Spatial Analysis Of Road Demage Levels On The Bayu - Geudong Road, Syamtalira District, North Aceh Regency Using GIS Based SDI Method

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Abstract
The Bayu–Geudong Road, located in Syamtalira Bayu District, North Aceh Regency, is a national highway situated in the northern region of Aceh Province. This road serves as a strategic link between Aceh Province and North Sumatra Province. The selection of this road section for research was based on its function as a collector road and the visible damage it has sustained. Various types of vehicles ranging from light, medium, to heavy frequently travel this route, which has contributed to the deterioration of the pavement. The research employed a field survey method to collect data directly from the road. The pavement was divided into segments measuring 100 meters in length by the full width of the road. Each segment served as a sampling unit for the study. The condition of the road surface was assessed by walking along the entire 2.5 km stretch of the Bayu–Geudong Road. For each segment, the types and severity of damage were identified, measured, and recorded, including the damaged area and depth for each damage type, using a standardized form. Based on the Surface Distress Index (SDI) calculations, the average SDI score across all segments was 34.9, indicating that the road is in good condition and falls under the routine maintenance category. The SDI data was then integrated into ArcMap to produce spatial analysis maps, which included attributes such as segment number, STA (stationing), coordinates, damage types, and damage levels. Based on the condition data and spatial analysis, a budget plan and work program were formulated to support maintenance and improvement efforts for the Syamtalira Bayu–Geudong Road, covering STA 0+000 to STA 2+500 in North Aceh

Keywords: *Analysis Spatial, Road Damage, SDI Method, GIS*

Abstrak
Jalan Bayu–Geudong yang terletak di Kecamatan Syamtalira Bayu, Kabupaten Aceh Utara, merupakan jalan nasional di wilayah utara Provinsi Aceh. Jalan ini berfungsi sebagai penghubung strategis antara Provinsi Aceh dan Provinsi Sumatera Utara. Pemilihan ruas jalan ini sebagai objek penelitian didasarkan pada fungsinya sebagai jalan kolektor serta kerusakan yang terlihat jelas di permukaannya. Berbagai jenis kendaraan, mulai dari ringan, menengah, hingga berat, sering melintasi jalan ini, sehingga menyebabkan penurunan kualitas perkerasan. Penelitian ini menggunakan metode survei lapangan untuk mengumpulkan data langsung dari lokasi jalan. Permukaan jalan dibagi menjadi segmen-segmen sepanjang 100 meter dengan lebar penuh jalan, di mana setiap segmen menjadi unit sampel penelitian. Kondisi permukaan jalan dinilai dengan berjalan menyusuri seluruh panjang jalan Bayu–Geudong sejauh 2,5 km. Untuk setiap segmen, jenis dan tingkat kerusakan diidentifikasi, diukur, dan dicatat, termasuk luas dan kedalaman kerusakan untuk setiap jenis kerusakan, menggunakan formulir standar. Berdasarkan perhitungan Surface Distress Index (SDI), nilai rata-rata SDI pada semua segmen adalah 34,9, yang menunjukkan bahwa jalan tersebut berada dalam kondisi baik dan termasuk dalam kategori pemeliharaan rutin. Data SDI kemudian diintegrasikan ke dalam ArcMap untuk menghasilkan peta analisis spasial yang mencakup atribut seperti nomor segmen, STA (stationing), koordinat, jenis kerusakan, dan tingkat kerusakan. Berdasarkan data kondisi dan analisis spasial, disusun rencana anggaran dan program kerja untuk mendukung upaya pemeliharaan dan perbaikan Jalan Syamtalira Bayu–Geudong, mencakup STA 0+000 hingga STA 2+500 di Aceh Utara.

Kata Kunci: *Analisis Spasial, Kerusakan Jalan, Metode SDI, SIG*

1. Introduction

Roads serve as critical infrastructure in transportation, directly influencing economic, social, cultural, and political development within a region. As an integral component of transportation networks, highways facilitate connectivity and mobility, which are essential for economic growth and national progress [1]. The condition of road infrastructure significantly impacts the efficiency of economic activities, with the rise of globalization, increased vehicle usage has further emphasized the need for well-maintained roadways [2].

In Indonesia, provincial roads managed by provincial governments play a vital role in interconnecting districts and cities within a province, enhancing regional mobility and accessibility to key areas [3]. Similarly, regency roads support local transportation networks by linking villages, sub-districts, and urban centers, thereby fostering economic activities by improving access to markets, resources, and public facilities [4]

The focus of this study is the Bayu-Geudong Road in Syamtalira Bayu District, North Aceh Regency. This national cross-country road serves as a crucial artery along the northern route of Aceh Province, connecting Aceh to North Sumatra Province (Trans-Sumatra Corridor). The selection of this road segment for research is based on its classification as a collector road, its visibly deteriorated condition, and the diverse range of vehicle traffic including light, medium, and heavy vehicles that contribute to its degradation. Regional road infrastructure assessments, such as analysis of intersection effectiveness in Lhokseumawe [5], highlight the need for systematic condition monitoring in high-traffic corridors like the Bayu-Geudong Road.

To assess road conditions systematically, this study employs the Surface Distress Index (SDI), a method that evaluates pavement damage through structured visual observation. The SDI provides quantifiable data on road surface deterioration, which is essential for determining appropriate repair and maintenance strategies [6]. Additionally, Geographic Information Systems (GIS) are utilized to integrate spatial data with road condition assessments. GIS enables the mapping, analysis, and visualization of geographic information, offering valuable insights into road characteristics such as length, width, and damage distribution [7]. Similar GIS applications for road damage assessment have been demonstrated in studies like [8], which mapped topographic and pavement conditions in Aceh's urban networks, validating the spatial approach adopted in this study Given the pressing need for effective road maintenance, this study aims to develop a comprehensive mapping of road damage levels using the SDI method within a GIS framework [9]. By combining these approaches, the research seeks to provide actionable recommendations for road rehabilitation, ensuring both safety and sustainability in transportation infrastructure.

2. Material and Methods

2.1 Surface Distress Index (SDI)

The Surface Distress Index (SDI) is a standardized method for assessing road pavement conditions through systematic visual observation of surface damage [10]]. This approach enables consistent monitoring of road quality by identifying various types of deterioration, including cracks, potholes, surface wear, and rutting, while also helping prioritize necessary repairs and maintenance [11]. The SDI scale quantifies road performance based on field observations, with key influencing factors being the extent of cracking (total area and average width), the frequency of potholes (per 100 meters of road length), and rutting depth. SDI Calculation Methodology following the steps below: [12]

The SDI is determined through a stepwise evaluation of different damage parameters:

1. SDI1 (Crack Area Assessment)

The first step involves calculating the percentage of cracked area within 100-meter road segments. The formula used is:

$$\% \text{ Crack Area} = (L / B) \times 100 \quad (1)$$

Where:
LL = Total crack area (m²)
BB = Segment area (m²)

The resulting percentage is then classified into weighted categories:

- No cracks: SDI1 = 0
- Crack area < 10%: SDI1 = 5
- Crack area 10–30%: SDI1 = 20

- Crack area > 30%: SDI1 = 40
-

2. SDI2 (Crack Width Adjustment)
   The initial SDI1 value is adjusted based on crack width severity:
- No cracks: No adjustment
- Fine cracks (<1 mm): SDI2 = SDI1
- Medium cracks (1–5 mm): SDI2 = SDI1
- Wide cracks (>5 mm): SDI2 = SDI1 × 2
3. SDI3 (Pothole Frequency Integration)
   The SDI2 value is further modified by accounting for pothole frequency per 100 meters:
- No potholes: SDI3 = SDI2
- <10 potholes/100 m: SDI3 = SDI2 + 15
- 10–50 potholes/100 m: SDI3 = SDI2 + 75
- >50 potholes/100 m: SDI3 = SDI2 + 225
4. SDI4 (Rutting Depth Consideration)
   The final SDI value incorporates rutting depth, applying additional weight:
- No rutting: SDI4 = SDI3
- Rut depth <1 cm: SDI4 = SDI3 + (5 × 0.5)
- Rut depth 1–3 cm: SDI4 = SDI3 + (5 × 2)
- Rut depth >3 cm: SDI4 = SDI3 + (20 × 5)

This structured approach ensures a comprehensive evaluation of road distress, facilitating data-driven maintenance decisions. The SDI method's strength lies in its ability to systematically quantify pavement deterioration, making it an essential tool for infrastructure management.

2.2 Geographic Information System

The subsystems owned by Geographic Information Systems (GIS) are input data, output data, data management, data manipulation and analysis. GIS subsystems are explained as follows:

1. Input Data serves as the foundational stage where spatial data (coordinates, boundaries) and attribute data (descriptive information) are acquired from multiple sources including satellite imagery, GPS surveys, and existing databases. This function includes critical preprocessing steps such as format conversion, georeferencing, and quality validation to ensure compatibility with GIS software standards.
2. Output Data transforms processed geospatial information into actionable formats through cartographic outputs (thematic maps, 3D models), statistical visualizations (charts, graphs), and tabular reports. These outputs support decision-making across sectors like urban planning and environmental management by presenting complex spatial relationships in accessible formats.
3. Data Management implements systematic organization of geospatial datasets within relational database structures, enabling efficient storage, retrieval, and version control. This includes establishing topological relationships between features, implementing metadata standards, and maintaining data integrity through access controls and update protocols.
4. Data Manipulation and Analysis performs advanced spatial operations including overlay analysis, network analysis, and spatial statistics. These analytical capabilities allow for pattern detection, predictive modeling, and scenario simulation - converting raw geospatial data into actionable intelligence for strategic planning.

GIS distinguishes itself through rapid processing of large, complex datasets while maintaining analytical precision. Its dynamic data handling capacity facilitates real-time monitoring of changing spatial phenomena, offering superior perspective for terrain evaluation, infrastructure assessment, and environmental tracking compared to conventional mapping methods.

3. Results and Discussion

3.1 SDI Road Damage Rating and Level

Based on the road damage data presented in Table 1, a data analysis was conducted to determine the road damage value and classification using the Surface Distress Index (SDI) method.

A summary of the road damage level assessment using the SDI method is presented in Table 1

Table 1. Road Damage Level SDI Method

Segment	Sdi value	Road handling conditions	Handling
1	0	Good	Routine maintenance
2	10	Good	Routine maintenance
3	15	Good	Routine maintenance
4	27,5	Good	Routine maintenance
5	10	Good	Routine maintenance
6	25	Good	Routine maintenance
7	25	Good	Routine maintenance
8	25	Good	Routine maintenance
9	125	Minor damage	Periodic maintenance
10	27,5	Good	Routine maintenance
11	100	Currently	Routine maintenance
12	25	Good	Routine maintenance
13	10	Good	Routine maintenance
14	10	Good	Routine maintenance
15	15	Good	Routine maintenance
16	25	Good	Routine maintenance
17	100	Currently	Routine maintenance
18	0	Good	Routine maintenance
19	100	Currently	Routine maintenance
20	27,5	Good	Routine maintenance
21	25	Good	Routine maintenance
22	125	Minor damage	Periodic maintenance
23	0	Good	Routine maintenance
24	10	Good	Routine maintenance
25	10	Good	Routine maintenance

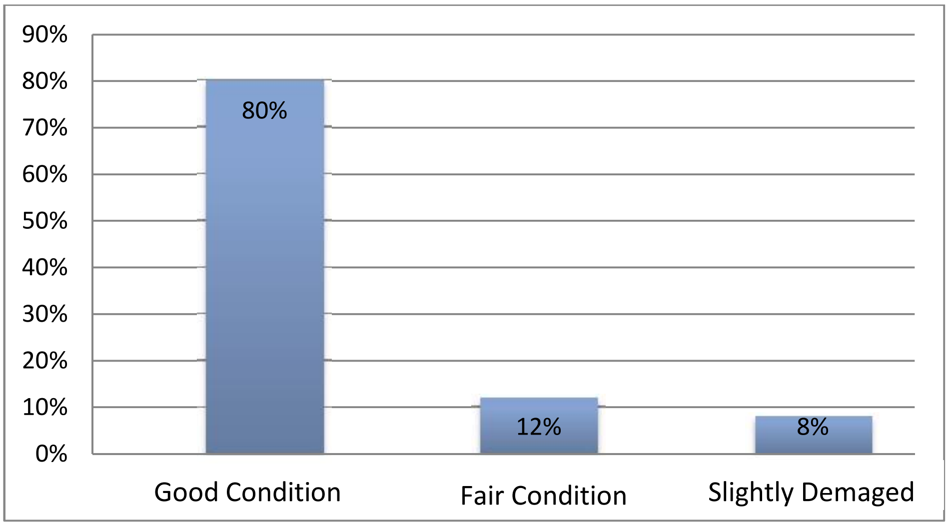

Figure 1. SDI Value Percentage

Based on the data obtained, the 2.5 km road was divided into 25 segments, each measuring 100 meters in length. The initial stationing point is at STA 0+000, and the final point is at STA 2+500. After calculating the Surface Distress Index (SDI) values, the results show that 3 segments are classified as having moderate damage, 2 segments as having light damage, and the remaining 20 segments are in good condition. The observed prevalence of rutting damage aligns with studies such as [13], which identified heavy vehicle traffic as a key contributor to structural road deterioration in Aceh's expanded roadways.

The concentration of damage in specific segments, where heavy vehicle activity near constrained urban areas accelerated pavement degradation in Lhokseumawe [14].

3.2 ArcGIS

Based on the data and analysis results, the 2.5 km research road starting from Syamtalira Bayu at STA 0+000 and ending in Geudong at STA 2+500, North Aceh Regency was found to exhibit three types of pavement damage: cracks, potholes, and rutting (wheel track depressions). The most severe damage was recorded in Segment 9, with a total of eight instances consisting of three cracks, four potholes, and one rutting. The GIS-derived damage hotspots mirror findings in [15], where prioritized repair segments were identified using similar spatial analysis techniques in Aceh's coastal roads.

The field survey was conducted over three days, from December 25 to December 27, 2024. On the first day, the survey team established STA markers along the 2.5 km stretch of road, placing a marker every 100 meters, resulting in a total of 25 segments. On the second day, the team surveyed the types of pavement damage within each segment, covering the entire road from STA 0+000 to STA 2+500. The survey identified three types of damage: 23 cracks, 19 potholes, and 10 instances of rutting (wheel track depressions).

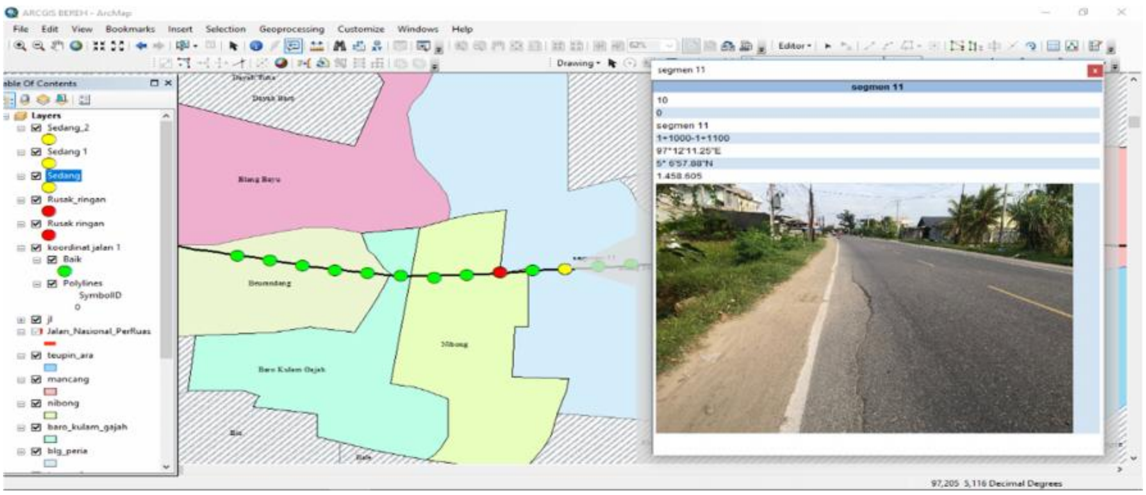

Figure 2. Attributes at Segment Point 2

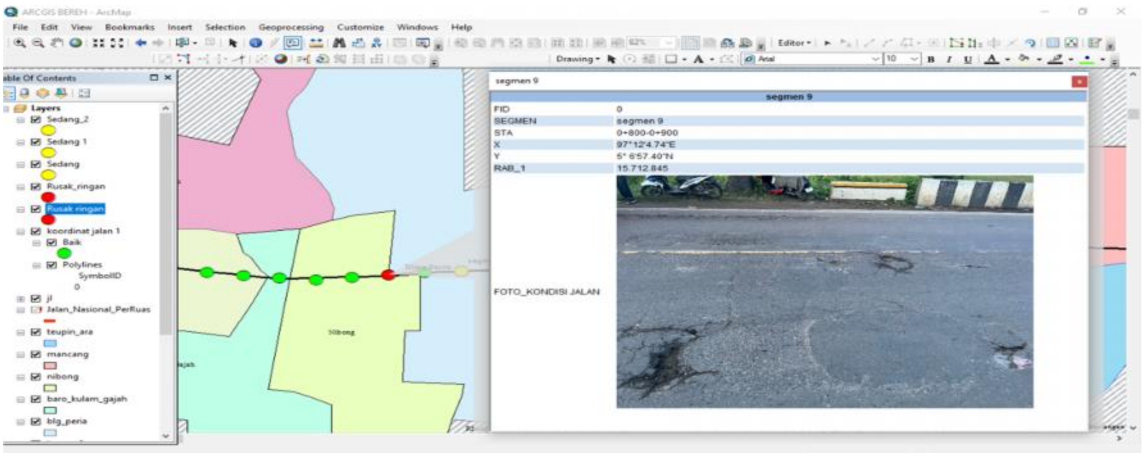

Figure 3. Attributes at Segment Point 9

On the third day, a field survey was conducted to measure the length and width of each type of damage. After completing the assessment along the road segment from STA 0+000 to STA 2+500, the Surface Distress Index (SDI) for each segment was calculated. Based on the average SDI value, the overall road condition was classified as good and categorized under routine maintenance.

The results of this ArcGIS-based mapping involve the integration of SDI data into ArcMap, which includes attributes such as the SDI value, type of damage, segment number, STA, coordinate points, and damage level. The initial step was to create a database of the road sections under review, using the basic data collected during the field survey. Subsequently, the damage points were mapped onto the corresponding road segments using Google Earth, incorporating STA references and damage levels.

4. Conclusion

Here are some conclusions obtained after conducting this study:

1. The types of damage analyzed along the 2.5 km Syamtalira Bayu–Geudong road section in North Aceh Regency include cracks, potholes, and wheel track depressions. The highest number of damages was recorded in Segment 9, with a total of eight instances: three cracks, four potholes, and one wheel track depression.
2. Based on the average value obtained from the total SDI scores across all segments, the road condition is categorized as good and falls under the routine maintenance classification.
3. The results of the mapping of the Syamtalira Bayu - Geudong road, North Aceh Regency, through the integrating of SDI data into ArcMap, include analytical maps and attributes data for each segment. The attributes consist of segment number, stationing (STA), coordinate points, type of damage, and level of damage.

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