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Utilization of AWS Data in Landslide Risk Analysis in Manado City Using a WebGIS Approach

Yves Vincent De Paul Muaya[1*], Fernando Victor Dotulong[1], Ifon Kojo[1], Eliasta Ketaren[2]
[1,] North Sulawesi University of Technology , Indonesia
[2] Information Systems, Sam Ratulangi University, Indonesia
Email: [1*]yvmuaya@gmail.com, [2]fernandodotulong84@gmail.com, [3]kojoifon94@gmail.com, [4]eliasketaren@unsrat.ac.id
(*:yvmuaya@gmail.com)
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Abstract-The City of Manado has a complex topography and hug rainfall, making it highly susceptible to landslide. This vulnerability is further exacerbated by urban development that does not always take geological and spatial planning aspects into account. The availability of an early warning system based on spatial data is therefore crucial to reduce risks and potential losses. This study aims to utilize rainfall data from the Automatic Weather Station (AWS) as the main indicator in landslide risk analysis, supported by WebGIS technology to present information in a more interctive and accesible manner. The research method consists of three main stages: daily AWS data collection, spatial analysis using overlay techniques and weighting of environmental parameters (such as rainfall, temperature, wind, and soil moisture), and the development of a WebGIS-based system to visualize risk zones. The collected data were processed to determine rainfall thresholds that have the potential to trigger landslides and were then integrated with other geospatial factors to generate more accurate risk maps. The results indicate that the integration of AWS data with spatial analysis improves the accuracy of landslide-prone area mapping in Manado. Furthermore, the implementation of WebGIS facilitates the dissemination of information to the community and local government, thereby supporting mitigation efforts and data-driven decision-making.

Keywords: Automatic Weather Station (AWS); Landslide Risk Analysis; WebGIS; Manado City; Early Warning System

1. INTRODUCTION

Manado City is an area in North Sulawesi with hilly topography and high rainfall intensity. These conditions make Manado an area prone to landslides, especially during the rainy season. Data from the National Disaster Management Agency (BNPB) notes that landslide incidents in urban areas are increasing due to changes in land use, urbanization, and extreme rainfall intensity influenced by climate change. Therefore, an accurate, real-time, and easily accessible risk monitoring and analysis system is needed to support disaster mitigation efforts. Automatic Weather Stations (AWS) are one of the important tools in disaster early warning systems because they are able to provide rainfall data automatically, continuously, and periodically [1]. AWS data can be used to calculate rainfall thresholds that function as indicators of landslide triggers. However, this data needs to be processed and presented in an informative platform so that it can be accessed by stakeholders and the public. One relevant approach is the integration of AWS data with WebGIS, which allows for spatial visualization and interactive mapping of landslide risks.

Several previous studies have shown that the integration of rainfall data with web-based systems and GIS provides a significant contribution to interactive and real-time landslide risk management [2]. Systematic studies show that WebGIS is one of the main approaches in disaster risk management because it is able to integrate spatial data, rainfall, and field information comprehensively [3]. Rainfall-based early warning systems can remain effective even in areas with limited data, as long as there is integration between the mesoscale model and AWS data [4]. GIS methods based on regression and machine learning can improve the accuracy of landslide susceptibility maps, which can then be integrated with the WebGIS platform [5]. Adjusting rainfall thresholds through a quantitative approach is key to improving the accuracy of landslide early warning systems [6]. The use of AWS data in Indonesia has successfully developed dynamic thresholds for landslide early warning, which are more suited to local climate conditions [7]. The development of web-based tools makes it easy for users to model the potential for landslides due to rainfall directly through an interactive interface [8]. The integration of real-time sensor data, including AWS, contributes significantly to improving the accuracy and reliability of local landslide early warning systems [9]. The combination of physical slope stability models with real-world rainfall data results in more realistic landslide hazard mapping [10]. Global landslide analysis systems emphasize the importance of data fusion from various sources, including AWS, to support early warning operations [11]. Rainfall distribution patterns and geotechnical conditions can be integrated to produce process-based physical thresholds, making them more adaptive to local conditions [12]. Validation of rainfall thresholds with AWS and radar data has been shown to improve the reliability of regional landslide warning systems [13]. A probabilistic approach to determining rainfall thresholds can strengthen the scientific basis of rainfall-based early warning systems [14]. Operational studies of early warning systems show that AWS is a vital component in supporting real-time rainfall measurements [15]. The use of AWS in tropical mountainous areas is crucial for capturing extreme rainfall intensities that often trigger landslides [16].

Although various studies have demonstrated the benefits of AWS and WebGIS data in landslide early warning systems, the main problem is the lack of a focused study in Manado City that integrates local AWS data with a WebGIS platform for risk analysis [17]. In addition, there is still limited research testing the effectiveness of AWS-based rainfall thresholds in the typical wet tropical climate conditions of the North Sulawesi region. Therefore, the hypothesis of this

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study is that the integration of AWS data with a WebGIS approach can improve the accuracy of landslide risk analysis in Manado City and provide a more accessible information system for disaster mitigation purposes [18].

The purpose of this study is to collect and analyze rainfall data from the AWS in Manado City as a basis for determining rainfall thresholds that trigger landslides. This study aims to develop a landslide risk analysis model by integrating AWS data into a WebGIS platform. This study aims to provide an interactive and informative WebGIS-based landslide risk map to support disaster mitigation decision-making in Manado City.

The geological characteristics of Manado City, such as steep slopes, easily saturated soil, and the presence of densely populated residential areas at the foothills, further increase the region's sensitivity to landslides. The young volcanic soil structure commonly found in North Sulawesi has a high water absorption capacity, but when saturated, it experiences a drastic decrease in shear strength. This condition becomes even more critical when extreme rainfall occurs over a short period, increasing pore pressure and triggering slope instability. Therefore, accurate and measurable rainfall data is crucial for predicting slope stability dynamics in Manado.

The development of infrastructure and the expansion of Manado's urban area over the past two decades have also influenced surface runoff patterns. Many areas that were previously open spaces and forests have now been converted into residential areas, commercial centers, and road infrastructure [19]. These changes in land use reduce the soil's ability to absorb water, thereby increasing the concentration of surface runoff, which then accelerates erosion and increases the likelihood of landslides. Various local government reports confirm that urbanization without considering land carrying capacity plays a significant role in increasing landslide occurrences, both small and large scale [20]. Therefore, managing rainfall data integrated with spatial mapping is a strategic step in understanding the latest vulnerability patterns.

The use of WebGIS is not only about displaying digital maps, but also providing an analytical platform that can process sensor data in real-time so that its benefits can be felt by various parties. In many countries, WebGIS has been used by local governments, disaster management agencies, and even the public to monitor weather conditions, check potential hazards, and plan mitigation measures [21]. By integrating AWS into the WebGIS platform, rainfall information is not only displayed in numerical form, but is also visualized spatially so that the relationship between rainfall intensity and landslide-prone locations can be analyzed more intuitively. This spatial visualization is very helpful, especially in formulating spatial planning policies that are more adaptive and responsive to disaster threats [22].

The integration of AWS and WebGIS enables the development of a zone-based early warning system, where each monitoring area has a different rainfall threshold value according to its geotechnical and topographical conditions. This approach is much more effective than using a single rainfall threshold for an entire city, which often does not accurately reflect the risk [23]. By leveraging historical data from AWS, statistical or machine learning models can be used to determine location-specific rainfall thresholds, allowing warnings to be tailored to the slope sensitivity level in a given area. This has the potential to reduce prediction errors, both in the form of false alarms and warning delays, which have been a challenge in early warning systems in many areas [24].

The development of an AWS-based WebGIS platform for Manado City not only contributes to improving the accuracy of early warnings but also supports information transparency for the public. With an easily accessible system, the public can independently obtain information on potential landslides and take preventative measures before a disaster occurs. The local government can also use this platform to plan evacuations, prioritize vulnerable areas, and provide data-driven education to residents. Therefore, this research is expected to contribute not only to academic aspects but also to have a tangible impact on the safety of the Manado City community.

2. RESEARCH METHODOLOGY

2.1 Research methods

This research was conducted in Manado City, North Sulawesi, which is characterized by hilly topography and high rainfall intensity. The study area encompassed urban and hilly areas in the districts of Tikala, Mapanget, and Malalayang.

The Tikala District was chosen because it is one of the areas experiencing significant urbanization pressure in recent years. Rapid changes in land use, from residential development to public facilities, have made the slopes in the area increasingly vulnerable to instability [25]. Furthermore, several landslide incidents have been reported during the rainy season, indicating the need for more intensive rainfall monitoring. These conditions make Tikala a representative area for evaluating the relationship between rainfall intensity, spatial changes, and landslide potential.

Mapanget District was chosen because it combines hilly terrain, an international airport, and a new economic growth area. The decreasing availability of open space and increasing land conversion have impacted surface runoff patterns. Mapanget also experiences high rainfall, especially during the peak rainy season. By utilizing AWS data from the surrounding area, the study was able to more accurately observe rainfall dynamics and the potential for landslides in this area, which serves as a major gateway for public mobility in Manado City.

Malalayang District has unique characteristics, combining hills and coastal areas. This area is known to be prone to landslides, especially in areas adjacent to steep cliffs and densely populated areas. Increasing road infrastructure and vertical settlements also increase pressure on slope stability. By including Malalayang as a research location, the analysis can encompass a variety of geomorphological conditions, from extreme slopes to transitional areas between hills and

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coast. These conditions provide a more comprehensive picture in testing the effectiveness of AWS and WebGIS data integration for landslide risk analysis in Manado City.

2.2 Instrumen Penelitian

The main instrument for this research is an Automatic Weather Station (AWS) designed and assembled independently with the following specifications [26], [27]:

1. Rain Gauge (tipping bucket rain sensor) with a resolution of 0.2 mm per tip.
2. Air Temperature and Humidity Sensor (DHT22/SHT31) with an accuracy of ±0.5°C and ±2% RH.
3. Anemometer and Wind Vane to measure wind speed and direction with a resolution of 0.1 m/s.
4. Capacitive soil moisture sensor at a depth of 20-40 cm.
5. ESP32-based data logger with a GSM/Wi-Fi communication module for real-time data transmission.

The Automatic Weather Station (AWS) instrument used in this study was independently designed to meet the needs of monitoring rainfall and environmental parameters relevant to landslide potential in Manado City. Each component was selected based on its accuracy, reliability, and integration capabilities with real-time data collection systems. A tipping bucket rain gauge with a resolution of 0.2 mm per tip serves to precisely record rainfall intensity and accumulation, making it crucial for calculating rainfall thresholds. Temperature and humidity sensors such as the DHT22 or SHT31 help monitor atmospheric conditions that can affect evaporation rates and soil moisture, while an anemometer and wind vane provide information on wind patterns that can contribute to rainfall distribution and local weather dynamics.

AWS is equipped with soil moisture sensors at a depth of 20-40 cm to measure soil saturation levels, a critical variable in landslide occurrence. Data from all sensors is collected by an ESP32-based data logger equipped with a GSM or Wi-Fi communication module to enable continuous data transmission to a central server. The use of ESP32 offers the advantages of low power consumption, data processing capabilities, and stable connectivity, allowing AWS devices to operate autonomously in various environmental conditions. The integration of all these components enables AWS to work as a comprehensive and responsive monitoring instrument, and supports the development of a real-time data-based WebGIS system for landslide risk analysis.

The data used consists of:

1. Primary Data: AWS measurements (rainfall, temperature, air humidity, soil moisture, and wind speed).
2. Secondary Data: Digital Elevation Model Map (30 m DEM), geological maps, land use, and landslide data from the North Sulawesi Regional Disaster Management Agency (2020–2024).

The data used in this study consists of complementary primary and secondary data to produce a comprehensive landslide risk analysis. Primary data was obtained directly from AWS measurements, which include rainfall, temperature, air humidity, soil moisture, and wind speed, all of which serve to monitor the dynamics of atmospheric and soil conditions in real time. Meanwhile, secondary data includes a 30-meter resolution Digital Elevation Model (DEM), geological maps, land use maps, and historical landslide data from the North Sulawesi Regional Disaster Management Agency (BPBD) for the 2020-2024 period. The DEM is used to map slope gradients and topographic aspects, geological maps help understand soil and rock characteristics, land use illustrates spatial changes that influence vulnerability, and landslide data provides the basis for model validation. The combination of these two types of data allows for more accurate determination of rainfall thresholds and landslide risk mapping that is more representative of actual conditions in Manado City.

2.3 Research Stages

The research stages were as follows [28], [29]:

1. AWS Data Collection
   Weather data was automatically recorded every 10 minutes and stored on a PostgreSQL/PostGIS-based server. Anomalous data was removed through a data cleaning process.
2. Rainfall Threshold Analysis
   a. Daily rainfall was analyzed using the percentile method (90-95%).
   b. Thresholds were tested against historical landslide data using ROC (Receiver Operating Characteristic) to assess sensitivity.
3. Spatial Analysis of Landslide Risk
   a. Main parameters: rainfall, slope, soil type, land use, and soil moisture.
   b. Weighting was applied using the Analytical Hierarchy Process (AHP) with a consistency value <0.1.
   c. The integration results were analyzed using the weighted sum overlay method to generate a landslide risk map.
4. WebGIS Development
   a. Landslide risk maps were integrated into a LeafletJS-based WebGIS.
   b. Features: layer control, location search, risk zone classification, and real-time AWS data access.

The research phase began with the collection of AWS data, recorded every 10 minutes and stored in a PostgreSQL/PostGIS database to ensure compatibility with spatial analysis. The raw data then underwent a data cleaning process to remove anomalies such as missing values or illogical spikes in extreme values. Next, a rainfall threshold analysis was performed using the 90-95% percentile method to determine critical limits that could potentially trigger landslides. These thresholds were tested using historical landslide data using the ROC approach to assess the sensitivity and accuracy of the predictions. The next stage was a spatial analysis of landslide risk, involving slope, soil type, land use, soil moisture, and rainfall as the main factors. Weights between parameters were determined using the Analytical Hierarchy Process (AHP) method, ensuring a consistency value of <0.1 to maintain the validity of the assessment. All parameters were then integrated using a weighted sum overlay technique to produce a landslide risk map that represented actual field conditions.

The final stage was the development of a LeafletJS-based WebGIS platform that serves as a visualization platform and interactive presentation of risk maps. Previously analyzed maps are uploaded and integrated into the system, allowing users to quickly and accurately access risk zones. WebGIS is equipped with features such as layer control for selecting map types, location search to facilitate searching for specific areas, and color classification of risk zones. Furthermore, real-time AWS data is displayed on the platform, allowing users to monitor the latest rainfall developments. With this integration, WebGIS becomes an effective tool to support disaster mitigation efforts, providing easily understandable information to the government, disaster practitioners, and the general public.

3. RESULTS AND DISCUSSION

Rainfall threshold analysis and landslide risk mapping are two key components of data-driven disaster mitigation efforts for Manado City. Given the city's hilly topography and high annual rainfall, identifying rainfall thresholds that trigger landslides is a crucial step in developing an accurate and reliable early warning system. Rainfall thresholds derived from AWS data not only reflect local climatological conditions but also provide a strong scientific basis for predicting when landslide potential increases significantly. By combining rainfall parameters, soil moisture, and trends in changing ground conditions, the early warning model can provide hazard, warning, alert, or safe statuses more adaptively and in a timely manner.

In addition to determining rainfall thresholds, spatial analysis-based landslide risk mapping allows for the identification of vulnerable zones by considering physical factors such as slope gradient, soil type, and land use. The resulting risk map serves not only as a technical analysis tool but also as a crucial tool for local governments, the Regional Disaster Management Agency (BPBD), and the public to understand the distribution of vulnerability within Manado City. By dividing the area into three risk categories, stakeholders can design more targeted mitigation strategies, from spatial planning and infrastructure development to developing evacuation procedures. This integration of rainfall analysis and risk mapping ensures that disaster mitigation efforts are comprehensive and evidence-based.

3.1 Rainfall Threshold Triggering Landslides

Determining rainfall thresholds is a crucial step in building an effective landslide early warning system, particularly in areas with extreme hydrometeorological characteristics such as Manado City. High rainfall, combined with saturated soil conditions and hilly topography, makes this region highly susceptible to landslides. Therefore, rainfall threshold analysis based on AWS data is the primary foundation for scientifically identifying critical thresholds that trigger slope instability. These thresholds not only help predict potential landslides but also establish an operational framework for the Regional Disaster Management Agency (BPBD), local governments, and communities to make rapid and informed decisions.

During the analysis, various meteorological and hydrological parameters were considered to ensure the resulting model accurately reflects real-world conditions. In addition to daily rainfall and three-day accumulation, the soil saturation index, represented in this study by the Antecedent Precipitation Index (API), was calculated to assess the soil's capacity to retain additional rainfall. Threshold validation using the ROC method yielded an AUC of 0.86, indicating the model's excellent predictive capability. These results reinforce the belief that the established thresholds reflect the dynamics of a humid tropical climate and are operationally feasible.

To ensure optimal operation of the early warning system, the rainfall threshold is then translated into a landslide hazard assessment model. This model classifies hazard levels from safe, alert, warning, to dangerous based on a combination of short-term and long-term rainfall and soil moisture conditions. This approach enables the system to provide more adaptive warnings, considering not only rainfall intensity but also changes in soil conditions over the past 24 hours. Thus, the resulting model minimizes the risk of false alarms while increasing public awareness of potential landslides, which can occur at any time.

The analysis results indicate that landslides in Manado City are likely to occur if rainfall reaches ≥120 mm/day or ≥220 mm for three consecutive days. This value aligns with research findings that place the rainfall threshold in tropical mountainous areas at 100–150 mm/day. Validation using the ROC method yielded an AUC of 0.86, indicating a high level of accuracy.

With the following assessment model:

1. Hazard status if either:
   a. (rain_24h ≥ 80 or rain_72h ≥ 150 or API ≥ 120) and (sm ≥ 45 or sm_trend_24h ≥ +3)
   b. rain_1h ≥ 25 and sm ≥ 40
   c. rain_6h ≥ 70 and (sm ≥ 40 or sm_trend_24h ≥ +2)
2. Warning status if either:
   a. 40 ≤ rain_24h < 80 or 80 ≤ rain_72h < 150 or 80 ≤ API < 120, and (sm ≥ 38 or sm_trend_24h ≥ +2)

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   b. $15 \leq$ rain_1h < 25 and sm ≥ 38
3. Alert status if any of the following:
   a. $10 \leq$ rain_24h < 40 or $30 \leq$ rain_72h < 80 or $50 \leq$ API < 80
   b. (sm ≥ 35 dan sm_trend_24h $\geq +1$)
4. Safe status if all of the following are met:
   a. rain_24h < 10, rain_72h < 30, API < 50
   b. sm < 35 and sm_trend_24h $< +1$, and no short-term intensity: rain_1h < 10 and rain_6h < 20

3.2 Landslide Risk Map of Manado City

Landslide risk mapping is a crucial step in understanding how factors such as rainfall, slope gradient, soil type, and land-use patterns interact to shape a region's vulnerability. Through GIS-based spatial analysis, this study successfully identified zones with varying levels of risk in Manado City. This division allows stakeholders to clearly identify areas that require the most priority in mitigation efforts, such as the development of safety infrastructure, increasing community capacity, or implementing stricter spatial planning. Thus, the mapping results serve not only as a technical analysis product but also as a basis for evidence-based policy planning.

Classifying risks into high, medium, and low categories provides a comprehensive overview of vulnerability distribution across various sub-districts in Manado City. Each zone has distinct geomorphological and land-use characteristics, requiring mitigation approaches to be tailored to the local conditions of each region. Presenting the results in tabular form facilitates a concise and informative understanding of the risk distribution. The following table summarizes the distribution of landslide risk zones in Manado City based on the results of the spatial analysis. The spatial analysis divides Manado City into three risk categories.

Table 1. Manado City Landslide Risk Zone

Broad Risk	Categories (Ha)	Percentage (%)	Dominant Location
Height	4.125	22	Tikala, Mapanget, Malalayang Atas
Medium	7.650	41	Wanea, Paal Dua, Tuminting
Low	6.850	37	Sario, Wenang, Malayang Baawah

Table 1 shows that the high-risk area covers 4,125 hectares, or approximately 22% of the total area of Manado City. This zone is dominated by hilly areas such as Tikala, Mapanget, and Upper Malalayang, which have steep slopes and high rainfall intensity. Geomorphological characteristics and the expanding development of residential areas on the slopes are the main factors that increase landslide vulnerability in these areas. This situation requires greater attention in spatial planning, development monitoring, and the installation of more intensive early warning systems.

Meanwhile, the medium risk category covers the largest area, at 7,650 hectares, or 41%, and includes areas such as Wanea, Paal Dua, and Tuminting. These areas typically lie in the transition between plains and hills, so the potential for landslides remains significant, but not as high as the critical zone. Meanwhile, the low risk category covers 6,850 hectares, or 37%, in plains areas such as Sario, Wenang, and Malalayang Bawah. Despite being categorized as low risk, these areas still require monitoring, as changes in land use or increased extreme rainfall can suddenly increase the risk. Overall, this table provides a clear picture of the distribution of landslide risk, which can serve as a basis for local governments in developing location-based mitigation priorities.

An Automatic Weather Station (AWS) is a weather monitoring device that automatically and continuously records atmospheric conditions. This equipment is typically equipped with various sensors, such as a rainfall gauge, air temperature, relative humidity, wind direction and speed, and air pressure. AWS's ability to collect real-time data makes it crucial for climatology, hydrometeorological disaster mitigation, and environmental research. With a system that operates without manual intervention, AWS ensures data accuracy and consistency, essential for long-term analysis.

In the context of disaster vulnerability research or risk mapping, AWS helps provide more detailed and precise climate data. Recorded weather information can be used to detect anomalous patterns, predict potential extreme events, and support early warning systems in a region. Therefore, Figure 1, which shows an Automatic Weather Station, is not simply an illustration of the device, but a representation of a vital instrument that plays a role in improving disaster preparedness and mitigation planning based on scientific data.

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Fig 1. Automatic Weather Station

3.3 WebGIS Implementation

The developed WebGIS is capable of displaying interactive maps of landslide risk zones, integrating AWS data, and providing location search and zone classification features. Trials have shown that WebGIS accelerates the identification of vulnerable locations, helps determine evacuation routes, and facilitates disaster mitigation outreach to the community.

WebGIS is also designed with an intuitive interface so it can be used by various stakeholders, from government officials and disaster relief volunteers to the general public. The integration of AWS data visualization in graphical form and automatic updates allows users to monitor current weather conditions that could potentially trigger landslides, such as rainfall intensity and soil moisture. Thus, WebGIS functions not only as a static map but as a dynamic information center that comprehensively combines spatial and temporal data.

WebGIS provides a collaborative space for disaster risk reduction. Openly presented data can be used for cross-sector discussions, from regional policy formulation and spatial planning to safer infrastructure development. A centralized data update mechanism also minimizes information gaps between agencies. With these capabilities, WebGIS not only improves analytical accuracy but also strengthens synergy between stakeholders to build a sustainable disaster mitigation system that is responsive to changing environmental conditions.

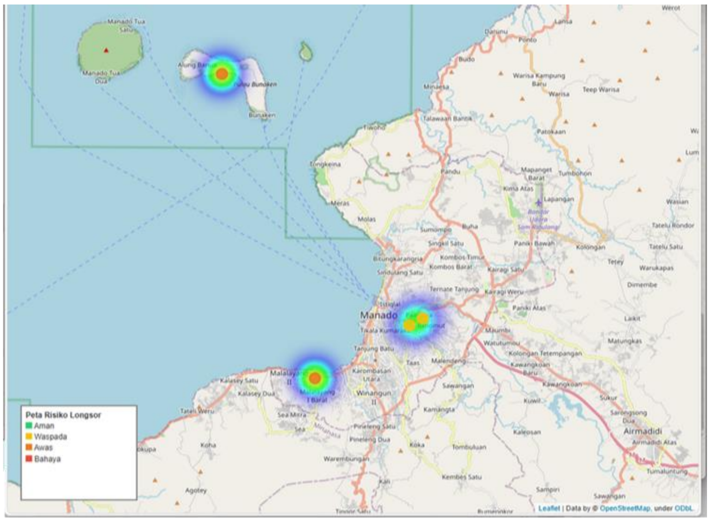

Fig 2. WebGIS Map of Manado City

Figure 2 displays the main view of the Manado City Map WebGIS, which has been developed as a supporting tool for landslide risk mitigation. In this view, users can view risk zones, displayed with different color classifications to distinguish high, medium, and low-risk areas. This visualization is a continuation of the results of a previous spatial analysis that divided Manado City into three risk categories. With an interactive map-based presentation, users can

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directly observe risk distribution patterns and understand the characteristics of vulnerable areas more easily and intuitively.

In addition to displaying risk zones, the WebGIS in the image also displays an Automatic Weather Station (AWS) data integration feature that allows monitoring of actual weather conditions such as rainfall, soil moisture, and wind speed. The presence of this feature strengthens WebGIS's function as a dynamic information system that not only displays static maps but also provides real-time information that can support rapid decision-making in emergency situations. The combination of risk maps, AWS data, and location search features makes WebGIS a comprehensive platform that can accelerate the process of identifying vulnerable locations and support more effective disaster mitigation efforts in Manado City.

4. CONCLUSION

This study demonstrates that the use of a self-designed Automatic Weather Station (AWS) is capable of providing real-time meteorological data (rainfall, temperature, air humidity, soil moisture, and wind speed) that is highly relevant to support landslide risk analysis in Manado City. Spatial analysis that integrates AWS data with environmental parameters (slope gradient, soil type, and land use) successfully produces a landslide risk zoning map that is more accurate and appropriate to local conditions. The main finding of this study is that a daily rainfall threshold of ≥120 mm or a three-day accumulation of ≥220 mm has the potential to be the main trigger for landslides in Manado City, so it can be used as a basis for establishing an early warning system. The implementation of WebGIS makes a significant contribution in visualizing and disseminating landslide risk information to local governments and the public. This system simplifies the process of identifying vulnerable areas, developing mitigation strategies, and making data-driven decisions.

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