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Analysis Geological and Geophysical Data for Prediction Landslide Hazard Zone with Weight of Evidence Method in Pacitan District East Java

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Abstract

Pacitan district have an interesting anomaly. Every time mostly impacted by disaster especially landslide. Landslides in their various forms are common hazard in mountainous terrain, especially in seismically active areas and regions of high rainfall. Landslides are one of the most common natural hazards in the Southern Range East Java terrain, causing widespread damage to property and infrastructure, besides the loss of human lives almost every year. The aim of this study predicted the potential landslide using Weight of Evidence Method. The geological data used lithological data, structural data, contour data and, alteration. Results from this data analysis are six evidence maps, such as NE-SW lineament, NW-SE lineament, host rock, heat source, kaolinite alteration and iron oxide alteration maps. The geophysical data analysis the distribution of rock density to interpretation the landslides. Evidence maps were analyzed by weight of evidence methods to result in favorable maps where the validity was tested using conditional independence (CI), the pairwise and overall tests. Then, the analyses produced a posterior probability map of the landslide. Posterior probability map (mineral potential maps) was validated by checking field. Posterior probability map (after validation) or favorable map predicted approximately favorable zone and non-favourable zones. Favorable zones of Potential Landslide Hazard Zonation, are divided into three classes. They are high-potensial hazard, moderate hazard and low hazard.

Keywords: Pacitan, GIS, Weight of Evidence, Landslide

1. Introduction

Pacitan district have an interesting anomaly. Every time mostly impact by disaster especialy landslide. Landslides in their various forms are common hazard in mountainous terrain, especially in seismically active areas and regions of high rainfall. Landslides are one of the most common natural hazards in the Southern Range East Java terrain, causing widespread damage to property and infrastructure, besides the loss of human lives almost every year. Appropriate management measures taken at the right time will reduce the risk change of potential landslides. In order to prioritize the area for hazard-mitigation efforts, it is beneficial to have a Potential Landslide Hazard Zonation (PLHZ) map or Landslide Susceptibility Map (LSM) prepared to depict the ranking of the area based on actual and/or potential threat of slides in future. Any approach towards LHZ would require identification of the conditions leading to slope failure, their systematic mapping and evaluation of their relative contributions to landsliding in the area. LHZ mapping is being carried out using qualitative or quantitative approaches.

The qualitative methods essentially depend on expert opinion in dividing an area into different zones of varying landslide susceptibility. Using an training point area of existing landslides, the expert can assess the hazard of the area by identifying regions of similar geological and geomorphological conditions, geophysical and qualitative methods for assessing landslide hazard, likely to have landslides in the future by correlating some of the principal factors that contribute to landslides with the past distribution of landslide area (Yalcin, 2008). It associates on the stated geological principle that “the past and the present are the keys to the future”. That is, future landslides are most likely to occur in the same conditions that sight to past and present landslides (Dai and Lee, 2002).

2. Research Methods

This study uses the “weights of evidence” (*WofE*) method, which was first developed by Bonham Carter (1994), for use in mineral potential assessment for the mining industry in Nova Scotia, Canada and applied to landslide susceptibility analysis (Westen, 2003), it has been successfully used for this problem in many different and diverse study areas (Dai and Lee, 2002; Gulla *et al,* 2008). During early experimentation (in this study) with these techniques it became obvious that the terrain variables that act as control factors in the occurrence of landslides are very different across the study area.

2.1. Study Area

The study area located in Pacitan district, the west part of East Java Province (Figure 1) is a hilly region with high and steep topography, only a few places that form the plains. The administrative of Pacitan includes 12 subdistricts.

Figure 1. The research location in the shaded gray, Pacitan District, East Java.

2.2. Data

In addition to Lithological data, structure, and satellite images, other data required in further processing are the hardcopy of the geological map of Pacitan district, landslide data compilation and alteration elaboration with slope, rainfall, and change to geophysics, and as well as earlier research.

2.3 Data Processing

GIS modeling was discussed in the method. The resul of the spatian pattern were discussed in result and discussion section (Taki, H.M., & Lubis, M.Z. (2017). processing is using some software satellite imagery processing softwares and geographic information system (GIS) that consist of ENVI 5, Arc.GIS 9.3, Map Info 10 Discover 12, Global Mapper 11 and Microsoft Excel 2010. The whole data then converted into the local projection of Pacitan WGS 1984 with the coordinate system of latitude and longitude (long-lat) units of degrees, minutes and seconds.

Landslide sample locations

About 313 landslide data compilation from BPBD Pacitan District was February 2018 and Regional Mapping after Syclon Tropic “Cempaka” were November 2, 2017. The data used is then divided into two parts, the first is used as a model for the deposit and the rest is used as a validation point.

Geological Map Data Processing

The geological map using earlier data, scale 1:25.000 consisting of local lithology (Widiasmoro, 2003 in Hidayah, 2015). The major lithological units (Fig.2) that based on general character closely linked in landslide area are generally dominated by volcanic clastic rocks Oligo-Miocene age. It has been observed that landslides are common in the area dominated by polymic breccias unit, volcanic sandstone unit, microdiorit unit, the lava flow breccias unit and andesite-dacite unit (Widiasmoro, 2003 in Hidayah, 2015). The presence of weak planes makes the rocks weaker and thereby facilitates slope instability.

The geological structures which exist in the geological map are also digitized so that at the end it can be used as the consideration of Data Elevation Model (DEM) structure delineation.

Lineament Analysis

Traces of faults/fractures which appear as linear to curvilinear features (lineaments) on the DEM, image are considered as important geological structures which influence landslides. The process of delineation of geological structure performed manually (on screen) by dragging a line on the areas that are considered to have certain characteristics, by changing the solar radiance direction on the angle of radiation in 0 °, 45 °, 90 °, 135 °, 180 ° and then the whole map is combined into one (fusion). Results of structure derived from the former geological map which is combined with the map of Hillshade DEM, eventually it can be determined the confirmed alignment as the new geological structure and lineament as the results of the manual on the hillshade DEM map. The result can be identified how far the relation between the presence of a landslide as well as geological structure.

Regional Anomaly Gravity

Gravitational data used are secondary data from topex.ucsd.edu. It is processed at map of Complete Bouguer Anomaly (CBA) (Fig. 5). CBA is the interpretation of subsurface condition in the research area. The gravity acceleration value is 80-205 mgal divided into three types of anomalies, namely: high, medium and low anomaly. The Areas which have a high anomaly of 155-205 mgal in the elevation of about 750-1150 mdpl be composed by intrusive rocks. It is shown with the color contour yellow to red. The medium anomaly with a gravitational anomaly value of about 120-150 mgal is dominated by weathered weathering rocks in the elevation of 250-650 mdpl. It shown by green contour. The low anomaly which worth 80-115 mgal, which shown by blue color in low elevation area less than 100 mdpl, is the lake to sea with a thick weathered rock. In the research area is dominated by rocks with high rock density of intrusion rocks around 2.67-3.2 g/cm^3 which is overlain by rocks with low-density 2.00-2.4 g/cm^3. It is composed of sedimentary rock. The areas prone to landslides occur in zones that have significant contours (high to low) of anomalous change especially when it was raining.

Geomorphological

The study area capable formed in tectonic mountainous terrain. The area dominated by hills and valley. The Grindulu River in center area research flows predominantly Northeast-Southwest and turn into north-south relative, and v-shape river valley, and high run-off indicates the younger to mature geomorphological staged. The elevation varies contour from 0 to 1025 m amsl.

Landuse cover

The land cover map of the area has been prepared with supporting from B.I.G (Indonesian Spatial Agency) figure 4.

Distance to road

It has been observed that many landslides occur close to the road. It is possible that the slope destabilization has been caused either by the widening of the roads or by the loss of support due to the removal of material from the lower portion of the slopes during road construction

2.4 Analysis and Interpretation

The evidential themes can be integrated together to find the combined influence of the different input parameter classes. The posterior probability of each unique combination of input parameter classes can then be estimated, provided the themes are conditionally independent with respect to the occurrence of landslides. The evidential themes have been combined pair-wise and the conditional independence (CI) has been tested in each pair which is the ratio of observed number of slide points (n) to the predicted number of slide points (T).

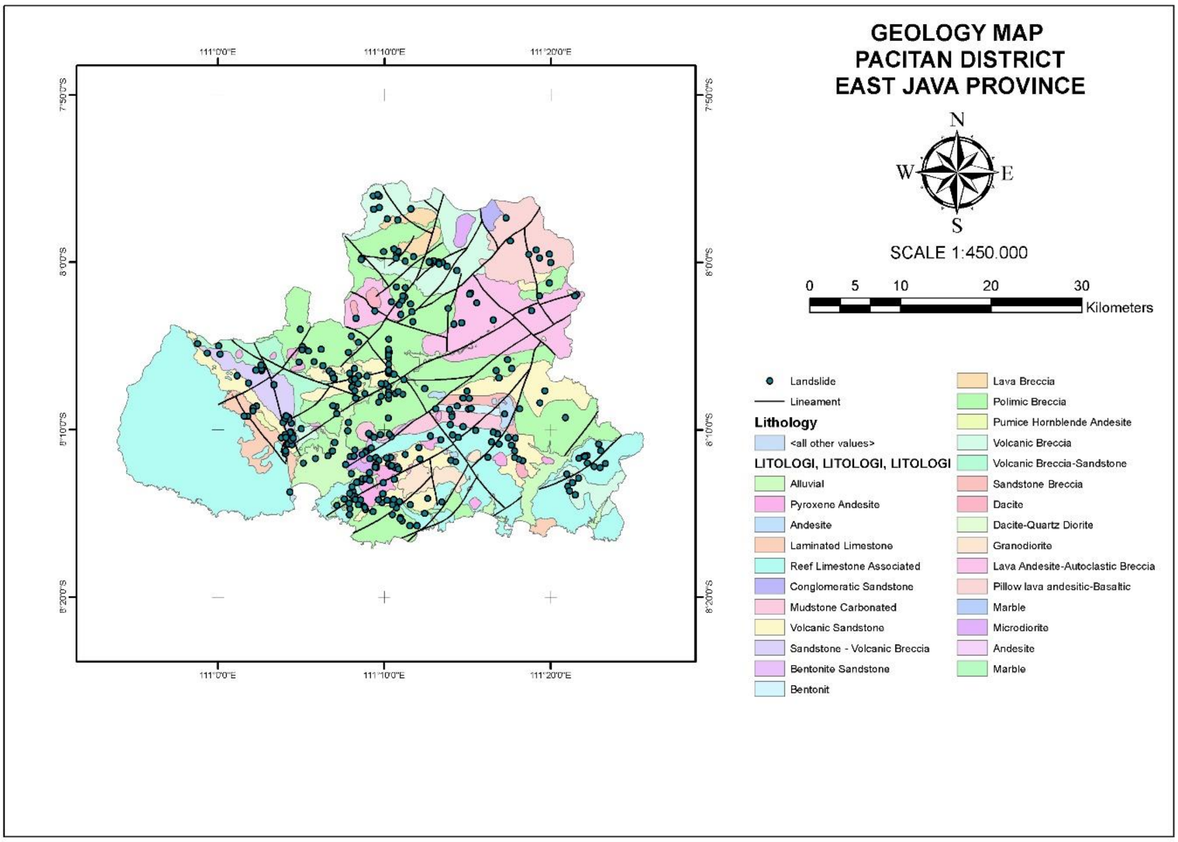

Figure 2. Geological Map showing the major faults triggering landslide

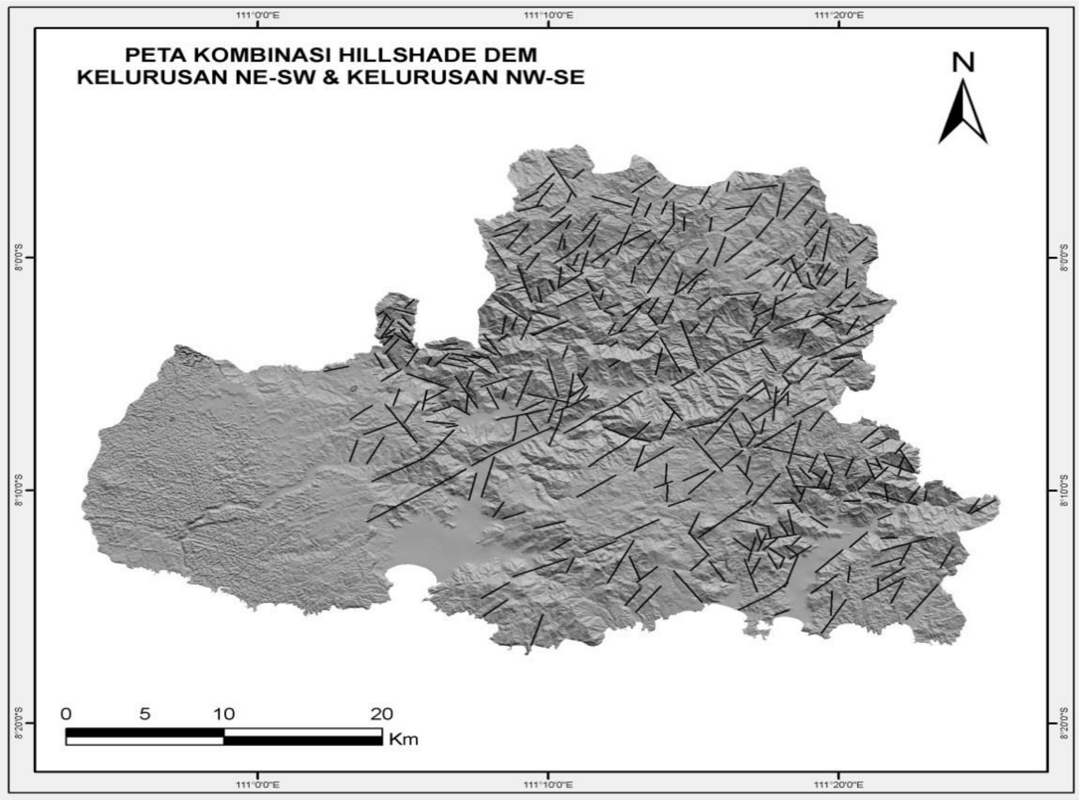

Figure 3. Hillshade DEM 300^0 ,0^0, 45^0 , 90^0 combination map, and lineation from manual on screen

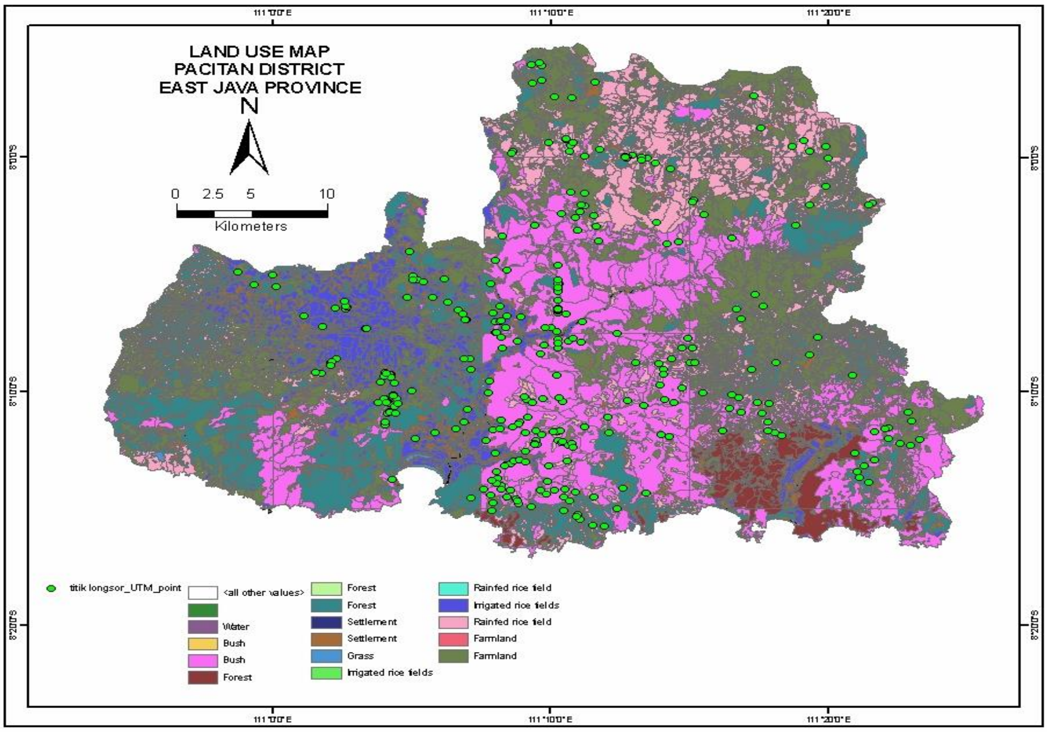

Figure 4. Land use cover map modified from B.I.G (Indonesia Spatial Agency).

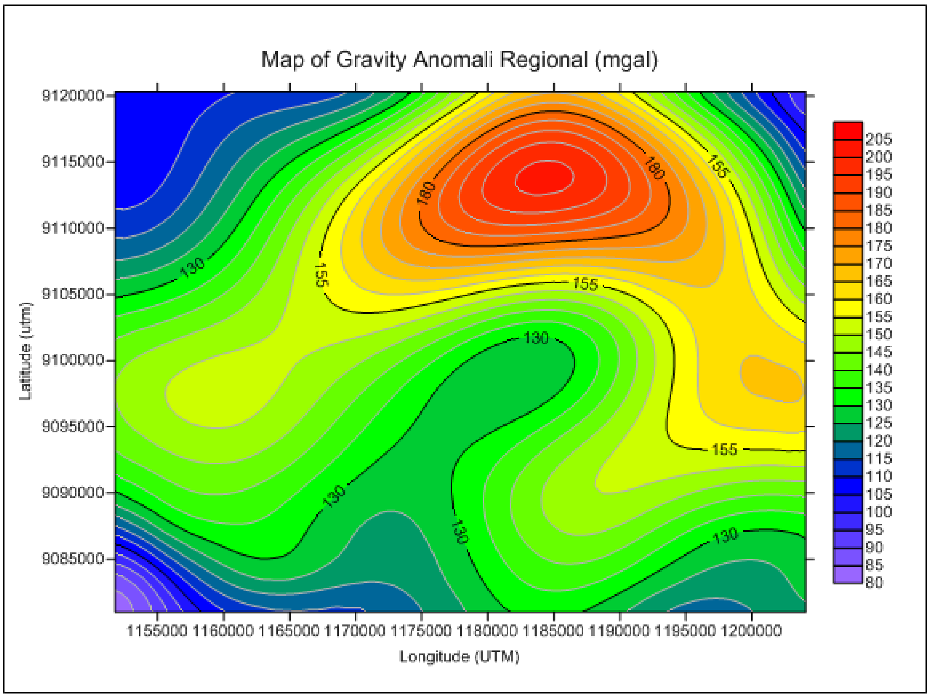

Figure 5. Map of Anomaly Gravity Regional, Pacitan District, East Java

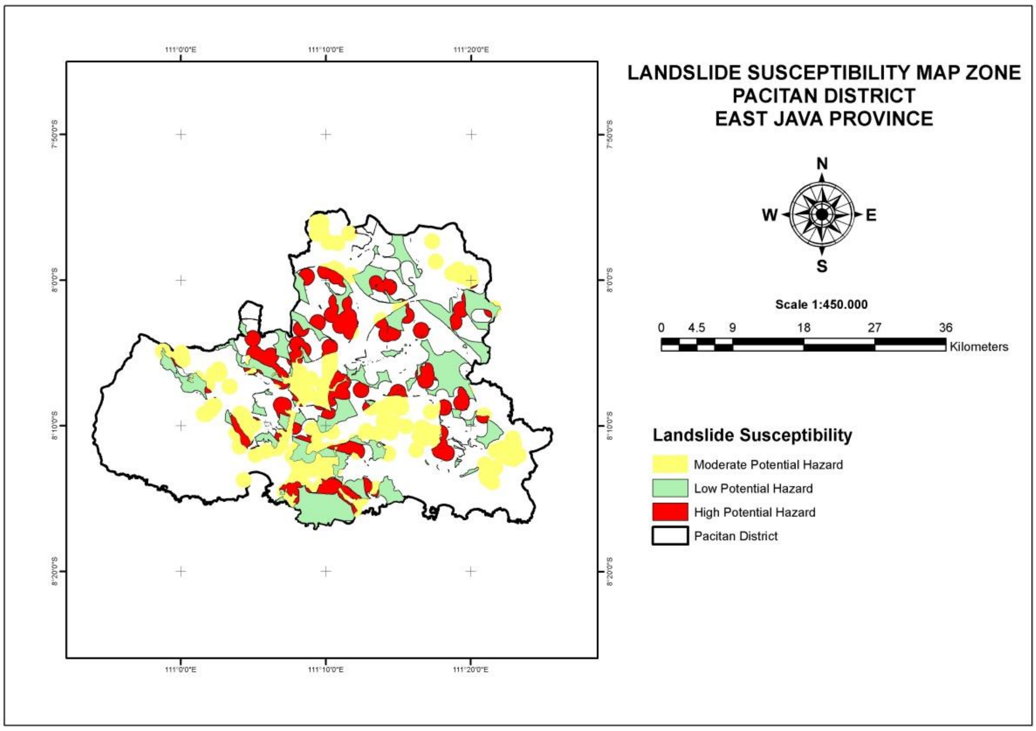

Figure 6 .Landslide Susceptibility Map of Pacitan District/Potential Landslide Hazard Zonation (PLZH). The model is based on the calculation of positive W+ and negative W− weights, which magnitude depends on the observed association between the RV and the PV.

The data preparation, archiving and simulations were performed in ArcGIS 9.3 GIS environment. An indirect approach based on statistical models of spatial analysis was used to quantify the susceptibility. The susceptibility is defined as a space probability of landsliade occurs in an area for different local environmental conditions (Maquaire, 2002). The susceptibility has been simulated by a model based on the theory of evidence. The weight of evidence is a quantitative „data-driven" method used to combine datasets.

The method uses the log-linear form of the Bayesian probability model to estimate the relative importance of evidence by statistical means. This method was first applied to landslide susceptibility mapping by (Van Westen, 1993; Van Westen and al.,2003; Suzen and Doyuran, 2004, Yannik Theiry and al., 2006. Prior probabilities (PriorP) and posterior probabilities (PostP) are the most important concepts in the Bayesian approach. PriorP is the probability that a TU (terrain unit) contains the RV (response variable) before taking PVs (predictive variables) into account, and its estimation is based on the RV density for the study area. This initial estimate can be modified by the introduction of other evidences. PostP is then estimated according to the RV density for each class of the PV. Formula below:

$$W^{+} = ln\frac{P(B \mid RV)}{P(B \mid \overline{RV})} \quad (Eqs.1)$$

$$W^{-} = ln\frac{P(\bar{B} \mid RV)}{P(\bar{B} \mid \overline{RV})} \quad (Eqs.2)$$

In Eqs. (1) and (2), B is a class of the PV and the overbar sign „¯" represents the absence of the class and/or RV. The ratio of the probability of RV presence to that of RV absence is called odds (Carter, 1994). The WOE for all PVs is combined using the natural logarithm of the odds (logit), in order to estimate the conditional probability of landslide occurrence. When several PVs are combined, areas with high or low weights correspond to high or lowprobabilities of presence of the RV.

$$W^{+} = ln\,\{P\,(VP/VM))/(P\,(VP/\overline{VM})\,\} \text{ (Eq.1)}$$

$$W^{-} = ln\,\{P\,(\overline{VP}/VM))/(P\,(\overline{VP}/\overline{VM})\,\} \text{ (Eq.2)}$$

Mapping of susceptibility occurs in several steps, the first corresponds to the statistical analysis of the landslides observed (identification and inventory of landslides), the second step is the characterization and identification of factors affecting (parameters predisposition) lithology, fracturing, slope, precipitation, etc.. The third is the evaluation of the conditional independence of predictive variables. The fourth is the application of the bivariate approach by the theory of evidence.

2.5 Result

Different weights can be summed calculated using the natural logarithm of odds called logit. In this case, the contrast C (C = W + - W-) gives a measure of spatial association between the predictors and landslides (Yannick Thiery and al.2005). This contrast has a value of zero when these two variables are completely independent. The contrast value gives the first overview to accept or reject a predictor in estimating the spatial correlation between this and the landslides.

Calculations of values of W + and W- for all selected variables used to calculate the posterior probability, which updates the prior probability. When multiple predictors are combined, areas that have a weight higher or lower respectively correspond to a greater or smaller probability of finding the landslides.

This statistical model is introduced in the ArcGIS 9.3 with Map Info 10.5 and Microsoft Excel 2007. The model calculates the prior probabilities, posterior probabilities and hypothesis testing using chi-square test, conditional independence , and pairwise test. The procedure to determine the best combination is made add one to one every predictor.

The maps show a good agreement with the landslide inventory map. The surfaces of high, moderate, low and null susceptibility something that is quite understandable given the extent occupied by these sites. This leads us to propose to incorporate other factors namely hydrographical networks, seismicity and the anthropic factor in its various aspects (construction of roads, quarrying, earthworks, etc.).

The analysis of the susceptibility map developed shows that the high susceptibility is largely concentrated in northern and west parts of the study area where local environmental conditions are very favourable to the trigging (combination of a slope gradient> 25 °, Relief delivered, strong fracturing, extremely degraded soils or dissected, the absence of forest and vegetation or poorly maintained), high potentially hazard about 140 km^2, moderatly hazard about 238km^2 and low hazard about 194 km^2

2.5 Discussion

The landslide susceptibility work is based on the assumption that "the past is key to the future", and that historical landslides and their causal relationships can be used to predict future ones. As soon as there are changes in the causal factors (e.g. a road with steep cuts is constructed in a slope which was considered as low susceptibility before (westen iet al., 2006).

This study has demonstrated the necessity of using specific procedures for landslide susceptibility assessment by bivariate methods, especially at 1:25000 scale in the Southern Mountain, East Java. The thematic maps introduced in the model represent slope gradient, lithology, land use cover, lineament controlled fracturing, and anomaly gravity.

The susceptibility maps describe the conditional probability of future landslide occurrences, which depends on the values of unstable landform densities, it proves to be best suited to guide choices in implementation of development sites, the level of urban extensions, and that at the layout of new roads and highways in the national development program in the East Java Province.

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