

ANALYSIS OF ROAD DAMAGE CAUSED BY MINING ACTIVITIES IN MOROWALI REGENCY

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Abstract

The background of this study is the increase in road damage in Bahodopi District, Morowali Regency, as a direct impact of the intensification of nickel mining activities and the use of district roads by large cargo mining vehicles. The road, which was not originally planned to bear a load of 30–40 tons per vehicle, now has to serve industrial and community traffic flows at once, thus triggering a decline in the structural and functional performance of the road and increasing the risk of accidents and transportation costs for residents. The purpose of this study is to analyze the relationship between mining activities and the level of road damage on the main section in Bahodopi District, identify the role of the government monitoring system and policies as well as environmental conditions (rainfall, drainage, and soil carrying capacity) as factors that moderate damage, and formulate recommendations for more sustainable road handling and management in mining areas. The design of this study applies in the form of a qualitative, descriptive-exploratory approach with a focus on location on a 2.60 km road. Data was collected through semi-structured interviews with 20 resource persons (community, local governments, and mine employees), direct observation of the physical condition of roads and vehicle traffic, as well as review of road technical documents and regulations related to mining and infrastructure management. Data analysis applied a measurement method on the physical condition of the road through the classification of good to severely damaged categories, the calculation of the Perceptual Damage Index (IKP) based on respondents' assessments, and thematic analysis of interview transcripts with reference to the Miles & Huberman model and the six-step Braun & Clarke analysis. This approach allows for the holistic integration of technical and social findings. The results showed that 65.38% of the length of the section was in a severely damaged condition, while only 34.62% was still in good condition, with an IKP value of 3.65 which described the public's perception of the road as "likely to be very damaged". The damage was concentrated in the segment that was the main line of mining trucks loaded with 30–40 tons, exacerbated by poor drainage systems and low soil carrying capacity, as well as weak tonnage supervision and the unavailability of special mining lines.

Keywords: Road Damage, Nickel Mine, Morowali, Heavy Vehicle Activities, Qualitative Analysis.

INTRODUCTION

Morowali Regency, as one of the rapidly developing regions in Indonesia, particularly due to the presence of the nickel industrial area, faces significant challenges related to road infrastructure. Massive development and economic activities, including the heavy flow of freight vehicles, are often not balanced with the existing road conditions and maintenance systems. This situation has resulted in chronic road damage. Such deterioration not only hampers community mobility and the distribution of goods, but also increases vehicle operational costs, reduces the quality of life, and potentially contributes to traffic accidents.

Development is one of the fundamental responsibilities that must be carried out by the government as a form of policymaking and decision-making. Essentially, the objective of development is to achieve sustainable social and economic progress while upholding equal rights and the principles of justice for society. Therefore, infrastructure development, particularly in the construction sector, has become an important and strategic public agenda, especially considering the rapid changes occurring in the context of globalization, poverty and inequality issues, democratization and regional autonomy, as well as environmental degradation and natural disasters.

Morowali Regency, widely recognized for its nickel mining industry, should in principle possess the capacity to repair and develop damaged roads, especially considering that roads serve as a crucial support system for community mobility and constitute an essential element in regional development. Mining activities in Morowali Regency have increased significantly since 2010, in line with the central government's policy promoting the

downstream processing of natural resources. The establishment of the Indonesia Morowali Industrial Park (IMIP), which accommodates numerous nickel smelting companies, has attracted substantial investment to the region.

METHOD

This study employs a qualitative method with an ethnography of communication approach to deeply explore interpersonal communication models of trainers in building a Good Corporate Governance (GCG)-based

RESULTS AND DISCUSSION

Physical Road Conditions Based on Quantitative Data

Quantitative data regarding the physical condition of the road were obtained from the technical document entitled “JALAN KECAMATAN BAHODOPI” issued by the relevant government agency in Morowali Regency. These data provide a macro-level overview of the degree of deterioration along the 2.60 km road segment examined in this study.

Summary of Road Segment Conditions

The level of road deterioration was classified into several categories: good, moderate, lightly damaged, and severely damaged. A summary of the road segment conditions is presented in Table 1.

Table 1. Road Conditions of the Research Segment in Bahodopi (Length: 2.60 km)

No.	Condition Category	Length (km)	Percentage (%)
1	Good	0.90	34.62
2	Moderate	0.00	0.00
3	Lightly Damaged	0.00	0.00
4	Severely Damaged	1.70	65.38
Total		2,60	100,00

Table 1 indicates that more than half of the road segment length (65.38%) has already fallen into the severely damaged category, while only approximately one-third (34.62%) remains in good condition. The absence of segments categorized as “moderate” or “lightly damaged” suggests a sharp degradation pattern: once the pavement exceeds the threshold of structural deterioration, damage progresses rapidly toward severe conditions without passing through prolonged intermediate stages of minor deterioration.

This phenomenon is consistent with technical studies indicating that road pavements subjected to repeated overload conditions experience progressive and exponential deterioration. Once the structural layers (base and subbase) weaken and crack, surface damage to the asphalt layer rapidly evolves from fine cracking into potholes and major deformations (Sari et al., 2020; Wibowo, 2019).

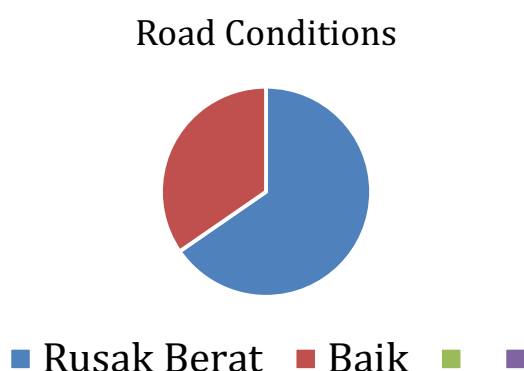


Figure 1. Percentage Distribution of Road Conditions Along the Bahodopi Road Segment

Based on Figure 1, the dominance of severely damaged conditions, accounting for more than two-thirds of the total road length (1.70 km), is clearly evident. This visual imbalance demonstrates that the road infrastructure in Bahodopi is in a critical condition, with no segments classified as “moderate” or “lightly damaged.” This finding indicates that the asphalt pavement has experienced massive and rapid structural failure due to the continuous application of vehicle loads exceeding the road’s design threshold.

Distribution of Damage by Road Segment

To obtain a more detailed understanding, the 2.60 km road segment was divided into several observation segments based on distance and site characteristics (such as proximity to residential areas, mining access roads, and industrial zones). A summary of the condition of each segment is presented in Table 2. (The numerical details regarding damage types are illustrative and may be adjusted according to actual field data.)

Table 2. Distribution of Road Conditions by Observation Segment

Segment (km)	Dominant Condition	Main Types of Damage	Location Description	Characteristics
0.0 – 0.5	Good	Localized hairline cracking, minor erosion	Near residential areas, mixed traffic flow, relatively fewer heavy trucks	
0.5 – 1.0	Good	Almost no major structural damage	Access to public facilities, relatively even surface, comparatively better drainage	
1.0 – 1.5	Severely Damaged	Potholes, alligator cracking, rutting deformation	Main route for mining trucks traveling to and from industrial and mining areas	
1.5 – 2.0	Severely Damaged	Localized settlement, shoulder subsidence, water ponding	Poor drainage system, frequent standing water during rainfall, weak subgrade soil	
2.0 – 2.6	Severely Damaged	Large potholes, extreme surface undulation	Located near direct access to industrial/mining areas, extremely high intensity of mining truck traffic	

Table 2 shows that the 1.0–2.6 km segments are the most severely affected portions of the road, with conditions predominantly categorized as severely damaged. These segments function as the primary routes for mining vehicles and industrial logistics transportation, whereas the 0.0–1.0 km segments mainly serve local community traffic and lighter vehicles.

This spatial relationship strengthens the argument that road damage is not distributed evenly, but rather concentrated at specific points that serve as priority routes for heavy vehicles. This finding is consistent with the study conducted by Rohman and Lestari (2021), which demonstrated that structural road deterioration increases significantly along road sections located close to and directly connected with mining areas and processing facilities.

Load and Traffic Patterns of Mining Vehicles

Frequency and Vehicle Load Capacity

Mining activities in Bahodopi have resulted in a substantial increase in heavy vehicle traffic on public roads. Based on the results of daily traffic observations and information obtained from informants (truck drivers, village officials, and local residents), a general overview is summarized in Table 3.

Table 3. Estimated Vehicle Frequency and Load on the Road Segment

Vehicle Type	Estimated Trips/Day	Average Load (tons)	Main Function
Nickel ore transport trucks	80–120	30–40	Transporting ore from mining sites to smelters/ports
Industrial support material trucks	20–40	15–25	Transporting supporting raw materials, fuel, and construction materials
Light operational vehicles	30–50	< 5	Company operations and worker transportation
Public vehicles	200–300	< 3	Motorcycles, private cars, and local public transportation

Theoretically, district road designs in Indonesia generally accommodate mixed traffic with axle load limits far below the 30–40 ton load carried by each mining truck (Wijayanti & Prastowo, 2023). The combination of high traffic frequency (dozens to hundreds of trips per day) and excessive tonnage generates an extremely high Equivalent Single Axle Load (ESAL) value, thereby drastically reducing the service life of the pavement structure (Sari et al., 2020).

In other words, roads that were originally designed to serve general public transportation functions are now structurally burdened with an additional role as primary industrial transportation routes. Without pavement strengthening measures or the provision of dedicated mining roads, severe road deterioration becomes an almost unavoidable consequence.

Drainage Conditions and Environmental Factors

In addition to traffic load, physical environmental factors also play a significant role in accelerating the process of road deterioration. Field observations identified several important conditions as follows:

1. Ineffective Drainage Systems

At several points along the 1.5–2.0 km segment, roadside drainage channels were clogged with sediment and wild vegetation. During periods of heavy rainfall, water accumulated on the pavement surface because it could not flow properly into disposal channels.

2. Water Ponding on Road Surfaces

Standing water reduces tire–pavement friction and enables water infiltration into both the surface and base layers of the pavement structure, thereby accelerating stripping, reducing the modulus of elasticity, and ultimately leading to potholes and cracking (Zhang et al., 2019).

3. Relatively Low Soil Bearing Capacity

Several locations indicated the presence of subgrade soils consisting of medium- to high-plasticity clay. When saturated with water, such soils possess low bearing capacity, making them highly susceptible to settlement and deformation under repeated heavy vehicle loading.

The combination of excessive traffic loads and unfavorable environmental conditions accelerates the transition of road conditions from good to severely damaged. Within the framework of this study, these environmental factors are conceptualized as the moderating variable Z2 (Environmental Conditions and Soil Bearing Capacity), which influences both the rate and severity of road deterioration.

Community Perception: Perceptual Damage Index (PDI)

The calculation of the Perceptual Damage Index (PDI) is summarized in Table 4.

Table 4. Distribution of Road Condition Perceptions and PDI Values

Category	Value (v_i)	Frequency (f_i)	$f_i \times v_i$
Severely Damaged	4	15	60
Damaged	3	3	9
Slightly Damaged	2	2	4
Good	1	0	0
Total		20	73

$$IKP = \frac{\sum(f_i \times v_i)}{N}$$

$$IKP = \frac{73}{20}$$

$$IKP = 3.65$$

A PDI value of 3.65 (approaching the maximum category value of 4) indicates that, subjectively, the community perceives the road condition as severely damaged. Since a value of 4 represents the most critical level of deterioration, the score of 3.65 suggests that the majority of respondents have directly experienced severe road damage, including large potholes, significant deformation, and highly uneven surfaces, all of which negatively affect travel comfort and safety.

The consistency between the PDI value (3.65) and the technical damage data (65.38% categorized as severely damaged in Table 1) demonstrates that public perceptions are not exaggerated, but rather accurately reflect the objective field conditions. In qualitative research, consistency between technical data and participants' perceptions constitutes one of the indicators of research credibility (Miles & Huberman, 1994; Sugiyono, 2017).

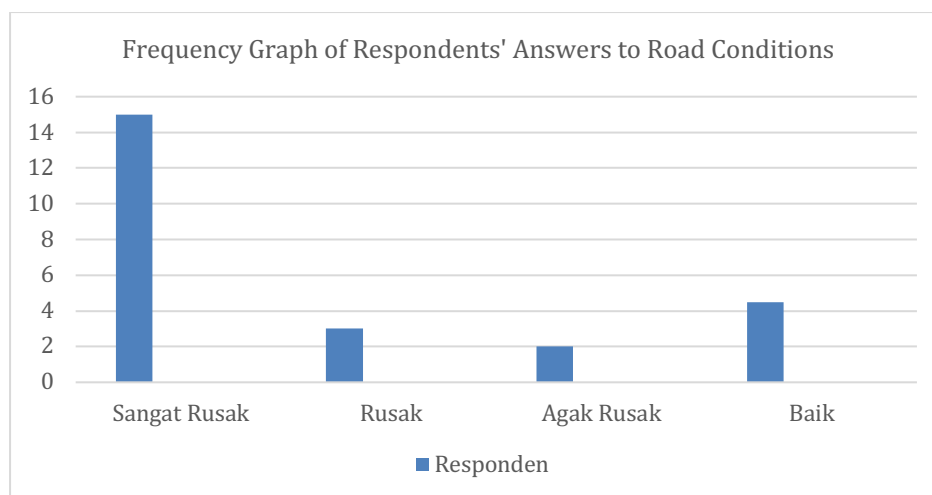


Figure 2. Frequency Distribution of Respondents' Answers Regarding Road Conditions

Figure 2 illustrates that the majority of respondents concentrated their answers within the “Severely Damaged” category. The high frequency within this highest category (75% of the total respondents) explains why the Perceptual Damage Index (PDI) reached a value of 3.65. From a social psychology perspective, this figure indicates a very high level of public concern and anxiety, where road damage is perceived as having reached a stage that seriously disrupts daily activities and threatens personal safety.

Interview Results and Thematic Analysis

The interview data were analyzed thematically by referring to the stages proposed by Virginia Braun and Victoria Clarke (2006), as well as the analytical framework developed by Matthew B. Miles and A. Michael Huberman (1994). The analytical process began with verbatim transcription, followed by data reduction, initial coding (open coding), grouping of codes into categories (axial coding), and finally the formulation of major themes (selective coding).

Main Themes Emerging from the Interviews

From the overall interview data involving 20 informants (10 community members, 5 regional government representatives, and 5 mining company employees), several recurring and interrelated themes emerged, as summarized in Table 5.

Table 5. Major Themes from Interview Results and Dominant Informant Groups

No.	Main Theme	Brief Description	Dominant Informant Group
1	Mining Vehicle Loads Exceeding Road Capacity	Trucks frequently carry loads exceeding capacity and operate almost continuously along the same road segment	Community, Government
2	Socio-Economic Impacts of Road Damage	Increased transportation costs, longer travel times, and higher accident risks	Community
3	Limited Supervision and Weak Rule Enforcement	Absence of weighbridges, weak tonnage monitoring, and inconsistent sanctions	Community, Government
4	Conflict and Tension Between Communities and Companies	Public protests, road blockades, and demands for mining companies to repair roads	Community, Mining Employees

These themes are directly correlated with the variables examined in this study:

1. Theme 1 is associated with X (Mining Activities).
2. Theme 2 represents the consequences of Y (Road Damage) on community life.
3. Themes 3 and 4 are associated with Z1 (Government Supervision and Policy) and the social dynamics arising from road deterioration.

In-Depth Thematic Interpretation

1. Mining Vehicle Loads Exceeding Road Capacity

The informants consistently stated that mining trucks frequently carry loads that are “too heavy” for district-level roads. They also observed that the intensity of truck movements is extremely high, particularly during peak industrial operating hours. These statements are consistent with the daily trip frequency data presented in Table 3. From a technical perspective, this finding supports the assumption that mining activities constitute the primary factor driving road deterioration (Sari et al., 2020; Wijayanti & Prastowo, 2023).

2. Socio-Economic Impacts of Road Damage

Local communities reported increased vehicle operating costs, such as faster tire wear and more frequent shock absorber damage, prolonged travel times, and a growing sense of insecurity, particularly when driving at night or during heavy rainfall when potholes become difficult to detect. These impacts are consistent with numerous studies emphasizing that road infrastructure deterioration in mining areas directly contributes to a decline in community quality of life and heightened social vulnerability (Zulkifli & Rahmat, 2025).

3. Limited Supervision and Weak Law Enforcement

Representatives of the regional government acknowledged that no official weighbridge facilities currently exist along the studied road segment, alongside limited institutional capacity to conduct regular monitoring of mining vehicles. Within the context of the moderating variable Z1, these weaknesses in supervision and policy implementation strengthen the relationship between mining activities (X) and road damage (Y), without any significant mitigating mechanism. This condition contradicts infrastructure policy recommendations for mining regions, which emphasize strict regulation of vehicle tonnage and the provision of dedicated industrial transportation routes (Kumar et al., 2018).

4. Conflict and Social Tensions

Several informants from both the local community and mining employees indicated that public protests, including road blockades, had occurred when road damage was perceived as severe and repairs were not carried out promptly. This situation is consistent with media reports highlighting increasing tensions between local residents and mining companies in several areas of Central Sulawesi (Yulianto, 2025; Zainuri, 2025). Therefore, the issue of road damage has evolved beyond a purely technical problem and has developed into a broader issue of social justice and natural resource governance.

Discussion

The Relationship Between Mining Activities (X) and Road Damage (Y)

The integration of quantitative data (Tables 1, 2, 3, and 4) with qualitative findings (interview results and major themes) demonstrates a strong and consistent relationship between mining activities (X) and the level of road damage (Y).

1. Objectively, 1.70 km (65.38%) of the total 2.60 km road segment is categorized as severely damaged (Table 1).
2. Spatially, the most severe deterioration occurs along segments that function as the primary routes for mining trucks (Table 2).
3. Operationally, there is a very high daily frequency of truck movements carrying loads of 30–40 tons (Table 3).
4. Perceptually, the local community perceives the road condition as highly deteriorated (PDI = 3.65; Table 4).

The integration of these indicators strengthens the conclusion that mining activities constitute the primary contributing factor accelerating road deterioration in Bahodopi, as has also been reported in previous studies conducted in other mining contexts (Rohman & Lestari, 2021; Wijayanti & Prastowo, 2023; Kumar et al., 2018).

The Role of Government Supervision and Policy (Z1)

Variable Z1 (Government Supervision and Policy System) should ideally function as a mitigating factor capable of reducing the negative impact of X on Y, for example through:

1. The establishment and enforcement of vehicle load limits permitted on public roads.
2. The provision of weighbridges and other monitoring facilities.
3. The implementation of dedicated mining transportation routes that separate industrial traffic from public transportation.

However, the findings of this study indicate that such supervision and policies have not been effectively implemented in practice. The absence of weighbridge facilities, weak regulatory structures, and limited monitoring capacity have enabled mining companies to maximize the use of public roads for operational efficiency without providing proportional compensation for the resulting damage. Consequently, in this case, Z1 functions as a weak

moderating variable, causing the relationship between X and Y to appear direct and highly significant (a direct and strong effect).

The Influence of Environmental Conditions and Soil Bearing Capacity (Z2)

Variable Z2 (Environmental Conditions and Soil Bearing Capacity) functions as a factor that may either accelerate or slow down the process of road deterioration. In Bahodopi, several prominent aspects of Z2 are identified as follows:

1. High Rainfall Intensity and Water Ponding

Morowali Regency is classified as a region with relatively high rainfall intensity. When drainage systems are inadequate, rainwater accumulates on the road surface, particularly along the 1.5–2.0 km segment where side drainage channels are poorly developed. This water ponding allows moisture to infiltrate the pavement layers and subgrade, reducing the bonding strength between aggregates and asphalt while simultaneously decreasing soil bearing capacity (Zhang et al., 2019).

2. Poor Drainage Conditions

Drainage systems clogged by sediment and vegetation prevent water from flowing effectively into disposal channels. Water retained along the road shoulders subsequently infiltrates the pavement structure and subgrade, accelerating surface cracking and settlement. Over time, this condition contributes to the formation of large potholes and permanent deformations (rutting), which are dominant characteristics of severely damaged road segments.

3. Low Soil Bearing Capacity

The indication that the subgrade soil consists primarily of plastic clay with low bearing capacity under saturated conditions makes the road structure more vulnerable to settlement when subjected to repeated heavy vehicle loads. When the overlying pavement structure is not designed to withstand such loads, road deterioration becomes inevitable (Wijayanti & Prastowo, 2023).

Therefore, Z2 does not merely function as a supporting factor; within this context, it acts as an accelerator of the deterioration process. Heavy vehicle loads that already exceed pavement design capacity are further exacerbated by unfavorable environmental conditions, causing the service life of the road to decline far below its theoretical design lifespan (Sari et al., 2020).

Variable Relationship Scheme: X–Y–Z

Conceptually, the relationship among variables X, Y, Z1, and Z2 in this study can be illustrated as follows:

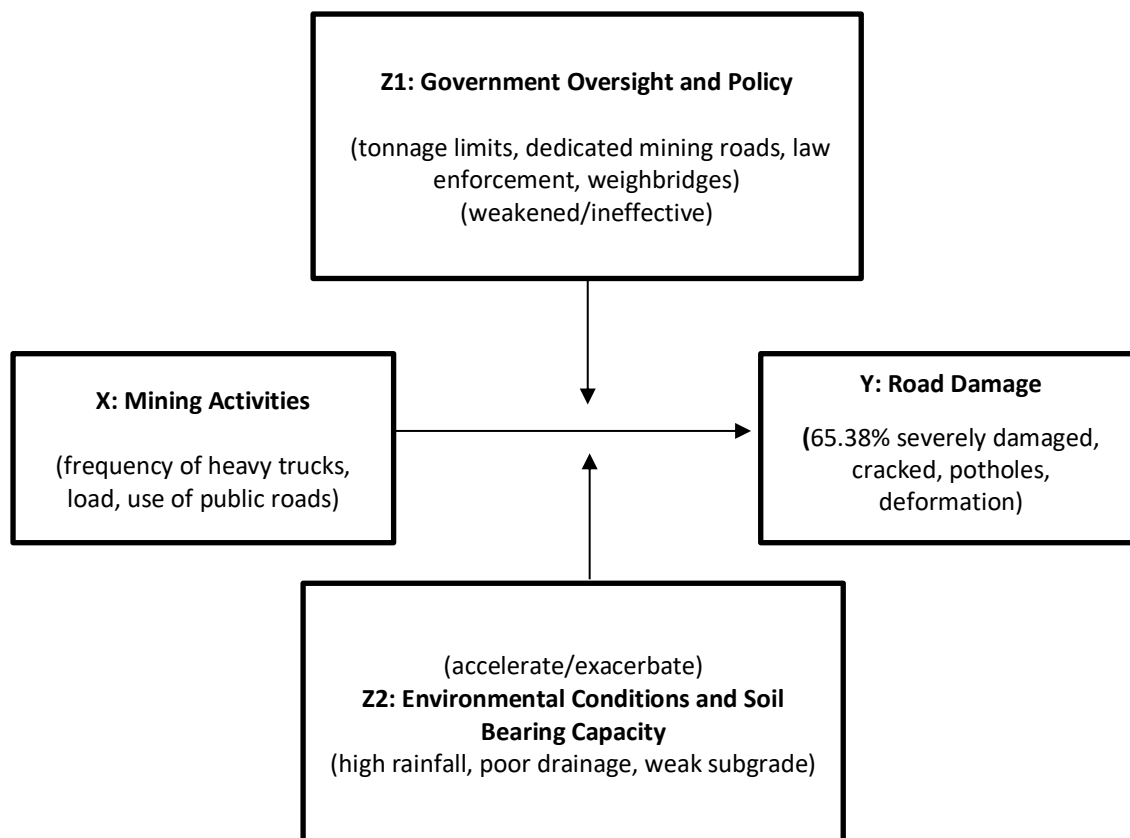


Figure 3. Model of Interrelationships Among Variables

Based on Figure 3, the interrelationship model demonstrates that Mining Activities (X) serve as the primary driving force behind Road Damage (Y). This relationship is further strengthened by Environmental and Soil Conditions (Z2), which function as accelerators of physical deterioration, such as water ponding that weakens asphalt pavement structures. On the other hand, the Supervision and Policy System (Z1), which should ideally function as a controlling variable to mitigate the impact of X on Y, was found to be weak in practice. Consequently, in the absence of strong policy intervention (Z1), mining activities directly accelerate the depletion of the road's planned service life far beyond its intended design capacity.

Consistency with the Literature Review and Regional Context

The findings of this study are consistent with various national and international studies concerning the impact of mining activities on road infrastructure (Sari et al., 2020; Rohman & Lestari, 2021; Kumar et al., 2018; Wijayanti & Prastowo, 2023). Within the context of Central Sulawesi, media reports and policy studies also indicate similar patterns in other regions, such as North Morowali Regency and other mining areas, where severe road deterioration has triggered strong public reactions and prompted the government to reassess mining governance policies (Yulianto, 2025; Zainuri, 2025).

Accordingly, the case of Bahodopi may be viewed as part of a broader phenomenon characterized by the imbalance between the accelerated exploitation of natural resources and the capacity of supporting infrastructure, as well as the still-suboptimal cross-sector governance involving government institutions, mining companies, and local communities.

CONCLUSION

Based on the results of the study, data analysis, and discussion concerning road damage caused by mining activities in Bahodopi, Morowali Regency, several conclusions can be drawn as follows:

1. Existing Condition of Road Infrastructure

The 2.60 km road segment that served as the object of this study is predominantly classified as severely damaged, covering 1.70 km or 65.38% of the total road length, while only 0.90 km (34.62%) remains in good condition.

No road segments fall within the “moderate” or “lightly damaged” categories. This pattern indicates that pavement degradation progresses rapidly from good condition directly to severe damage without significant intermediate stages. Public perception further supports these findings: the Perceptual Damage Index (PDI) score of 3.65 (on a scale of 1–4) suggests that the community perceives the road condition as highly deteriorated.

2. The Influence of Mining Activities (X) on Road Damage (Y)

Nickel mining activities in Bahodopi, particularly the movement of ore transport trucks carrying loads of 30–40 tons with a frequency of 80–120 trips per day, contribute significantly to the accelerated deterioration of road infrastructure. Road segments intensively traversed by mining vehicles (1.0–2.6 km) represent the areas experiencing the most severe damage. These findings are consistent with existing theories and previous studies indicating that heavy vehicle loads exceeding road design capacity substantially accelerate the reduction of pavement service life, leaving only a fraction of the originally planned lifespan.

3. The Role of Government Supervision and Policy (Z1)

The system of government supervision and regional policies concerning load restrictions, the regulation of dedicated mining routes, and the provision of monitoring facilities such as weighbridges has not been implemented optimally. This weakness in Z1 allows mining activities to operate with insufficient control over their impact on road infrastructure. Within the theoretical framework, Z1 should ideally function as a moderating variable capable of reducing the influence of X on Y; however, in this case, it has failed to significantly mitigate the magnitude of that impact.

4. The Influence of Environmental Conditions and Soil Bearing Capacity (Z2)

Environmental factors, including high rainfall intensity, poor drainage systems, and weak subgrade bearing capacity, further accelerate the process of road deterioration. Water ponding on road surfaces and shoulders, along with water infiltration into pavement layers and the subgrade, reduces the structural strength of the road. In this context, Z2 acts as an accelerating factor that intensifies the effect of X on Y, causing severe road damage to occur more rapidly and extensively than would be the case under more favorable environmental conditions.

5. Socio-Economic Impacts and Potential Conflicts

Road damage along the studied road segment has had tangible socio-economic impacts on the community of Bahodopi, including increased transportation costs, longer travel times, higher risks of traffic accidents, and a decline in road user safety and comfort. This condition has triggered tensions between local communities, mining companies, and regional governments, as reflected in public protests, road blockades, and demands for greater corporate contributions toward infrastructure improvement. Consequently, the issue of road damage is no longer merely a technical matter, but has evolved into a broader issue of governance, distributive justice, and power relations among key stakeholders within the mining region.

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