

Spatial clasification of land suitability factors

In this study, land suitability classification was conducted to evaluate the feasibility of areas for development based on a spatial approach. Each factor influencing land suitability was analyzed using specific methods tailored to their characteristics, utilizing relevant spatial data. The classification of these factors was based on relevant theories and regulations regarding spatial planning, land use, and resource management anticipating the growth.

The classification results are presented in an ordinal scale from 5 to 1, with the highest value (5) indicating optimal suitability, and the lowest value (1) representing the least suitability (Table 6). This method offers a systematic approach to understand how factors such as distance, accessibility, infrastructure, topography, disaster risk, and ecosystem sustainability are quantitatively projected to affect overall land suitability.

The land suitability classification maps provide a spatial analysis, with each factor's suitability visually represented through color gradation. The color scale ranges from green-blue, indicating the highest suitability (value of 5), to red, representing medium suitability (value of 3), and yellow, signifying the lowest suitability (value

Table 5. Deffuzzifikation and normalization

Criterias	Fuzzy weight			Defuzzifikasi (crisp value)	Normalization	Percentage (%)	Rank
	L	M	U				
DD	0.10	0.13	0.15	0.13	0.15	15.36	1
DS	0.08	0.10	0.13	0.10	0.13	12.76	2
DC	0.05	0.06	0.07	0.06	0.07	7.29	9
FA	0.08	0.10	0.11	0.10	0.12	11.79	4
SL	0.03	0.04	0.05	0.04	0.05	4.61	10
RD	0.07	0.08	0.10	0.08	0.10	10.11	5
LU	0.05	0.06	0.08	0.07	0.08	8.08	8
WS	0.06	0.07	0.09	0.07	0.09	9.08	6
ES	0.06	0.07	0.09	0.07	0.09	8.54	7
EC	0.08	0.10	0.12	0.10	0.12	12.39	3
				0.82	1.00		

Table 6. Land suitability factor classification

No.	Factor	Classification	Ordinal value
1	Distance to train station	0–400 m	5
		400–800 m	4
		800–1000 m	3
		1000–1200 m	2
		>1200 m	1
2	Distance to road	0–100 m	5
		100–300 m	4
		300–600 m	3
		600–1000 m	2
		>1000 m	1
3	Distance to city	<2000 m	5
		2000–4000 m	4
		4000–6000 m	3
		6000–8000 m	2
		>10000 m	1
4	Public facilities availability	Very high density	5
		High density	4
		Medium density	3
		Low density	2
		Very low density	1
5	Slope gradient	0–8% (flat)	5
		8–15% (gently sloping)	4
		15–25% (moderately steep)	3
		25–40% (steep)	2
		>40% (very steep)	1
6	Disaster risk	0–0.20 (very low)	5
		0.20–0.40 (low)	4
		0.40–0.60 (medium)	3
		0.60–0.80 (high)	2
		0.80–1.00 (very high)	1
7	Current land use	Residential, vacant land	5
		Scrubland	4
		Dry farming fields	3
		Productive rice fields, ponds	2
		Rivers, rail tracks	1
8	Water supply network	0–100 m	5
		100–300 m	4
		300–600 m	3
		600–900 m	2
		>900 m	1
9	Electricity supply network	0–100 m	5
		100–300 m	4
		300–600 m	3
		600–900 m	2
		>900 m	1
10	Ecosystem sustainability/restricted areas	Cultivation area	5
		River boundary areas	2
		Protected areas (railway tracks, rivers, forests)	1

of 1). This color scheme facilitates interpretation and highlights areas that are most favorable for anticipating the development.

Weighted overlay of land suitabilty

The assessment of land suitability for residential development around the Makassar-Parepare railway stations was conducted using the spatial multi-criteria analysis (SMCA) approach combined with a weighted overlay technique. This analysis considered ten critical factors, including accessibility, ecosystem sustainability, disaster risk, and infrastructure availability, as identified during the initial stages of the study (Figure 7 and Figure 8). The factors were weighted using the fuzzy AHP method, based on input from ten experts, to produce a land suitability map that categorized areas into five classifications: Highly Suitable, Suitable, Moderately Suitable, Unsuitable, and Highly Unsuitable (Figure 10).

The land suitability analysis revealed notable variations across the four major railway stations – Maros, Pangkajene, Tanete Rilau, and Barru – highlighting differences in physical, spatial, and socio-economic conditions (Figure 11) . At Maros Station, 46.44% of the land is categorized as moderately suitable, while 31.62% is deemed unsuitable, reflecting challenges that need to be addressed through infrastructure and planning improvements. In contrast, Pangkajene Station has the highest proportion of suitable land (50.86%), with 34.64% classified as moderately suitable, suggesting significant potential for development with relatively low barriers. Tanete Rilau Station is the most favorable site, with 63.11% of its land categorized as suitable, making it highly attractive for residential and transit-oriented development. Similarly, Barru Station shows promise, with 53.81% of land classified as suitable and 10.72% as highly suitable, indicating strong potential for sustainable and high-quality development.

These findings highlight significant opportunities to implement transit-oriented development (TOD) along the Makassar-Parepare railway corridor. TOD strategies can capitalize on high-suitability areas, such as those near Tanete

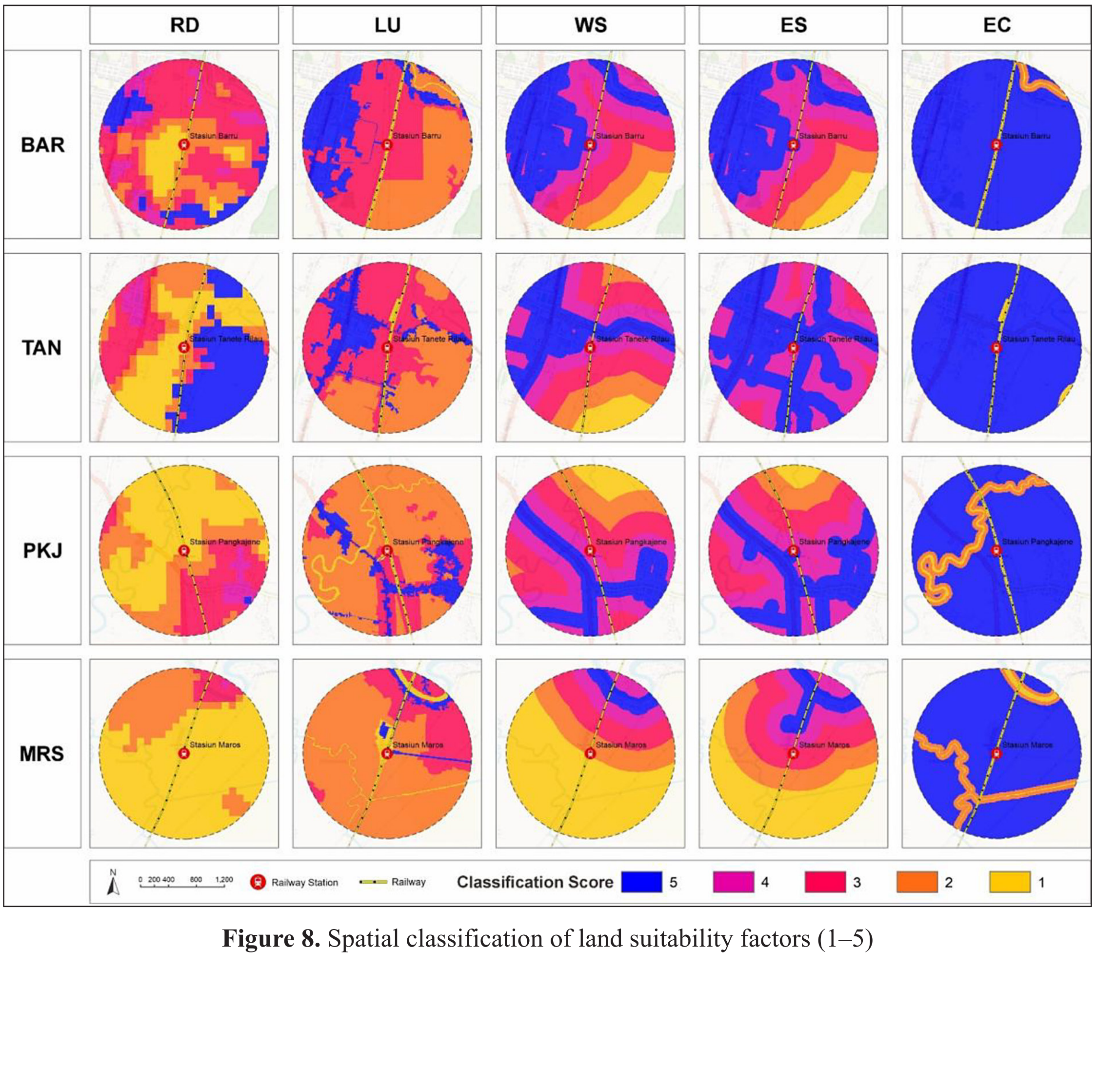

Figure 8. Spatial classification of land suitability factors (1–5)

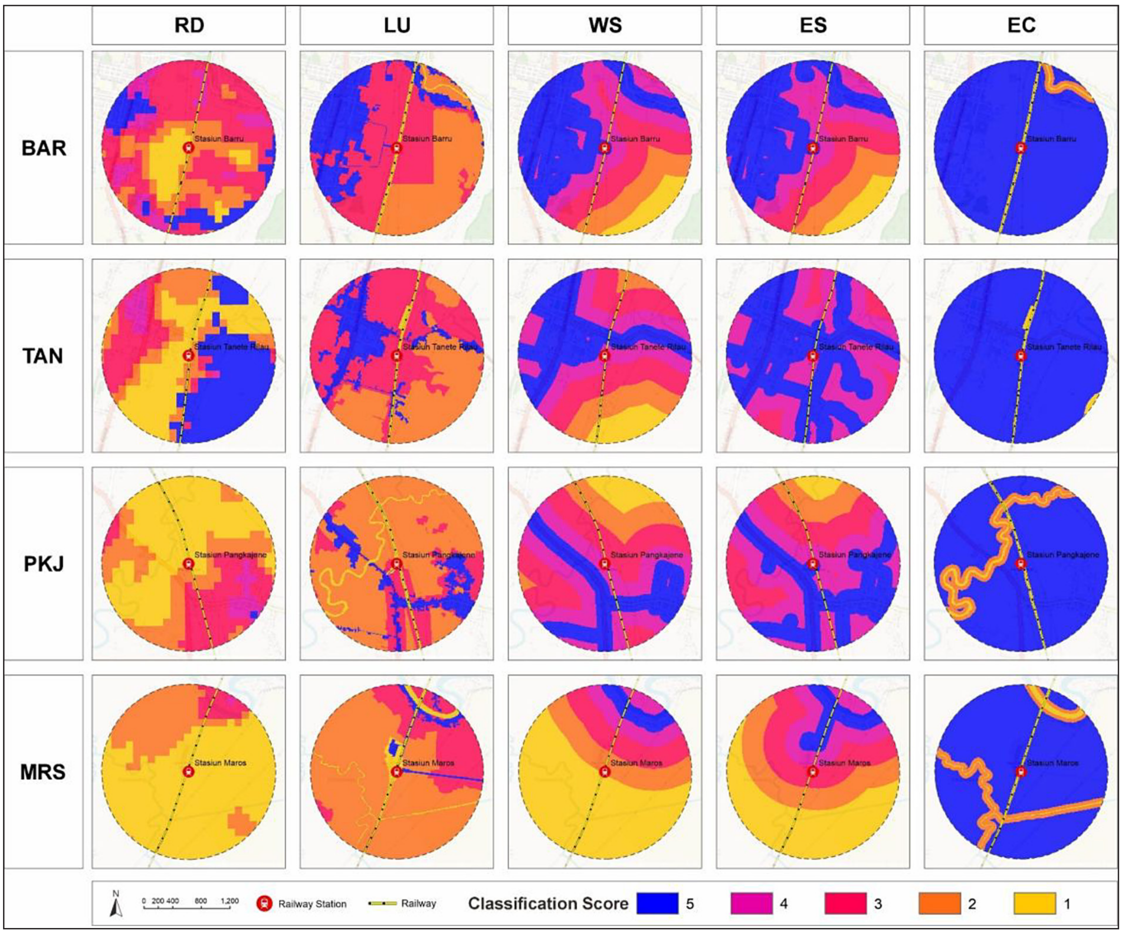

Figure 9. Spatial classification of land suitability factors (6–10)

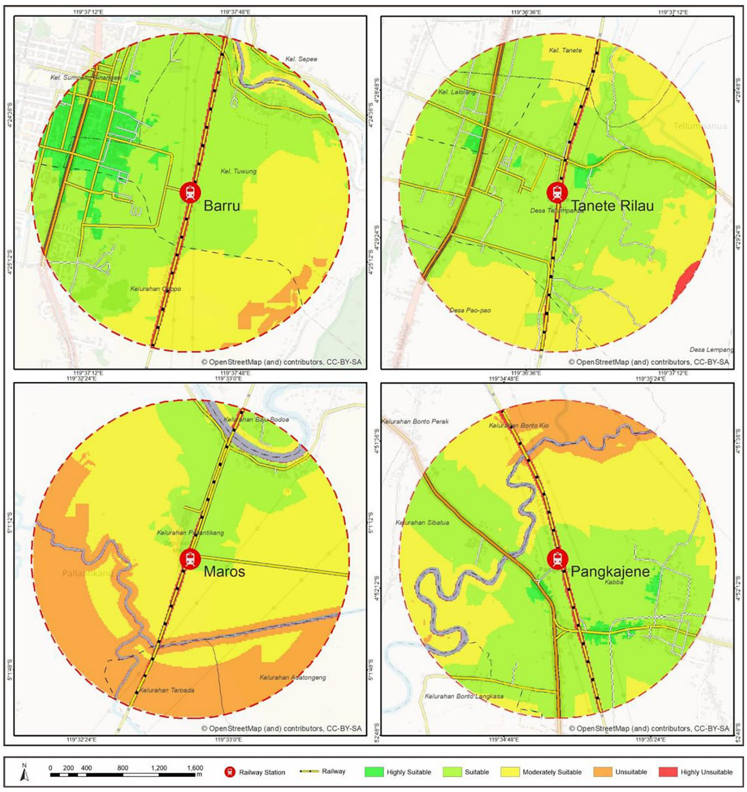

Figure 10. Land suitability of TOD potential development around railways stastion

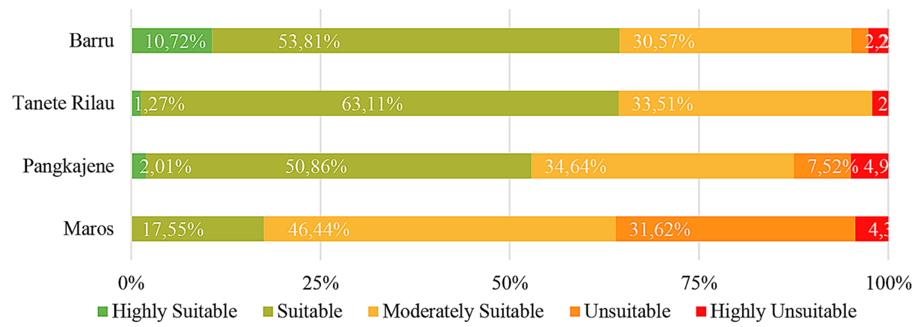

Figure 11. Distribution areas of land suitability around stations

Rilau, Barru, and Pangkajene Stations, by promoting compact, mixed-use developments that enhance accessibility and reduce car dependency. In areas like Maros, where land is predominantly moderately suitable, TOD can focus on upgrading infrastructure and improving connectivity to unlock development potential. Furthermore, TOD approaches can ensure the protection of ecologically sensitive zone.

Overall, adequate clean water and electricity infrastructure are essential enablers of TOD. Barru and Tanete Rilau demonstrate the highest readiness due to their extensive utility networks, supporting compact, sustainable urban growth. In contrast, Maros requires infrastructure enhancements to optimize its TOD potential, while Pangkajene presents balanced opportunities that could be enhanced through targeted utility expansions. Strategic investments in infrastructure will be crucial to ensuring that TOD principles are effectively implemented across all four station areas.

CONCLUSIONS

Each railway station along the Makassar-Parepare corridor presents distinct characteristics based on land suitability factors, which highlight opportunities for transit-oriented development. Maros Station requires significant infrastructure upgrades and flood risk mitigation to unlock its potential for TOD, while Pangkajene Station shows promising development opportunities but would benefit from enhanced public facilities to support compact, transit-connected growth. Tanete Rilau, with its complete infrastructure, is well-positioned for sustainable TOD, offering opportunities to integrate residential, commercial, and transit facilities seamlessly. Barru Station stands out with excellent accessibility and low disaster risk, making it ideal for eco-friendly TOD initiatives.

The fuzzy AHP weighting results emphasize that proximity to stations (15.36%) and road access (12.76%) are the most critical factors for sustainable development, aligning well with TOD principles of accessibility and connectivity. Other factors, such as restricted areas (12.39%) and public facilities (11.79%), are crucial for ecological and urban sustainability. Basic infrastructure, including clean water (9.08%) and electricity (8.54%), supports the feasibility of TOD projects, while slope gradients (4.61%) remain important for ensuring physical stability.

Tanete Rilau and Barru Stations emerge as the most favorable for TOD implementation, with a majority of land categorized as “suitable” or “highly suitable.” Tanete Rilau boasts 63.11% suitable land, making it a prime location for transit-integrated, sustainable development. Barru, leading in highly suitable land (10.72%), is well-prepared for high-quality, greenfield-preserving TOD. These findings highlight the potential for eco-friendly and connected development, with a focus on enhancing accessibility, optimizing land use, and preserving environmental sustainability along the railway corridor.

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