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Landslide Prediction Model of Prone Areas in Pulung, Ponorogo East Java

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Abstract

Ponorogo (7°52'15.3"S, 111°27'44.5"E) has various typical landscapes. A total of 59 landslides occurred during 2012-2018 in those common areas. The most severe landslide occurred in Banaran, Pulung sub-district, which caused several deaths and material losses. This research aimed to predict the areas which have the highest landslide probabilities based on daily rainfall. The methods were applied are scoring in four parameters, including daily rainfall, slope, land type, and land use. The data sets obtained from a local government authority (BAPPEDA). The data were treated using ArcGIS, Map server for windows, PostgreSQL database, and framework pmapper. The results are a real-time map based on the website, which provided three main categories of landslide probabilities. The highest vulnerability level of landslide were located in villages of Munggung (7°50'46.4"S, 111°38'36.9"E), Bekiring (7°51'11.9"S, 111°39'31.0"E), Singgahan (7°52'26.1"S, 111°39'05.8"E), Bedrug (7°53'20.1"S, 111°38'53.4"E), Wagirkidul (7°52'11.0"S, 111°40'46.3"E), and Banaran (7°50'47.9"S, 111°40'49.2"E). The system based on the website can be updated real-time depends on four parameters mentioned. These current results expected as an early warning system for those all potential areas, especially during the rainy season.

Keywords: Ponorogo; landslide prediction; daily rainfall; early warning system; geographical information system

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1. Introduction

The National Agency for Disaster Countermeasure (BNPB) noted that Ponorogo is one of the city with substantial potential landslide [1]. Recorded 59 times of landslide happened during 2012-2018 [2, 3]. One of the landslides caused a lot of victims has occurred in Pulung sub-district area. On April 1, 2017, the landslide happened in Banaran village caused death and material losses at least two dead, one seriously injured, 19 minor injuries, 26 lost, and 300 people are a refugee [4]. The material loosed including 32 houses are mud covered, 12.2 hectares of productive cultivated lands are losses. The landslide is spreading in almost 1.1 km [5]. On December 3, 2018, rainy season, another landslide occurred in Wagirkidul. It caused the villagers cannot access the road because almost fifteen-meter had landslides [6]. On November 7, 2017, a landslide occurred in Bekiring village caused two houses damaged. Its landslide triggered by heavy rains that flushed on that Monday afternoon [7]. The latest news on March 1, 2019, a landslide occurred in the hamlet of Puthuk Tranjang, the village of Munggung caused a kitchen home residents suffered damage from the heavy rain that night [8]. The precision predictive of the landslide is needed to prevent any critical condition to human and houses.

The previous research on landslide predictions mostly used eight parameters, namely: cumulative Cumulative daily rain 3 consecutive days, slope, rocks, the existence of a fault, depth of soil, land use, infrastructure, and density of settlements [9]. It parameters implemented in Ponorogo East Java produces 70.7% accuracy [10]. The same research used four parameters, namely: monthly rainfall, slope, land use, and soil type. Its first research is making the landslide-prone zones map in Semarang city with doing weighting parameters. It has resulted from this study is that the landslide susceptibility map divided into five classes of vulnerability, i.e., not prone, somewhat prone, quite prone, prone, and very prone [11]. The second research is geographical information system application for determining priority areas for erosion hazard handling (Case study of Citarum stream area) shown that the region with very high and high erosion potential catchment area about 32% [12]. The third research is geographic information system for detection of landslide-prone areas case study in the village of Karang Anyar Gunung, Semarang city, shown that the results of the mapping process is expected to generate an early warning system of landslides in the area and can help the government to decide the location of infrastructure [13].

This research used four parameters were used by the Gadjah Mada University team and the Indonesian Geological Survey to analyse the landslides that occurred in Pulung [14]. Its parameters used in this research are daily rainfall [15], slope [16], land use [16], and land type [16] based on the results of its survey. This research has proposed the model of geographical information system based on the website where the data are updateable. The up to date found real data are essential to get the best prediction. The research aims to predict landslide area in Pulung sub-district, which categories on three different status: high, medium, and low vulnerability based on daily rainfall.

2. Methods

The landslide prediction model used for the system development Waterfall System Development Life Cycle. The waterfall model where this illustrates a systematic and sequential approach to software development, starting with the specifications of user requirements [17]. The Waterfall model phases consist of 5 stages, as shown in Fig. 1.

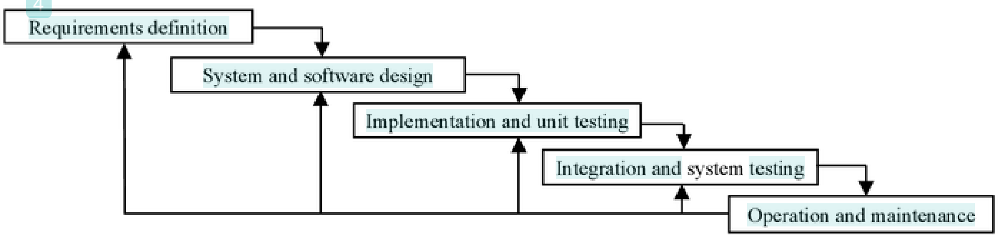


Fig. 1. Waterfall System Development [17].

2.1. Requirements definition

The first stage is requirements definition is performed the service, limitation, and objective. It also identifies a problem related to data of four parameters. It parameters namely: morphology map of Ponorogo with scale 1:25.000 [18], land type map of Ponorogo with scale 1:100.000 [18], Space pattern map Ponorogo with scale 1:250.000 [18], and daily rainfall (mm/day) in Pulung, Ponorogo 2017 [19].

This application provides a landslide-prone map in Pulung sub-district update every day. This maps update based on four parameters such as daily rainfall and land type shown in Table 1, slope and land use shown in Table 2. Each parameter weights with value based on Table 3. The vulnerability level of a landslide categorised by three models, shown in Table 4.

Table 1. Daily rainfall [15] and land type parameter [16].

No.	Daily rainfall (mm/day)	Daily rainfall Category	Land type	Land type category	Score
1	< 5	Very low/no rain	Regosol, latosol, organosol, rendzina	Very sensitive	1
2	> 5-20	Low	Andosol, laterite, grumusol, podzol, podzolic	Sensitive	2
3	> 21-50	Moderate	Brown forest land, mediteran land	Moderate	3
4	> 51-100	High	Latosol	A little sensitive	4
5	> 100	Very high	Alluvial, planasol, grey hydro morph, laterit groundwater	Not sensitive	5

Table 2. Slope and land use parameter [16].

No.	Slope (°)	Land use	Category	Score
1	< 14	Secondary dryland forest	Low	1
2	15 - 24	Farm and forest	Rather low	2
3	25 - 44	Settlement	Moderate	3
4	45 - 64	Agriculture, land	Rather high	4
5	> 65	Rice fields, grass	High	5

Table 3. Weighting parameter [12].

No	Parameters	Score
1	Slope	40%
2	Land use	30%
3	Land type	20%
4	Daily rainfall	10%

Table 4. Vulnerability level for landslide [13] .

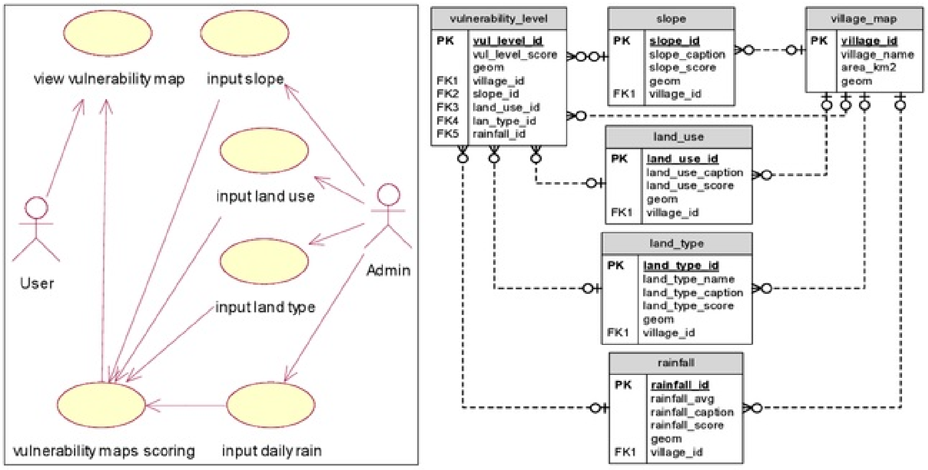
No.	Cumulative score	Vulnerability level
1	≤ 2,5	Low vulnerable
2	2,6 - 3,6	vulnerable
3	≥ 3,7	Highly vulnerable

2.2. System and software design

The locations studied were in Pulung Subdistrict, Ponorogo Regency, and for data analysis and processing at the University of Darussalam Gontor. Tools in this research are using computer hardware and software such as PHP language programming, ArcGIS Map, database PostgreSQL, Map server for windows as a server, and pmapper as a framework).

The process of SIG image (Fig. 2) in these researches divided into three different steps:

- Input data, admin, inputted main data such as new user, village information, slope, land use, land type, and rainfall.
- Calculation of landslide occurrence, these processes are continuously system from the first step. All stored data are analysed and figured an image of landslide probability.
- Searching and map appearance, the process of map searching based on keywords will be displayed and categorised on a different colour as a legend. The image represented by landslide probability in all area of Pulung subdistrict. The map, including the level of hazard, slope, land use, land type, and daily rainfall.



(a) Use Case Diagram of the proposed systems. (b) Database relational design of Pulung SIG for landslide prediction.

Fig. 2. Use case and database relational design of Pulung SIG for landslide prediction.

2.3. Implementation and unit testing

The results have appeared in Fig. 3. The main page contains eights submenu, which is a home admin, list of villages, slope, land use, rainfall, landslide potential, and user table. Since admin opened the system through the website, it will display as all data of villages identities, slope land used, landslide and rainfall. All the data are upgradeable when new data are different from inputted databased.

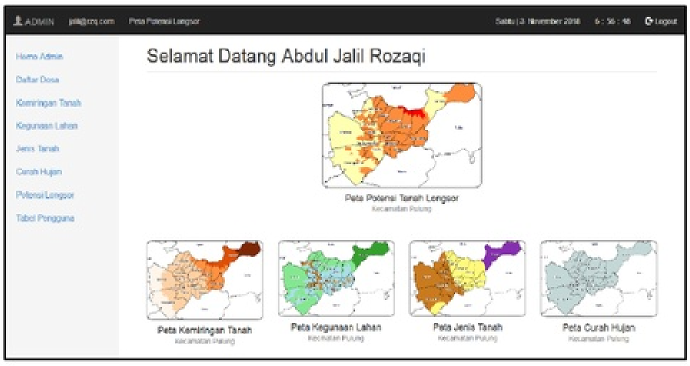


Fig. 3. The village identities of Pulung sub-district .

Fig. 4 is one menu of the admin page. The list namely is village data to input information of the village. The village information such as village name and village area (km ^{2}). All data is editable based on the geographical division of Pulung sub-district in Ponorogo regency.

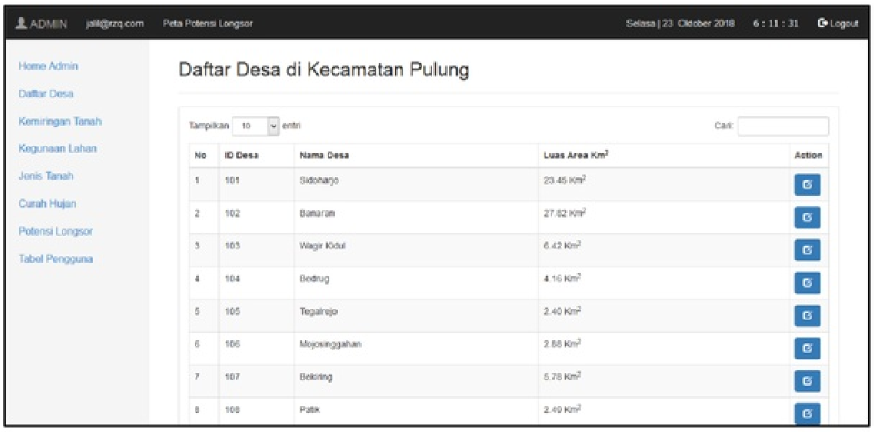


Fig. 4. The home admin to input the villages data of Pulung sub-district.

The sub menu of village identities for Pulung subdistrict (Fig. 5) are divided by different colour. The geographical site of Pulung permanently based on the geographical division of Ponorogo regency. So far, no information about new updated geographic.

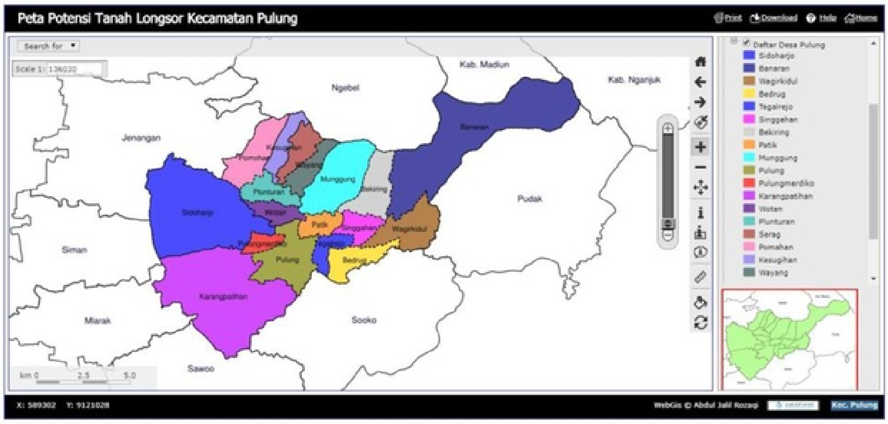


Fig. 5. The village identities of Pulung sub-district.

2.4. *Integration and system testing*

If all parts and requirements for system specifications are met, the integration stage can be continued. Data that has been entered on the admin page will be visible directly on the front-end menu. In this part of the system, the data is tested directly by the user.

2.5. *Operation and maintenance*

In the last part of this Web-GIS system are operation and maintenance. All data starts from the map, database, program code uploaded to the web server directly and serves the actual user. Furthermore, the Ponorogo BPBD can try and see instantly so that the data entered is valid. So that the information on this map can be useful for the community, especially in Pulung sub-district.

3. Result and Discussion

The projection of the landslide in Pulung after blended four parameters divided into two main groups. The first group has the samely potential for the low, moderate, high and very high level of rainfall (Fig. 6) and the second group since blended on to very low or no rain (Fig. 7). The figures give input to landslide with 10% of the daily rainfall parameter ("Curah Hujan"). The slope has a percentage of 40% ("Kemiringan Tanah"). The land use as a percentage of 30% ("Kegunaan Lahan"), and lastly, the land type has a rate of 20% ("Jenis Tanah").

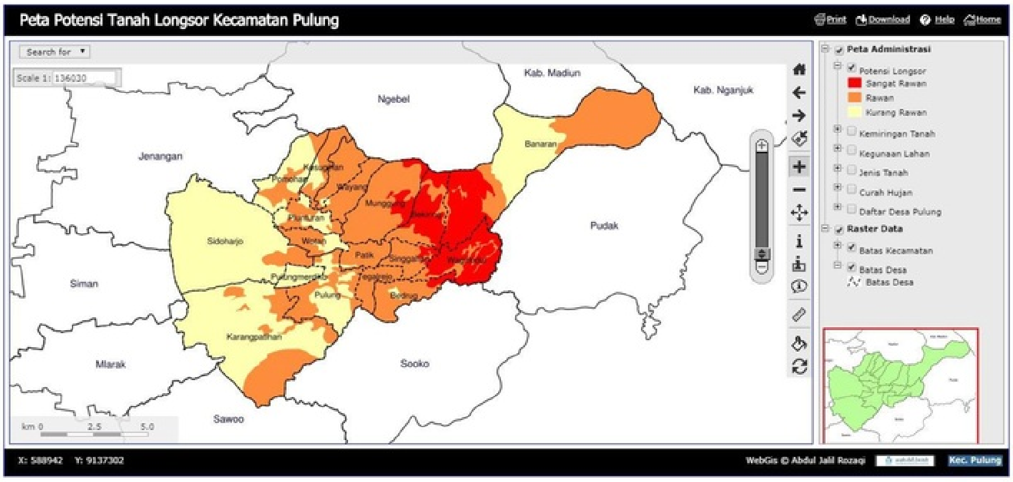


Fig. 6. Prediction of Landslide when rain in low, moderate, high and very high based on Indonesian Geological Institution.

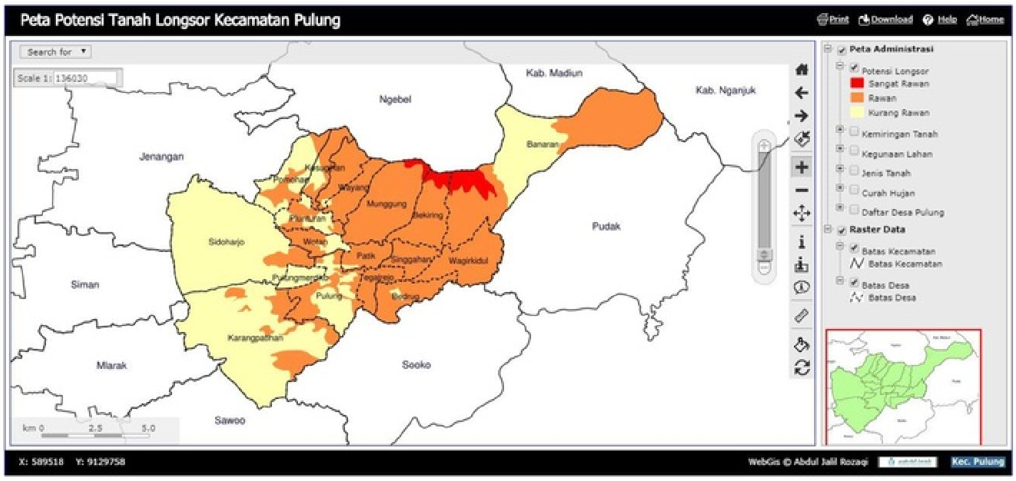
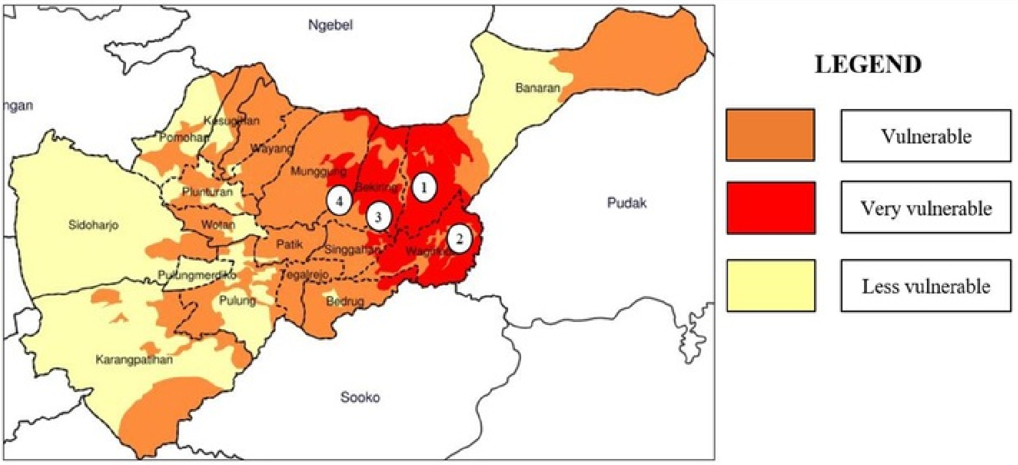


Fig. 7. Prediction of Landslide when very low or no rain based on Indonesian Geological Institution.



Landslide susceptibility when rain in low, moderate, high and very high.

(a) Location (1) Tangkil hamlet, Banaran village [14].

(b) Location (2) Bangunsari hamlet, Wagirkidul village [6].

(a) Location (3) Bekiring village [7].

(b) Location (4) Puthuk Tranjang hamlet, Munggung village [8].

Fig. 8. The four landslides occurred in Pulung sub-district.

Fig. 8 shows the location (1) the landslide happened in the village of Banaran, due to the high level of rainfall [14, 20]. In location (2) the landslide occurred in the village of Wagirkidul, due to triggered by high rainfall within four hours [6]. In location (3) The landslide happened in the village of Bekiring due to high rain [7]. In location (4) the landslide happened in the village of Munggung due to highly rainfall in one night [8]. The landslide location in the village of Bekiring, Munggung, Banaran, and Wagirkidul includes as a potential level of "highly vulnerable". Based on previous research with four parameters used by Kusratmoko [12] and Purba [11] proves that the percentage of weighting parameter is feasible to use. This research demonstrates that the prediction of a landslide in Pulung sub-district when daily rain in the category of low, moderate, high and very high is accurate.

4. Conclusion

The GIS-based on the web gives an updateable condition of geography such as in Pulung. This application also provides real-time prone maps based on daily rainfall. The percentage of the parameter (daily rainfall, slope, land use, and land type) is feasible to use. The features of the app are user-friendly, which covers some back end and new user. These model GIS platforms may be used for other areas since no different parameter's input in the system. In case more parameters are inputted this platform need to be improved for optimum performance. Further research needed to involve parameters of past data in the system to finest prediction.

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