Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 7, Issue, 08, pp.19782-19786, August, 2015

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

INTEGRATION OF GIS AND STATISTICAL MODELS FOR LANDSLIDE HAZARD ASSESSMENT IN WAHIG-INABANGA WATERSHED, BOHOL, PHILIPPINES

***Tomas D. Reyes, Jr.**

Bohol Island State University, Philippines

ARTICLE INFO

Article History:
Received 30th May, 2015
Received in revised form
17th June, 2015
Accepted 05th July, 2015
Published online 31st August, 2015

Key words:

Landslide,
GIS, Logistic regression,
Bivariate statistical analysis,
Hazard assessment.

ABSTRACT

The study generally aimed at integrating geographic information system (GIS) and statistical models in predicting landslide prone areas in Wahig-Inabanga Watershed, Bohol, Philippines. Logistic regression (LR) and bivariate statistical analysis (BSA) were employed to determine landslide prone areas using eleven significant landslide-related instability factors such as elevation, slope, aspect, lithology, soil order, soil type, fault line proximity, river proximity, road proximity, rainfall and land cover. The satisfactory results of model evaluation justified the application of the LR model for landslide hazard assessment. Out of eleven instability factors, only soil order and soil type were determined not significant. The first three most important instability factors based on the values of regression coefficients are elevation, slope, and lithology. Landslide hazard assessment revealed around 7,063 ha or 11.33% of the total area of the watershed has high to very high landslide hazard ratings. The study showed that GIS, in tandem with useful models, provides pertinent results which could be used as scientific basis for watershed management and land use planning in relation to landslide disaster risk reduction and management.

Citation: Tomas D. Reyes, Jr. 2015. “Integration of GIS and Statistical Models for Landslide Hazard Assessment in Wahig-Inabanga Watershed, Bohol, Philippines”, *International Journal of Current Research*, 7, (8), 19782-19786.

INTRODUCTION

Landslide, though believed to be unpredictable, usually occurs in high elevation and sloping areas. Severity is influenced by type of vegetation cover and the geomorphological structure of the soil. This geologic hazard is triggered by excessive and continuous rainfall, and seismic events. One of the most unforgettable landslide events which struck the country was that which happened in Guinsaugon, Leyte. Iin a matter of minutes, the homes and families in barangay of Guinsaugon were wiped out, buried under a mountain of soil and rock. Bohol, in particular, had experienced frequent landslides and massive erosion in the upland, and floods at lowland areas. The province’ susceptibility to landslides and floods had been recorded by the Mines and Geosciences Bureau (MGB) in 2007. There were more than 100 barangays identified prone to these hazards out of the 46 municipalities covered in the survey. Specifically for landslide events, 64 barangays within the Wahig-Inabanga watershed were rated with moderate to high vulnerability to landslides based on 13 out of 16 municipalities evaluated. The 52-hectare Mayana landslide which happened on July 13, 2005 was triggered by a surface-wave magnitude 4.9 earthquake with its epicenter recorded somewhere in Sierra Bullones on March 31, 2005. The landslide’s average slope was only about 13%, described as elongated, oriented east-west and had a total length of 1.4 km (Catane *et al*., 2005). Geospatial technology is increasingly being used in spatial decision support systems. This has been the trend since its functions and applications have been made known to the public, especially to experts, practitioners, and policy makers around the globe. In the Philippines, GIS, in tandem with remote sensing and modeling technologies, are used in many applications since the 90s from resource assessment, land use classification and mapping to environmental hazards assessment and management.

So far, the utilization of plain logistic regression model and GIS for landslide susceptibility mapping in the country was initially, and perhaps solely, conducted by Lee and Evangelista (2005) in Baguio City. The method which has been used in this present study was a modification from their work with the intention of increasing the predictive power of the LR model by initially applying the numerical values of landslide densities as class weights derived using bivariate statistical analysis (BSA) prior to the actual logistic regression analysis.

****Corresponding author: Tomas D. Reyes,***
Bohol Island State University, Philippines.

Objective

Assess the applicability of GIS and logistic regression combined with bivariate statistical analysis in determining landslide prone areas in Wahig-Inabanga Watershed, Bohol, Philippines.

MATERIALS AND METHODS

Study Site

The Wahig-Inabanga Watershed, also known as Wahig-Inabanga River Watershed Forest Reserve (WIRWFR), is the biggest watershed in the province of Bohol, Philippines. From the northwest bay of Inabanga, the river dissects the central part of the island embracing a total land area of more than 610 km^2. According to Genson (2006) and Ludevese (2010), this watershed is more or less 15.20% of the total land area of the province.

It is geographically located between 124^{o}3’36” and 124^{o}23’24” East longitude, and between 9^{o}43’48” to 10^{o}4’48” North latitude. It has two headwaters namely the Wahig and Pamacsalan Rivers and its outlet is geographically located at 10^{o}4’12” North latitude and 124^{o}4’12” East longitude. It traverses 16 municipalities such as Garcia Hernandez, Jagna, Duero, Sierra Bullones, Pilar, Alicia, Carmen, Dagohoy, San Miguel, Sagbayan, Trinidad, Talibon, Jetafe, Buenavista, Danao and Inabanga. The whole watershed is comprised of eight sub-catchments namely: Pamacsalan, Wahig, Hamoog, Mas-ing, Malitbog, Isumod, Cansuaob and Inabanga (DENR, 2000; Ludevese, 2010).

GIS Input Files Acquisition

Thematic layers which were used in this study were obtained from several government authorities and well-known sources.

Landslide Inventory

The identification and mapping of existing landslides are prerequisite to perform statistical analysis on the relation between the distribution of landslides and influencing parameters (Saha *et al.*, 2005). Any landslide susceptibility or hazard assessment must begin with the collection of information on where landslides are located. Collection of information is done in many forms. Most of the researchers utilized aerial photographs and satellite image interpretation to locate landslides. Others employed the same interpretation method in tandem with ground validation. In this study, image interpretation and extensive field surveys were performed. The ortho-rectified Spot 5 Image (scene: 313330) acquired from NAMRIA was used to delineate visible landslides. Ground validation was carried out during the field surveys. The complexity of image interpretation for a huge watershed like Wahig-Inabanga watershed led the conduct of extensive field surveys. This was done mostly in, but not limited to, areas within the watershed. Major [= deep-seated] and minor [= shallow] landslides along the buffer zone and near, yet outside, the boundary were also considered. A total of 215 landsides were recorded during the series of field surveys.

GIS Processing

Landslide Inventory Mapping

The geographic coordinates taken in the field were retrieved from GPS receivers using Garmin Base Camp software (version 4.2.1). Coordinates were identified as to those taken around the corners of huge and medium-sized landslides and those taken at the center of small landslides and classified as to size of the landslides.

To prepare the landslide inventory map, coordinates were all geo-processed in Arc Map. Polygon shape files were created for landslides with corner coordinates, while buffer function in Arc Map interface was used for landslides with coordinates taken at the center. These, including the digitized landslides from Spot 5 Image, were all clustered into one shape file using merge function and then projected to WGS84_UTM. To complete the landslide inventory map, the projected landslide polygons were combined with the Wahig-Inabanga Watershed mask and was finally converted to raster format with a pixel size of 10-m. The landslide pixels were given a value of 1 and non-landslide pixels as 0.

GIS Input Maps Preparation

The acquired GIS input files were used to create 11 thematic layers of landslide-related instability factors. The DEM from ASTERGDEM website was used to generate geomorphological layers such as elevation, slope and aspect. These were all prepared employing the surface analysis function of spatial analyst tool in ArcGIS. Kriging interpolation function of spatial analyst tool, on the other hand, was used to produce rainfall map, while simple ArcGIS processing tools were applied to prepare the other instability input parameters both in vector and raster (10m x 10m) formats. All of the thematic layers were registered to one common geographical reference.

Sample Selection

The rasterized landslide inventory map facilitated the preparation of combined landslides and non-landslides vector grid map with an aid of Hawth’s Analysis Tool, a freeware ArcGIS extension. Landslide and non-landslide samples selection was also performed from the vector grid map using the same tool. Two sets of samples were prepared, one for model generation and another for accuracy evaluation.

GIS and Statistical Analysis

The landslide hazard assessment using logistic regression (LR) adopted in this study followed the method of Ayalew *et al.* (2005) and Ayalew and Yamagishi (2005) which required class and factor weighing.

Bivariate Statistical Analysis (BSA)

BSA was applied to the first set of samples to determine class weights through the calculation of landslide densities on input parameter classes.

Overlay analysis and extract by samples in ArcGIS were used in this respect and the output dbase file was imported in Microsoft Excel for landslide density computation.

Logistic Regression Analysis

Logistic regression was used to define factor weights. The result of BSA in excel was imported in SPSS and the method of stepwise backward selection was used. The outputs of the regression analysis included the measures of model fit, model prediction probability and regression coefficients. The regression coefficient of each predictor [=parameter] served as the factor weight.

The model equation adopted in the study is shown below:

$$Y = b_o + b_1 (P_1) + b_2 (P_2) + b_3 (P_3) + \ldots + b_{11} (P_{11})$$

where: Y= landslide occurrence (presence or absence)

b_o=constant value (Y intercept)
$b_1, b_2, b_3 \ldots b_{11}$=regression coefficients
$P_1, P_2, P_3 \ldots P_{11}$=input parameters or instability factors

Below was the equation used to compute for the probability of landslide event:

$$P = \Pr[Y=1] = 1/1+e^{(-X*B)}$$

where: P= probability of landslide occurrence

$=\Pr[Y=1] = 0$ to 1

e=exponential function

X*B=Y value of the logistic regression function

RESULTS AND DISCUSSION

Model Assessment

Out of 11 parameters, only soil order and soil type were found not significant and were eliminated in the final model. Model rerun identified elevation as the most significant parameter based on the value of regression coefficient [B=0.007162]. This was followed by slope and lithology (Table 1).

Model assessment in SPSS was very satisfactory. The model of goodness of fit was significant [p-value < 5%] and the pseudo R^2 was relatively high [pseudo R^2 = 0.607] (Table 2). The pseudo R^2 value 0.607 means that the 60.7% of the total variation in the data is explained by the model.

According to Clark and Hosking (1986) as cited by Ayalew *et al.* (2005) and Ayalew and Yamagishi (2005), a pseudo R^2 greater than 0.2 shows a relatively good fit. The prediction probability was also determined very high [PredProb = 83.2%] (Table 3).

Landslide Hazard Assessment

Result of the landslide hazard assessment indicated that more than 60% of the total area of the watershed (about 38,180 ha) was identified to have very low probability of landslide occurrence. About 16.63% or 10,360 ha had low landslide hazard, while roughly 6,692 ha or 10.74% was estimated to fall under the moderate landslide class.

Conversely, high and very high landslide ratings were predicted for areas mostly situated on the upper elevations of the watershed, as shown on Figure 1, having 4,101 ha and 2,962 ha, respectively.

Table 1. Logistic regression output for the regression coefficient estimation using the model of significant parameters

Predictor (Factor)	Regression Coefficient (=factor weights) *B*	Std Error	P-Value
Elevation	0.007162	0.001	0.000
Slope	0.004933	0.001	0.000
Aspect	0.002949	0.001	0.000
Lithology	0.003533	0.000	0.000
Fault line proximity	0.000825	0.000	0.000
River proximity	-0.001247	0.000	0.000
Road proximity	-0.001002	0.000	0.000
Rainfall	0.000717	0.000	0.000
Land cover	0.001842	0.000	0.000
Constant	-6.069435	0.535	0.000

Table 2. Summary comparison of model fit statistics of the logistic regression function

Statistics	Value
Goodness of Fit	
Omnibus Test Chi-square	1290.114
P-value	0.000
Model Chi-square	
Hosmer and Lemeshow Test	17.330
P-value	0.051
Pseudo R^2	
Nagelkerke R^2	0.607

Table 3. Classification table showing the results of the landslide model prediction probability

Model	Observed	Predicted		Percentage Correct
		Absence	Presence	
Overall Percentage				83.0
LR with significant factors	Absence	879	188	82.4
	Presence	169	889	84.0
Overall Percentage				83.2

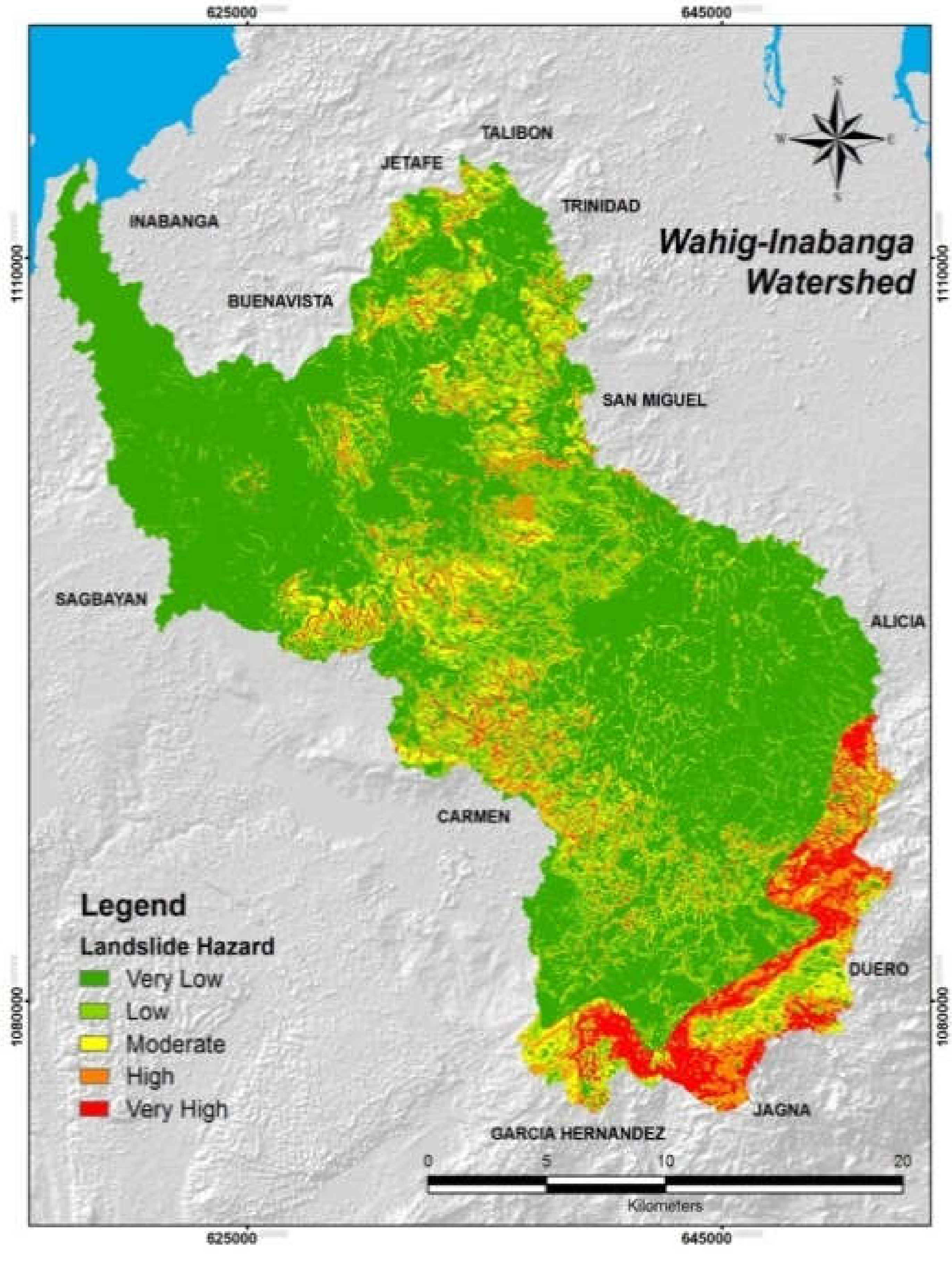

Figure 1. Landslide hazard map generated from logistic regression

Conclusion

Logistic regression, with bivariate statistical analysis, is best applied if landslide inventory is available. The landslide inventory aids in the quantitative assessment of landslide prediction probability and serves as a means of determining the accuracy of the model. The application of bivariate statistical analysis in determining landslide densities and the utilization of these computed densities as quantitative substitutes to nominal variables of landslide predictors simplify the logistic regression equation and the interpretation of its results.

Modeling landslide is very important to measure the relationship between each causative factor with every single landslide location. The relationship between landslide and its causative factors vary according to area, time and climate. By modeling landslide, the inherent characteristics of landslide activities can be quantified. This is very important in order to identify which causative factor plays a major or a minor role. Such information can then help the authority to plan the activities and land utilization in areas prone to landslides.

REFERENCES

Ayalew, L. and Yamagishi, H. 2005. The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. Geomorphology, 65, 15-31.

Ayalew, L., Yamagishi, H., Marui, H. and Kanno, T. 2005. Landslides in Sado Island of Japan: Part II. GIS-based susceptibility mapping with comparisons of results fro two methods and verifications. *Engineering and Geology*, 81, 432-445.

Catane, S. G., Foronda, F. and JR. Tamorong, C. 2005. Assessment of Hazards Resulting from July 11, 2005 Landslide, Barangay Mayana, Jagna, Bohol: A Report to the Local Government Unit of Jagna, Bohol. Unpublished Technical Report. National Institute of Geological Sciences. University of the Philippines, Diliman, Quezon City.

Genson. I. C. 2006. Erosion and Water Resources Assessment in the Upper Inbanga Watershed, Philippines: Application of WEPP and GIS Tools. Masteral Thesis. University of Western Sydney, Hawkesbury Campus, Richmond, New South Wales, Australia.

Lee, S. and Evangelista, D. G. 2005. Landslide Susceptibility Mapping using Probability and Statistics Models in Baguio City, Philippines.

Ludevese, E. G. 2006. Land Suitability Evaluation of the Wahig-Inabanga River Watershed Forest Reserve (Bohol, Philippines) Using geographic Information System. Masteral Thesis. Visayas State University, VISCA, Baybay City, Leyte.

Mines and Geosciences Bureau (MGB), 2007. Report on Landslide and Flood Prone Areas in Bohol. Unpublished Technical Report from Mines and Geosciences Bureau, Region 7.

Saha A.K., Gupta, R.P. Arora, M.K. Sarkar, I. and Csaplovics, E. 2005. An approach for GIS-based statistical landslide susceptibility zonation - with a case study in the Himalayas. Landslides 2(1) 61–69.

****