

Visibility Assessment of Rural Road Blackspots for Solar Powered Lighting Implementation

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Abstract— The lack of street lighting in rural areas can affect road users visibility and increase the potential risk of accidents, particularly in curves and hazard-prone points. This study aims to evaluate rural road visibility at hazard-prone points as a basis for solar panel based lighting recommendations on Bontongan Village Road, Baraka District, Enrekang Regency, South Sulawesi. The research employs a descriptive quantitative method with a technical evaluative approach through field observations, visual documentation, and light intensity measurements using a lux meter. Measurements were conducted at several observation points, including pre-curve areas, pothole locations, and post curve areas. The results indicate that the light intensity at hazard prone points is extremely low, at 4 lux, while the primary light source for road users comes from vehicle headlights with an intensity of 477 lux at a distance of 2 meters. Narrow road geometry, the presence of vegetation, and the positioning of potholes on the side of curves cause the visibility of hazardous objects to be limited at night. Based on the evaluation results, solar panel based lighting is recommended as an independent lighting solution for rural areas with minimal electrical infrastructure. The implementation of additional lighting at hazard-prone points has the potential to enhance road user visibility and support accident risk mitigation at night.

Keywords— Hazard-prone points, Light intensity, Road geometry, Independent lighting solution, Risk mitigation.

I. INTRODUCTION

Road lighting is a critical transportation infrastructure element that plays a vital role in supporting the safety, comfort, and visibility of road users, particularly under nighttime conditions. Low lighting intensity can reduce a driver's ability to identify objects, obstacles, and road geometric changes, thereby increasing the risk of traffic accidents. In rural areas, this issue tends to be more complex due to infrastructure limitations, non-uniform topography, and minimal access to the conventional electrical grid. Previous studies have demonstrated that road lighting quality is closely correlated with user visibility and sustainable transportation safety [1][2][3].

In Indonesia, the implementation of solar powered street lighting (SPSL) has emerged as an alternative infrastructure solution for regions with limited grid access. Solar lighting technology is considered capable of supporting energy efficiency while enhancing user safety in poorly lit areas [4][5][6]. However, most prior research has focused on system design, energy efficiency, power requirements, or technical optimization of solar public street lighting. Studies specifically linking rural road visibility to hazardous locations as a basis for solar powered lighting recommendations remain relatively limited, particularly for narrow rural roads with high visual hazard potential and challenging geometric conditions.

Enrekang Regency is a region characterized by hilly terrain and accident risks influenced by road geometry, a lack of safety facilities, and limited nighttime illumination. Based on traffic accident analysis in Enrekang using the Accident Rate and Equivalent Accident Number (EAN) methods, several road segments show vulnerability influenced by infrastructure conditions and user visibility factors [2][14]. Furthermore, identification of traffic accident rates in Enrekang indicates that road conditions and environmental factors are critical elements affecting road user safety. These conditions highlight that road lighting remains an essential requirement for accident risk mitigation in rural areas.

A representative location for these conditions is Bontongan Village Road, Baraka District, Enrekang Regency, South Sulawesi. Based on field observations, the road segment has a width of approximately 2.5 meters with minimal lighting, often lacking any permanent light sources at night. At one specific curve, a hole approximately 3 meters deep was identified immediately adjacent to the road shoulder, marked only by a simple bamboo pole tied with a plastic bag. This situation results in extremely low visibility of hazardous objects, especially at night and when motorists travel at certain speeds. Illuminance measurements using a motorcycle headlamp as the light source showed a value of 477 lux at a distance of 2 meters, while the surrounding environment exhibited very low lighting levels, approaching zero permanent illumination at 12 lux. This situation indicates that road user visibility is highly dependent on dynamic vehicle light sources, which are limited by the viewing angles at road curves.

Based on these conditions, this study aims to evaluate rural road visibility at hazardous locations on Bontongan Village Road as a basis for solar powered lighting recommendations.

TABLE I. Solar powered street lighting technology parameters

Parameter	Data Findings / Statistics
High Efficiency	36.7% energy savings with smart sensors.
Light Quality	90% improvement in environmental visibility.
Durability	6-hour charging for 16-hour operation.
Security	Reduction in reported crime in dark areas.
Reliability	AI-based system stability reaching 98%.

The evaluation is conducted through an analysis of light intensity, road geometric conditions, and the identification of visual hazard potential at night. This research is expected to provide technical recommendations regarding solar powered road lighting requirements to enhance user visibility and support accident risk mitigation in rural areas with minimal lighting infrastructure.

II. METHOD

This study employs a descriptive quantitative method with a technical evaluative approach to analyze rural road visibility conditions at hazardous locations as a basis for solar powered street lighting recommendations. This approach is utilized to evaluate existing illuminance levels, road geometric conditions, and visual hazards that affect road user visibility at night. The research focuses on the relationship between low lighting intensity and the degradation of user visibility regarding hazardous objects at rural road curves.

The research was conducted on Bontongan Village Road, Baraka District, Enrekang Regency, South Sulawesi. This site was selected due to its minimal lighting conditions, a road width of approximately 2.5 meters, and a hazardous point consisting of a hole roughly 3 meters deep located at the side of a road curve. The hazard at the study site is only marked by rudimentary markers, specifically a bamboo pole tied with a plastic bag, resulting in relatively low nighttime visibility. Furthermore, the surrounding environment, which is enclosed by vegetation, contributes to the limitation of both natural light and vehicle light reflection.

The research phases commenced with field observations to identify the existing conditions of the study site. The geometric features of the road, the presence of dangerous spots, visual obstructions, and the existing illumination conditions around the area were all observed during the day and night. Visual documentation was performed using a digital camera to record the visibility of the curve area and hazardous objects at night.



Fig. 1. Daytime Observations.



Fig. 2. Nighttime Observations.

Illuminance measurements were conducted using a lux meter at night across several observation points to obtain

representative lighting data regarding road visibility conditions. The measurement points included the approach area before the curve, the specific location of the roadside hole, and the exit area after the curve. These measurements were performed in an environment devoid of permanent lighting sources to establish a baseline of the existing illuminance at the study site. Additionally, light intensity was measured using a motorcycle headlamp to simulate the primary light source relied upon by road users at night. The measurement results showed a vehicle light intensity of 477 lux at a distance of 2 meters from the source.

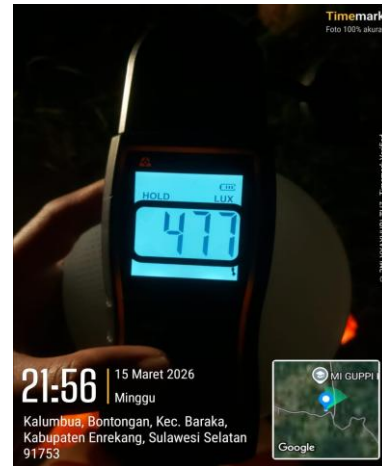


Fig. 3. Measurement of motorcycle headlamp intensity.

In the subsequent stage, visibility risk identification was performed based on field observations and illuminance data. The analysis considered road geometric conditions, the presence of curves, the position of the roadside hole relative to the pavement, visual obstructions caused by vegetation, and the perceptibility of hazardous objects at night. This visibility evaluation aimed to identify potential risks to road users resulting from low lighting levels at these hazardous locations.

The data from measurements and observations were analyzed using a descriptive quantitative method, comparing existing lighting conditions with nighttime visibility requirements based on relevant literature and road lighting standards. This analysis was utilized to evaluate the urgency of supplementary lighting at the study site as a measure to enhance road user visibility.

The final stage of the research involved formulating technical recommendations for solar powered street lighting as an autonomous lighting solution for rural areas with minimal electrical infrastructure. These recommendations were developed based on the conditions of hazardous points, user visibility requirements, and the environmental characteristics of the study site. The recommendations encompass the placement of lighting units, illumination direction, and lighting requirements at curve areas to improve visibility and support nighttime accident risk mitigation.

III. RESULT AND DISCUSSION

A. Existing Conditions of the Research Site

Field observations indicate that the Bontongan Village Road in Baraka District, Enrekang Regency, exhibits typical rural road characteristics, with a pavement width of approximately 2.5 meters and a location on a curve with limited visibility. A hazardous hole, approximately 3 meters deep, was identified at the study point immediately adjacent to the road shoulder. This hazard is only marked by a rudimentary indicator a bamboo pole tied with a plastic bag. Such conditions make it difficult for road users to recognize the hazard at night, particularly when environmental lighting levels are extremely low.



Fig. 4. Roadside hole during daytime.



Fig. 5. Roadside hole during nighttime.

In addition to the narrow road geometry, the surrounding vegetation obstructs natural light distribution and the reflection of vehicle lights. At night, the research area lacks a permanent lighting system, leaving road user visibility entirely dependent on passing vehicle light sources. This situation potentially increases visual risks, especially within curve areas that possess limited viewing angles.



Fig. 6. Vegetation obstructing the ravine and visibility.

Previous research explains that poor road lighting quality can reduce the ability of road users to identify objects or changes in road geometric conditions at night. Substandard road lighting also negatively impacts the comfort and safety of road users [1][2].

B. Lighting Intensity Measurement Results

Illuminance measurements were conducted at night using a lux meter at three observation points to obtain a profile of lighting distribution within the research area. These points consisted of the approach area before the curve, the location of the hole, and the exit area after the curve.

TABLE II. Light Intensity Measurement Results.

Observation Point	Environmental Condition	Illuminance
Before the curve	Minimal lighting	12 lux
Hazard point (hole/curve)	No existing lighting	4 lux
After the curve	Minimal lighting	9 lux
Motorcycle	Vehicle light source	477 lux

Based on the measurement results, the hazard point at the curve exhibited the lowest illuminance at 4 lux. This value indicates that the study area is under extremely low lighting conditions, resulting in limited visibility of hazardous objects. Meanwhile, the primary light source for road users originates from motor vehicle headlamps, with a measured value of 477 lux at a distance of 2 meters.

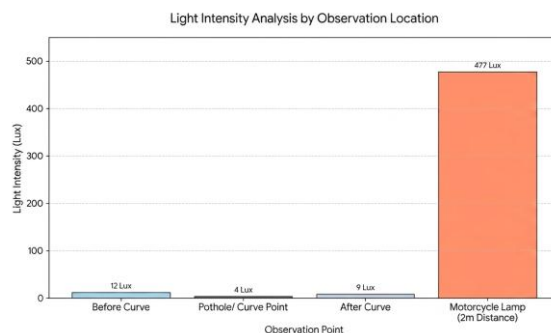


Fig. 7. Light intensity distribution graph.

The graph illustrates a significant discrepancy between the ambient environmental illuminance and the vehicle's light source. The ambient light intensity at the curve and hazard point falls substantially below the vehicle's lighting output. This condition demonstrates that the study area lacks permanent lighting support capable of optimally enhancing the visibility of hazardous objects. These results indicate that road user visibility at the research site is highly dependent on the direction and range of dynamic vehicle light sources. In curving sections, vehicle light distribution becomes sub-optimal due to restricted lighting angles relative to the hazard area located at the roadside. Research on road lighting indicates that low illumination quality can impair object detection and increase potential risks at night. Furthermore, road lighting standards emphasize the importance of uniform light distribution to support road user safety [1][2][7][11][12][13].

Observation results show that low illuminance at the curve makes the roadside hole difficult to identify from a safe distance. This condition is further exacerbated by:

- Relatively narrow road width;
- The proximity of the hole to the road shoulder;
- The presence of dense vegetation;
- The absence of road markings or guardrails.

At night, road users rely solely on vehicle lighting, which has limited field of view angles at curves. Consequently, the hazard point only becomes visible when the vehicle is in close proximity to the object. This phenomenon aligns with road lighting research stating that non-uniform light distribution can reduce user visibility and affect sustainable transportation safety [2][5]. Additionally, studies on lighting design for comfort and security suggest that adequate illumination quality significantly improves road user visibility levels at night [1].

C. Solar Powered Lighting Recommendations

Based on the visibility evaluation results, additional lighting intervention is required at the hazardous locations within the study area. Solar powered lighting was selected as it is deemed suitable for rural characteristics where conventional electrical infrastructure is limited. The proposed technical recommendations include:

- Installation of solar powered lighting units in the approach area (before the curve);
- Pole height of approximately 5 - 6 meters;
- Utilization of energy efficient LED lamps;
- Optimization of luminous flux direction focused on the curve and the hazardous hole location.

The implementation of solar-powered lighting in rural areas serves as a potential independent (off-grid) lighting solution that is more efficient and flexible than conventional systems. Previous studies have demonstrated that solar powered street lighting can enhance road illumination quality while supporting safety and energy efficiency aspects [4][5][8][9][10]. Consequently, the recommendation for solar powered lighting at hazardous points on Bontongan Village Road has the potential to significantly improve road user visibility and support accident risk mitigation at night.

IV. CONCLUSION

The results of this study indicate that visibility at hazardous locations on Bontongan Village Road, Baraka District, Enrekang Regency, is significantly low due to the lack of ambient environmental lighting at night. Illuminance measurements reveal that the curve area and the hazardous hole point only reach a lighting level of 4 lux. In contrast, the primary light source for road users is limited to motor vehicle headlamps, measuring 477 lux at a distance of 2 meters. These conditions demonstrate that the visibility of hazardous objects at the research site is highly dependent on dynamic vehicle light sources, which have restricted viewing angles relative to road curves.

In addition to low illuminance, the narrow road geometry, presence of vegetation, and the proximity of the hole to the road shoulder further increase visual risks for nighttime road users. The existing hazard markers, consisting of rudimentary bamboo poles and plastic bags, are considered inadequate for providing sufficient visibility under low light conditions.

Based on the technical evaluation, additional lighting intervention is required at hazardous points to enhance road user visibility. Solar powered lighting is identified as a suitable solution for rural areas with limited conventional

electrical infrastructure. The recommendation to install solar powered units in the approach area, with a luminous focus on the hazard point and the curve, is expected to improve the visibility of hazardous objects and support nighttime accident risk mitigation.

This study is subject to limitations regarding its observational scope and the absence of a post-implementation performance evaluation of the solar lighting system. Therefore, further research is required to analyze the effectiveness of solar powered lighting through lighting simulation approaches or before-after evaluations of nighttime road visibility improvements.

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