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A Geoprocessing Approach Using POI Visibility Index for Identifying Potential Routes in Designing Sustainable Tourism Development: The Case Study of Singkawang, Indonesia

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ABSTRACT
Regional planning and urban design are essential in developing a region or city. Point of Interest (POI) data in area planning can significantly influence resident perceptions and behaviors and shape investment decisions and development strategies in tourist areas. This study focuses on Singkawang City, a prominent coastal tourist destination on Kalimantan, Indonesia. Singkawang features a historical spatial layout but faces numerous contemporary challenges. The research aims to identify potential efficient tourist routes using geographic analysis based on the POI visibility index. The research has practical benefits, including promoting tourism development, supporting local economic growth, optimizing land use, and enhancing urban user-friendliness. The study employs data on road networks, buildings, and tourist attraction points. The analysis identifies the nodes (POIs and intersections) that concentrate the most efficient routes in the study area, actively connecting tourist attractions in the city center. These routes demonstrate greater importance than those connecting natural attractions in the city's peripheral areas. User visitation levels and the visibility of POIs influence the city's morphological movement patterns. The findings highlight the strategic role of POI-based geographic analysis in improving urban connectivity and guiding regional planning efforts, offering valuable insights for addressing urban challenges and advancing sustainable, tourism-focused urban development.

INTRODUCTION

Urban planning and design are fundamental aspects of regional and urban development. Area planning has become progressively important in ensuring efficient land use, fostering sustainable development, and optimizing user experience (Sitorus, 2016). Effective urban planning and design require a comprehensive understanding of how residents navigate urban spaces. It is essential to understand how urban residents engage with urban spaces and how these spaces develop and adapt in response to behavioral patterns (Natapov, Cohen, et al., 2024). Urban mobility networks are employed to comprehend the operational mechanisms of urban systems (C. Liu et al., 2022). The visibility of the Points of Interest (POI) network and its impact on the morphological movement patterns of cities represent significant areas of urban studies. Understanding how urban structures evolve and how people move within these structures can provide valuable insights into urban planning and development. The connectivity of urban traffic networks is closely associated with traffic flow and infrastructure (Ding et al., 2019; Sedubun et al., 2023).

Singkawang City and many other cities in Indonesia necessitate urban planning and design grounded in Point of Interest (POI) analysis for various critical purposes: fostering tourism development, enhancing the quality of life, promoting local economic growth, optimizing land use, and creating a user-friendly urban environment. Singkawang is an administrative city in

West Kalimantan Province, uniquely distinguished by its coastal and hilly geography. Mount Besar in the southern part of the city exemplifies this exceptional topography by directly merging with the shoreline of the Natuna Sea.

In addition to its natural assets, Singkawang boasts a significant cultural and historical heritage, establishing it as one of West Kalimantan's premier tourist destinations. The designation of heritage zones under Regional Regulation No. 1 of 2022, concerning the Spatial Plan of Singkawang City for 2022–2042, has elevated its status as a strategically urban area, particularly from social and cultural perspectives.

Renowned for its rich Chinese cultural and traditional legacy, Singkawang integrates various attractive POIs, including temples, monuments, and cultural festivals. Incorporating these elements into urban planning enhances the city's tourism appeal and catalyzes local economic development, thereby supporting the broader goals of tourism advancement. The integration of POIs into urban planning exerts a substantial influence on residents' perceptions and behaviors, shaping critical decisions related to investment and urban development (Liang et al., 2024).

POIs encompass locations of notable significance or interest to residents and visitors (Psyllidis et al., 2022; Yotifa et al., 2022). Their integration into urban planning can improve urban life quality by facilitating easy access to essential public amenities, such as parks, shopping centers, and recreational facilities. Moreover, prioritizing POIs with high potential as tourism hubs, such as traditional markets or culinary centers, within urban planning strategies can stimulate local economic growth and empower the surrounding community.

Point of Interest (POI) analysis is integral to urban planning, enabling the identification and allocation of land use in ways that efficiently meet community needs. POI analysis addresses congestion and underutilized spaces, boosting urban productivity and optimizing land use. Incorporating essential POI locations, such as public transportation hubs, healthcare facilities, and schools, into the planning of tourism areas positions Singkawang as a potential model for user-friendly and inclusive urban design that benefits all demographic groups.

Integrating POI analysis into urban planning enables Singkawang to maximize resource utilization, improve residents' quality of life, and enhance the city's identity and competitiveness on local, national, and international scales. Furthermore, embedding digital technology in urban planning fosters a more sustainable and livable city (Geshkov, 2023).

This research aims to design efficient tourism routes in Singkawang City using the POI visibility index. The POI visibility index is a metric that evaluates the visibility or obstruction of points of interest from various observation points within the area. This analysis considers factors like elevation, building density, vegetation, and other potential obstructions to line-of-sight visibility.

Open data mapping of tourism attractions offers valuable insights into visitor behavior and preferences (Abbasi-Moud et al., 2021; Dinis et al., 2019; Gil et al., 2020; Zhang & Zhang, 2023). This approach enables the development of urban spaces that cater to the needs of both residents and tourists, fostering a sustainable and competitive urban environment. Integrating these principles allows Singkawang to set a benchmark for urban sustainability and inclusivity.

The effective integration of Points of Interest (POI) can significantly improve urban residents' quality of life, enhance the identity of neighborhoods, and boost local economic competitiveness (Jannah et al., 2023). Therefore, prioritizing POIs in urban planning is crucial to improving user experience and significantly influencing overall urban development. POIs frequently guide pedestrian navigation (Natapov, Cohen, et al., 2024). However, many urban planning and design models overlook POIs, focusing primarily on road networks (Natapov, Cohen, et al., 2024).

By employing Network Analysis for Urban Centers, urban hubs and centers can be identified through graph centrality, providing a clearer understanding of the spatial structure of urban movement. This analysis also reveals community structures and socioeconomic clusters, often distinct from existing administrative boundaries. It enables a more accurate identification of neighborhoods and their boundaries. Connectivity between locations is crucial, as it directly influences people's ability to move and engage in activities efficiently within urban spaces, each serving different functions (Huynh & Ramli, 2022). A resilient transportation system reflects the capacity to move people even when facing significant barriers with minimal disruption or recovering swiftly from disruptions with reduced functionality and economic costs (Peng et al., 2022). Adaptive and resilient transportation infrastructure strengthens urban systems and supports economic development (Boeing & Ha, 2024; Celardo et al., 2023; C. Liu et al., 2022; Peng et al., 2022).

The research introduces a novel methodology by integrating POI visibility analysis into tourism route planning, a departure from traditional models that rely primarily on statistical data or visitor preferences. By emphasizing spatial visibility and aesthetic quality, the study pioneers a POI Visibility Index that enables route design based on POI density or proximity and visual appeal through viewshed analysis.

RESEARCH METHODS

The case study in this research focuses on Singkawang City and concentrates on a specific urban area. This study uses open data (big data) related to service activities in Singkawang. Researchers find Points of Interest (POIs) particularly significant due to their widespread applications in resource allocation, tourism development, travel recommendations, and event management (Lim et al., 2019). Digital platforms, such as Google Maps, increasingly identify functional urban areas (Huang et al., 2022; Yeow et al., 2021).

Data Collection

This study utilizes data on Singkawang City's building distribution, road network, and tourist attractions. Researchers use these datasets to analyze the urban form (Boeing, 2022). They extract tourist attraction data for Singkawang City from Google Maps with the Instant Data Scraper tool. The choice of keywords critically influences the quality of the collected data (Sitorus, 2016). For this study, the researchers use the keyword "Singkawang City tourism." After scraping the data, the researchers validate and verify it to ensure that it accurately reflects the tourism activities in Singkawang. The verification process aims to eliminate duplicate or erroneous data patterns (Vercruyssen & Loosveldt, 2017; Yeow et al., 2021).

In addition to the tourist attraction data, researchers obtain other data sources, including building distribution data from OpenStreetMap and road network data from the Singkawang City government. OpenStreetMap offers open-source geospatial data contributed by a global community of users. While its coverage in Singkawang is generally applicable, the accuracy may vary depending on the frequency of updates and the level of local contributor activity. The building data were cross-validated with official government sources and satellite imagery to ensure data reliability. Road network data from the city government is considered more authoritative and used as the primary reference for spatial analysis. Google Maps was also consulted for supplementary verification, particularly for major roads and landmarks, although its precision may be limited in informal or newly developed areas. The researchers present these datasets in Figure 1 below.

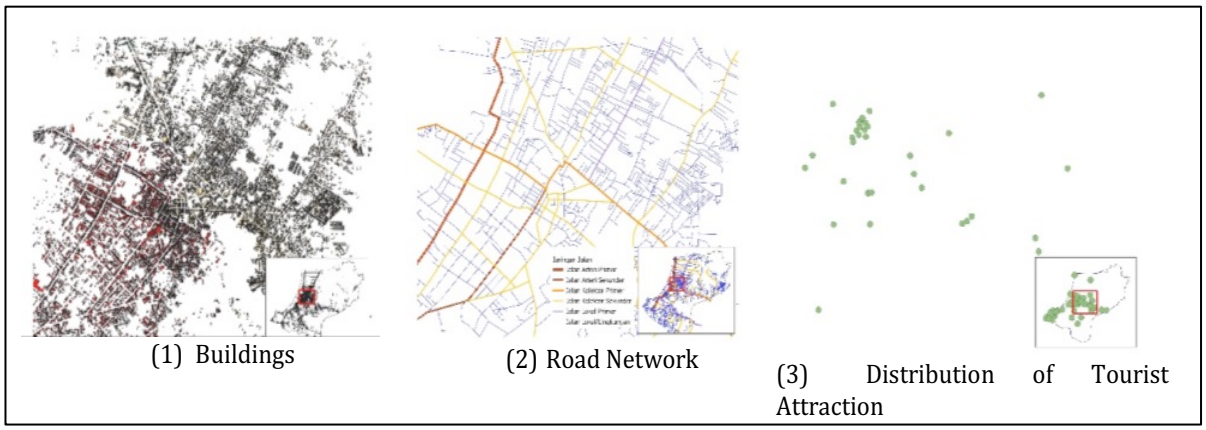

Figure 1. Research Data (Source: Map derived and processed from OpenStreetMap, 2024).

Analysis

The analysis is based on building data, road network data, and the distribution of tourist attractions in Singkawang City, processed using the QGIS POI VizNet software. The POI Visibility Index (POI VizNet) establishes visibility networks within the city. This application integrates GIS data related to Points of Interest (POI) and visibility into a unified network-based analysis framework (Natapov, Dalyot, et al., 2024). The analysis employs open-source geographic data to merge points of interest and visibility into a network-based framework.

Figure 2 illustrates the data used to generate visibility graphs in the POI VizNet application, including (1) the road network (represented as polyline segments), (2) visibility boundaries (represented as polygons for buildings), and (3) POI locations (depicted as points). In this study, we set a restricted vision distance of 400 meters, representing the maximum distance for pedestrians to observe their surroundings in an urban environment. The 400-meter rule is a fundamental guideline in pedestrian-oriented urban design, reflecting the optimal spacing of thoroughfares to support walkability and social interaction. (Mehaffy et al., 2010; Natapov, Cohen, et al., 2024).

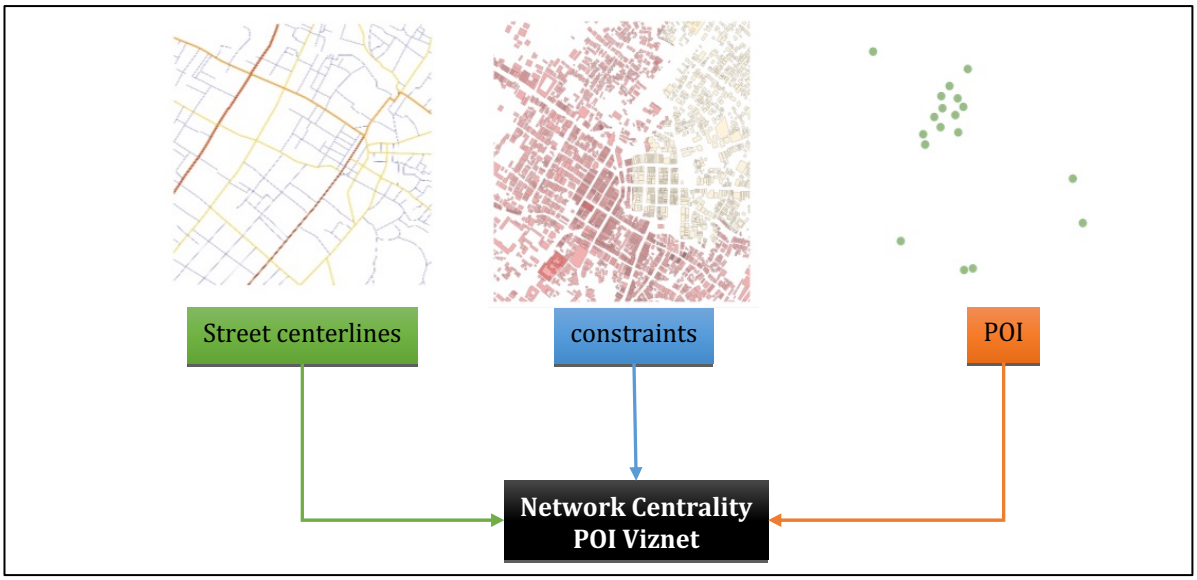

Figure 2. Roads form a network, buildings constrain, and tourist attractions are points in the methodology (Source: Authors, 2024).

The results from the POI VizNet analysis are further processed using Gephi. Gephi is an open-source software tool for network analysis and visualization. In the POI visibility analysis, several interrelated concepts emerge, including:

1. Degree Centrality is the number of direct connections a node (point) has within a network. In the context of Points of Interest (POIs), degree centrality indicates how visible a specific point is from other points within the network. The higher the centrality, the more visible the point is to others.
2. Modularity Analysis is used to identify communities or groups within a network. In the context of POIs, modularity analysis helps to identify groups of POIs that are strongly interconnected, providing insights into the structure of the communities within the visibility network. A high modularity value means the network has a well-defined and strong community structure (Natapov, Cohen, et al., 2024).
3. Closeness Centrality measures how close a node is to all other nodes in the network. A node with high closeness centrality can reach other nodes more quickly, reflecting the network efficiency.
4. Betweenness Centrality measures how often a node (in this case, a POI) lies on the shortest path between two other nodes. POIs with high betweenness centrality serve as crucial "connectors" in the network, facilitating the flow of information or visitors between various parts of the network (Susanto et al., 2012). Betweenness centrality identifies POIs that act as crucial links between groups, enabling the movement of information or visitors. POIs with a high degree of centrality serve as key connectors within the network
5. Weighted degree refers to the total weight of all connections a node holds. In POI analysis, this can refer to the total visibility or visual connections a POI has with other POIs. POIs with a high-weighted degree have numerous visual connections, indicating that they are evident from many observation points (Yadav, 2023). The weighted degree provides insights into how visible or interconnected a POI is within the network, which can influence its role within communities and as a key connector.

RESULTS AND DISCUSSION

Based on the analysis of 70 tourist attractions in Singkawang City, Figure 3 illustrates the distribution of tourist attractions within the city. Proximity analysis is necessary to identify the activity centers in Singkawang. Based on the distribution data of tourist attractions, the initial hypothesis of this study is that the tourist attractions in Singkawang are near each other, thus enabling the creation of closely interconnected alternative travel routes.

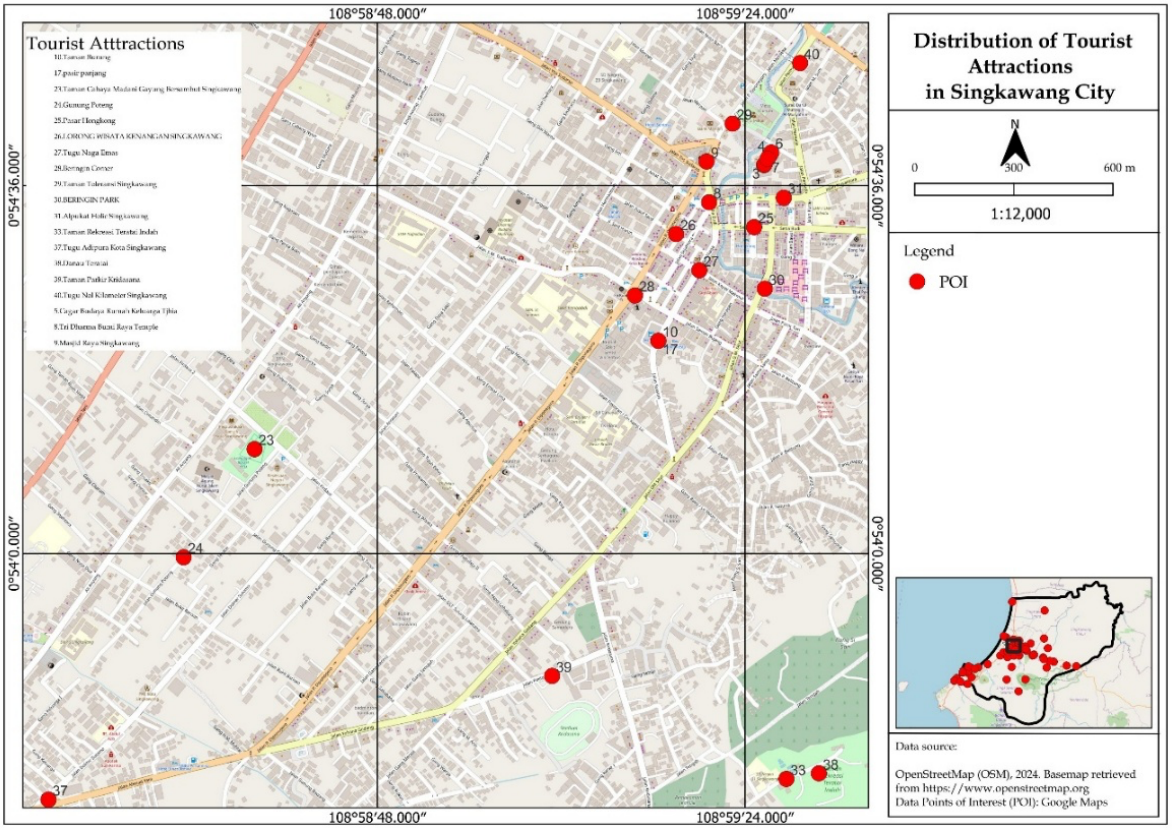

Figure 3. Distribution of Tourist Attractions in Singkawang City (Source: Authors, 2024).

After identifying the distribution of tourist attractions in Singkawang City as Points of Interest (POIs), the next step is to integrate the POIs with buildings and the road network. A well-connected road network enables users to reach POIs efficiently, reducing travel time and confusion. It also aids in better urban planning and enhances the overall user experience. The results from the POI Viznet analysis, shown in Figure 4, assist urban planners by considering human visual perception and urban activities, supporting more informative and sustainable design.

Figure 4 presents a color-coded map with red points for POI locations and black points for road intersections. This figure illustrates potential decision points for pedestrians along urban travel routes. It also provides a clear visualization of the distribution of POIs and road intersections in each area, which can be valuable for planning efficient routes for the Singkawang tourism area. When road intersections and POIs are visible to each other, sightlines connect them. (i.e., edges of the graph). Moreover, since building footprints along the streets are considered visibility constraints, the graph illustrates a hypothetical visual path of a person navigating open spaces between buildings or searching for a specific POI. The lines connecting these points represent the road network or routes linking various locations on the map. This map is insightful as it presents three types of visibility graphs (Natapov, Dalyot, et al., 2024), namely:

a. The Point of Interest Visibility Graph (POIVG) links visible POIs, showing how they can be seen from one another (Figure 4 (1)).
b. The Street Network Visibility Graph (SNVG) connects decision points within the road network, illustrating the visual relationships between road intersections (Figure 4 (2)).
c. The Integrative Visibility Graph (IVG) links decision points in the road network with POIs, visualizing the connections between POI locations within the road network (Figure 4 (3)).

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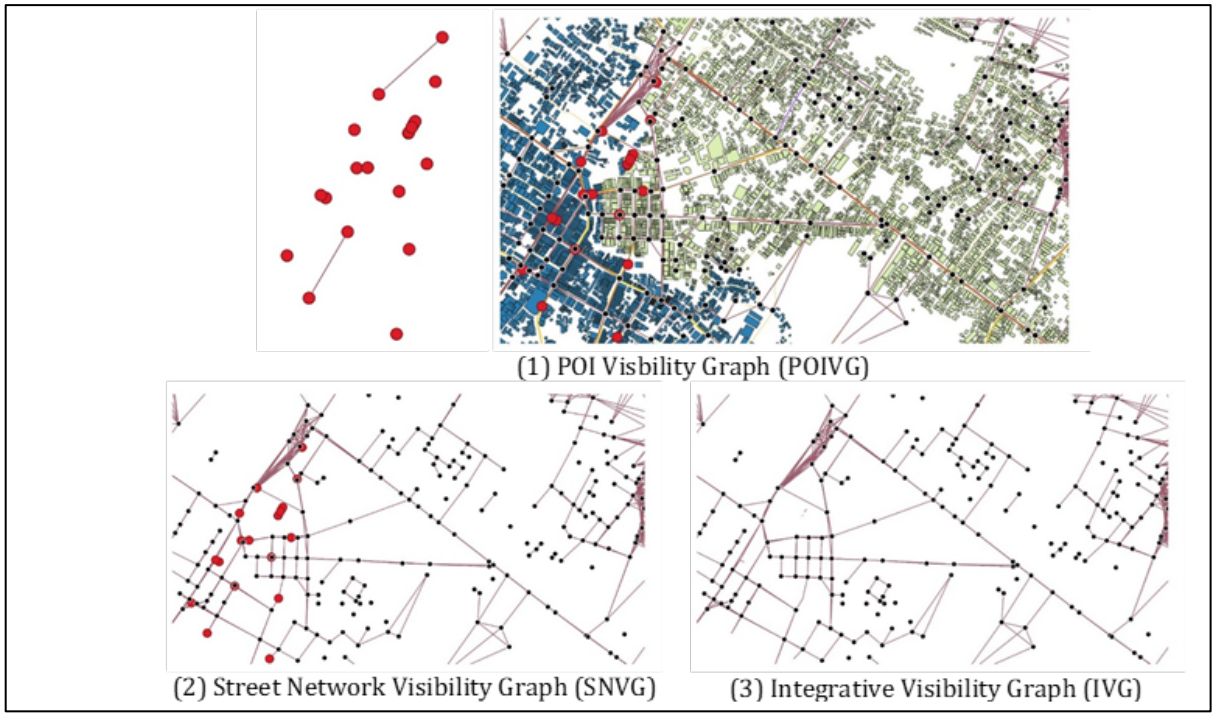

Figure 4. Viznet POI Analysis Results City Center (Source: Authors, 2024).

The next step involves analyzing the average degree and modularity values. The Average Degree refers to the average angle of view from observation points to the observed objects. The average degree value of 9.699 indicates that the average field of view from these observation points is 9.699 degrees, suggesting that the observed objects have relatively good visibility from various observation points.

Modularity is a metric used in network analysis to measure the strength of network division into communities or groups. The modularity score of 0.963 indicates that the POI visibility network has a forceful and well-defined community structure (Natapov, Cohen, et al., 2024). The Number of Communities, 609, represents the number of communities or groups identified within the POI visibility network. This high number of communities suggests a diverse structure within the network.

Additionally, this study analyzes betweenness centrality, closeness centrality, and weighted degree. Figure 5 (1) presents the nodes with the highest betweenness centrality values, identifying key connectors within the network. These nodes, which include specific points of interest (POIs) and road intersections, play a crucial role in facilitating connectivity. Notable nodes include the intersections of Jalan Jendral Sudirman-Jalan Pahlawan-Jalan Raya Pajintan, Jalan Merdeka-Jalan Ayani, Jalan Kalimantan, and Jalan Yos Sudarso.

The average closeness centrality of 0.418 shows that, on average, nodes in the network are relatively close to one another. Closeness centrality measures how quickly a node can reach other nodes in the network. Higher values indicate greater connectivity and efficiency. With an average value of 0.418, most nodes in Singkawang's network can efficiently reach other nodes, reflecting a well-connected network that facilitates efficient information or visitor flow between nodes.

The Weighted Degree analysis (Figure 5 (3)) illustrates the connectivity between POIs and other nodes. More oversized labels represent elevated connectivity. Some POIs in the city center did not achieve the maximum value due to physical barriers, such as building mass, narrow voids, or the lack of physical or visual access.

The findings of this study can aid urban planning by enhancing the understanding of the hierarchical urban

structure and connectivity (Huynh & Ramli, 2022). Urban planners can leverage this information to make more informed decisions regarding infrastructure development, mobility, and urban space (Gudmundsson & Mohajeri, 2013). Adaptive and resilient infrastructure strengthens transportation systems, supporting sustainable development and economic growth (Boeing & Ha, 2024; S. Liu et al., 2021; Peng et al., 2022; Soelistyo Pribadi et al., 2023).

Tourism attractions concentrate and play a pivotal role in city development, helping to depict the urban structure and connectivity (García-Hernández et al., 2017; Huynh & Ramli, 2022; Szromek et al., 2020). Based on the analysis of tourist sites, when developing a location, it is essential to consider the activities that can take place there. Travel decisions should not confine themselves to a single day; therefore, planners must carefully design routes for tourism activities. Optimizing tourist activities enhances the visitor experience (Abbasi-Moud et al., 2021; Celardo et al., 2023; Chalkiadakis et al., 2023; Mahdi et al., 2023; Natapov, Cohen, et al., 2024).

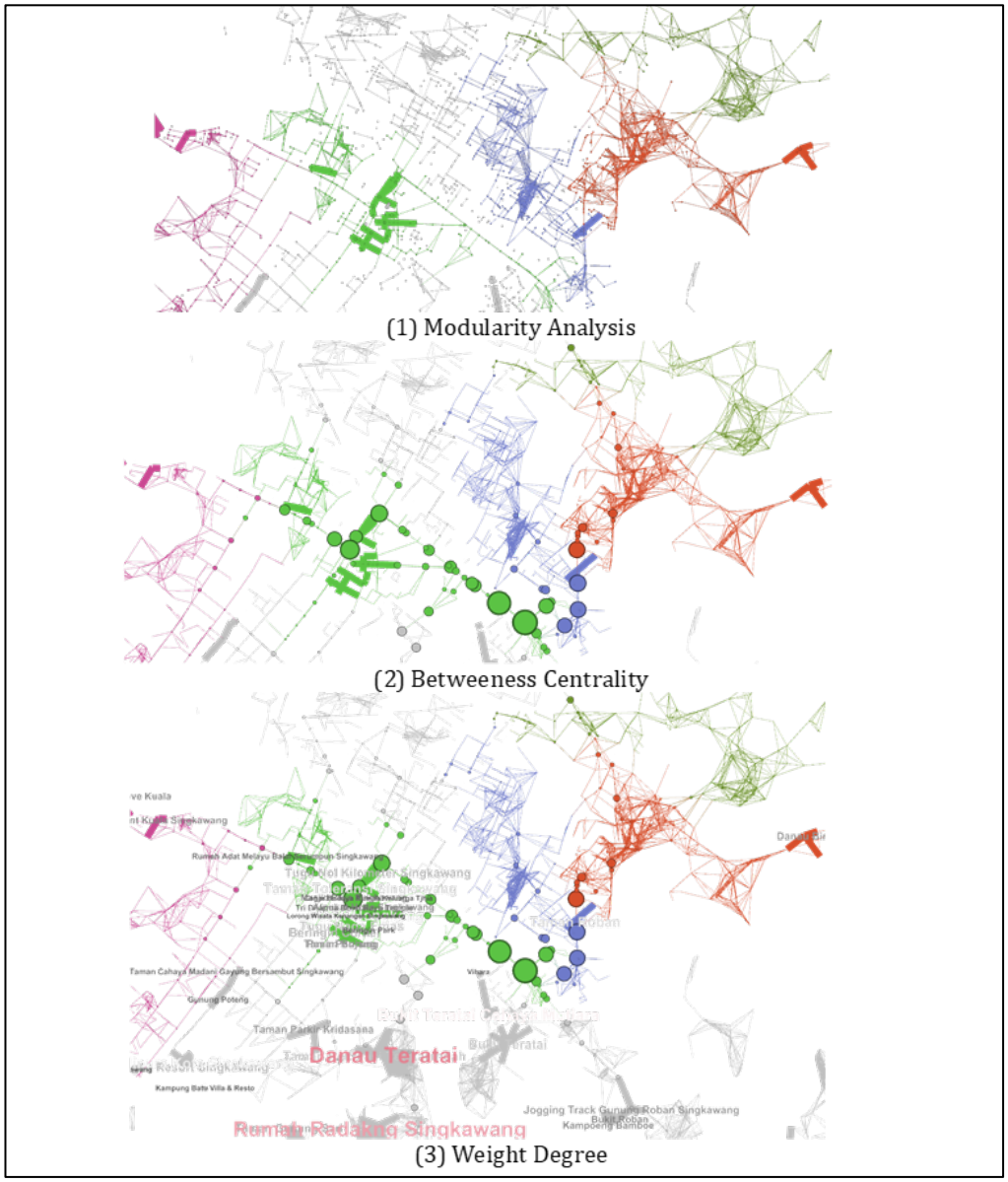

Figure 5. Analysis Results (Source: Authors, 2024)

The results of this analysis can assist in identifying effective routes for planning the tourism district in Singkawang. The study utilized the road network data of Singkawang, and the findings illustrate location patterns aligned with the project's planning objectives while considering urban activities, visibility, and accessibility. The developed methodology aims to support researchers and developers in making more accurate planning decisions, fostering a sustainable urban context with appropriate mixed-use land for pedestrians (Natapov, Cohen, et al., 2024). The key goals of route planning for the Singkawang tourism area using geoprocessing tools and POI visibility indices are as follows:

1. Enhancing Accessibility:
   Ensure that planned tourism routes are easily accessible to visitors by private vehicles and public transportation. Identify and eliminate visual barriers that hinder navigation and the overall tourist experience.
2. Optimizing Tourism Routes:
   Use geoprocessing tools to identify the fastest and most efficient routes between tourist attractions. Avoiding congested or challenging routes can minimize travel time and improve visitor comfort.
3. Enhancing the Tourist Experience:
   Utilize POI visibility indices to ensure that planned routes offer the best views and access to points of interest. Provide visual information that helps tourists enjoy scenic views and city landmarks.
4. Traffic Management:
   Plan efficient alternative routes to reduce congestion around tourist areas and optimize traffic distribution to avoid vehicle pileups at specific points.
5. Sustainability and Environment:
   Create more short and efficient routes to minimize the carbon footprint. Ensure that tourism routes do not damage the surrounding environment and support conservation efforts.
6. Safety and Security:
   Identify and address potential safety risks along tourism routes. Ensure the planned routes are safe for all visitors, including pedestrians and cyclists.

By focusing on these objectives, tourism route planning in Singkawang can enhance the tourist experience and support more efficient urban management.

This innovation aligns with emerging literature that leverages geospatial data—including POIs, accessibility layers, and satellite imagery—for sustainable tourism planning (X. Liu et al., 2025). It resonates with spatial-seasonal tourism analyses like those conducted in Hunan (Wei et al., 2022), identifying strong spatial correlations between nightlight visibility and POI activity. The study also supports regenerative tourism models by proposing visually attractive, accessible, and environmentally mindful travel routes (Rohaendi et al., 2025).

CONCLUSION

The analysis identifies the most efficient routes for tourism planning in Singkawang City as nodes (POI and intersections) that play significant roles as connectors within the network, including Jalan Jendral Sudirman-Jalan Pahlawan-Jalan Raya Pajintan, Jalan Merdeka-Jalan Ayani, Jalan Kalimantan, and Jalan Yos Sudarso. The study highlights tourist attractions situated in the central area of Singkawang City. The study determines Points of Interest (POI) based on user visit levels, which depend on user allocation. The visibility of the POI network significantly influences movement patterns and urban morphology. The emergence of a polycentric structure, the identification of urban centers and hubs, and the revelation of community structures all contribute to a deeper understanding of urban dynamics and transformations.

This study offers several recommendations, including:

a. Tourism Development: Singkawang is a city rich in Chinese cultural heritage and traditions. Identifying and incorporating attractive POIs, such as temples, monuments, and cultural festivals, into area planning can boost the city's tourism appeal and stimulate local economic growth.

b. Improvement of Quality of Life: Integrating POIs into regional planning can improve the quality of life for city residents by providing easy access to essential public facilities such as urban parks, shopping centers, or recreational hubs.
c. Local Economic Development: Incorporating POIs with potential as economic hubs, such as traditional markets and culinary centers, into area planning can foster local economic growth and empower the community.
d. Land Use Optimization: POI analysis aids in identifying and allocating land use efficiently to meet community needs, thus preventing congestion and enhancing the productivity of urban spaces.
e. User-Friendly City: By considering the locations of POIs crucial for area users, such as public transportation, healthcare facilities, or schools, Singkawang can become a more user-friendly and inclusive city for all societal levels.

This study introduces a geospatially grounded approach to sustainable tourism route planning by integrating POI visibility indices and advanced geoprocessing techniques. However, its application is subject to several limitations, including dependence on high-resolution spatial datasets, the inherent subjectivity of visual landscape assessment, and the exclusion of temporal variables such as seasonal vegetation dynamics. These constraints underscore the necessity for an enhanced spatial data infrastructure and the incorporating of behavioral and temporal dimensions in future models. From a policy perspective, the proposed methodology offers a strategic framework for visibility-informed tourism planning, encouraging participatory governance, investment in geospatial technologies, and developing innovative tourism systems that promote environmentally responsible and culturally contextualized tourism in micro-urban settings such as Singkawang.

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