Comparison of Existing and Modified Landslides Risk Algorithms by Development of Landslide Susceptibility Models Using GIS: A Case Study of Balakot, Pakistan

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ABSTRACT

This research study highlights two different existing and modified landslide risk algorithms for the development of landslide susceptibility models. The modified algorithm based landslide risk susceptibility model has highlighted such slope failures which possess the rate of very high velocity of the triggering at the local scale. The case study of this research is Balakot, one of the ruined city by the terrible earthquake induced landslide fissuring there in 2005. One of the previous landslide risk algorithm, developed by Varnes in 1984, was selected was modified by introducing additional parameters and criteria along with the modified landslide risk algorithm. The both algorithms entitled as mathematical models were incorporated in GIS (Geographical Information Systems) and were tested, compared and validated by the previous landslide occurred data, called as landslide inventory data. The statistical tests were applied to quantify various predicted regions in accordance of the verification of the predicted models. This comparison portrayed the significant difference in both models due to the notable difference due to significant control event parameters. It is assured that this research will help the decision makers by applying the modified algorithm based landslide susceptibility models in the field to avoid the landslide hazards for the future.

Key Words: **GIS, Landslide Inventory, Landslide Susceptibility, Risk Algorithm.**

1. INTRODUCTION

The different methods such as Heuristic, Probabilistic, Statistical and Deterministic [1-2] have been applied for studying the landslide hazard and risk. Such models based on the appropriate landslide risk algorithms prove very useful for the accuracy and reliability [3]. The various landslide risk formulas introduced, by the scholars [4-7] showed many drawbacks being subjective, uncertain, limited measure on susceptibility, empirical and complex, which badly influenced on the quality of the models. The different methods, utilizing the significant parameters, data and software not only need to concentrate on the different slope failures but also prove very beneficial for the development of the landslide susceptibility models. The various scholars have studied different types of fissuring [8] based on, one of the control event parameters e.g. speed, from the top of the hills to the plain grounds. It was ignored in past to concentrate on the risk algorithms for the development of landslide susceptibility models. Furthermore during the study of the triggering, the hazard and the risk have been overlooked. They were not studied as individual component. Mostly it has been practiced to

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develop such models by overlaying of the hazard and the risk models for prediction of the slope failures [9].

This research paper aims to focus on the modification of the very prominent algorithm for prediction of the landslide hazards based on the specific types of the slope fissuring unless it has been practiced to concentrate the general types of the landslides. In this study, two different landslide susceptibility models have been developed depending on the general and the specific types of the slope failures. After that, the models are compared by using the statistical method using log difference graph. The previous landslide risk algorithm developed by Varnes in 1984, was lacking the criteria, while in this research, the modified landslide risk algorithm has developed appropriate landslide risk criteria and parameters. Furthermore, one of the mostly applied method, known as Heuristics has been applied for obtaining various landslides threats categories including the landslide hazard and the landslide vulnerability in these models.

2. CASE STUDY OF THE MODELS

Both of the mathematical (existing and modified models) were applied on one of the most prominent case study, Balakot region; subdivision of Mansehra District in the north territory of Khyber Pakhtoonkhawa province in Pakistan. Balakot is mountainous area, totally covered with mountains of Himalaya [10] while the great fault line [11] is crossing from the center of this city along the Kunhar river. This river crosses through the city along the roads and human population which develops the erosion to the bottom of the mountains. This whole region is seismic [12] and very earthquake prone. The earthquake occurred in past in this region in 2005 [13] was with magnitude of 7 MW Scales [14].

3. METHODOLOGY

The methodology of this research is into three parts which are mentioned as; (1) modification of the pervious landslide risk algorithm, (2) development of landslide risk model based on the existing risk algorithm and (3) development of the landslide risk model based on the modified risk algorithm.

3.1 Modification of the Existing Landslide Susceptibility Formula

One of the very famous landslide risk formula was developed by the renowned researcher with his team [15] in 1984 which is given in Equation (1) as:

$$R_t = (E)(R_s) = (E)(H\text{x}V) \quad (1)$$

Where R_t is total risk, H is hazard, V is vulnerability, E is elements at risk and Rs is specific risk. This formula shows that the entire risk is the combination of the typical risk and their elements while the typical risk is the amalgamation of hazard and the vulnerability which are the components of the risk. There were many drawbacks in this formula as mentioned below:

- It proved inefficient to concentrate on the specific type of the slope failures by considering their different mechanical behaviors, speed, falling rate and the hydrological phenomenon.
- It also focused on the traditional parameters rather than considering new and the auxiliary parameters for developing the optimal landslide susceptibility models.

Due to the above mentioned drawbacks of this algorithm, it was improved and redeveloped as mentioned in Equation (2) as:

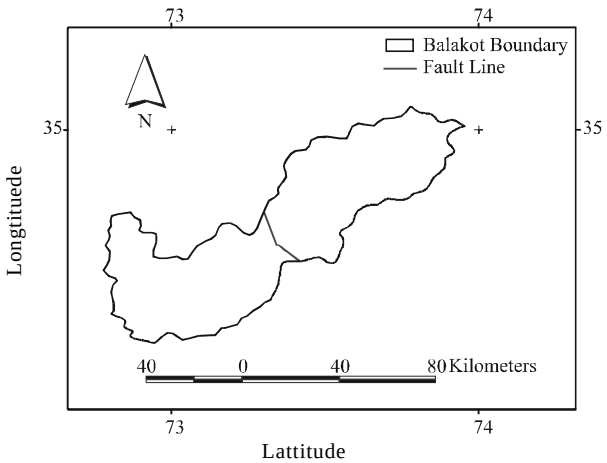

FIG. 1. BALAKOT STUDY AREA

$$R_{sl} = H_{sl} \text{ x } V_{sl} \text{ x } E_{sl} \quad (2)$$

As R_{sL} is Specific risk, H_{sL} is hazard of specific sorts of slope failures, E_{SL} is Elements at risk and V_{sL} is Vulnerability developed by the particular type of triggering. The modified formula as mentioned in Equation (2) is the combination of different components such as specific type of landslide hazard, vulnerability and the elements at risk. Furthermore, it is the combination of the mentioned elements at risk which is the incident of the particular type of the fissuring.

3.2 Landslide Susceptibility Model Based on Previous Landslide Risk Formula Using GIS

The flow chart for developing landslide susceptibility model is shown in Fig. 2.

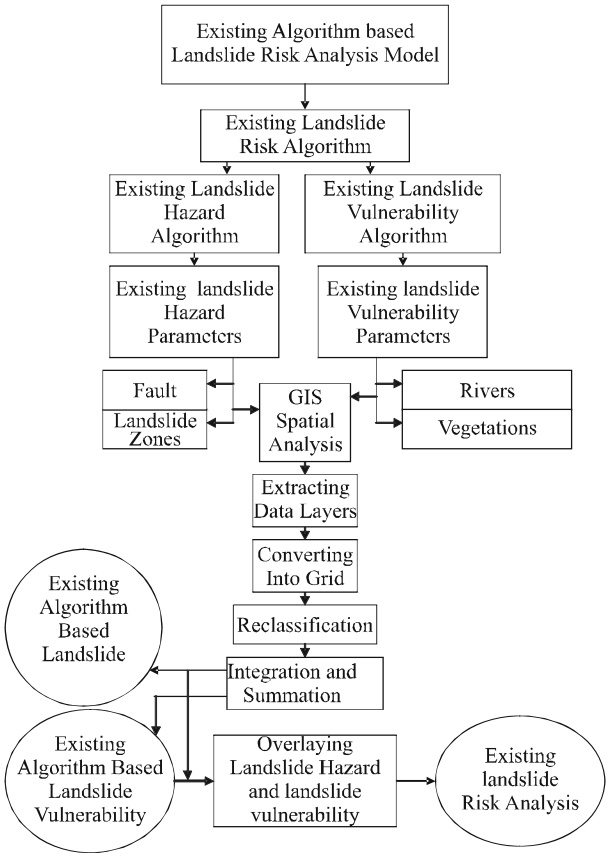

FIG. 2. METHODOLOGY FOR PREVIOUS ALGORITHM BASED LANDSLIDE RISK MODEL

The landslide susceptibility model has been developed using the pervious algorithm by considering its existing control event parameters which were seismicity and the fractures of the mountains while the vulnerability model utilized the criteria of vegetations and the hydrology. In this methodology, various parameters were utilized by using various techniques of GIS such as spatial analysis, subsetting the data themes into required data format, data conversion from vector to rastar format, reclassification of the data themes into various required data shapes and map algebra. The map algebra technique was applied on various classified data themes by adding the entire parameters and dividing the total parameters into required categories was obtained. Finally, the obtained landslide hazards and vulnerability models were overlaid to achieve the main result of landslide risk models with five classes.

3.3 Modified Algorithm Based Landslide Risk Models Methods

The methods applied for developing the landslide risk model based on the modified landslide risk algorithm are mentioned in Fig. 3. The various control event parameters of the modified landslide risk algorithm were developed for its sub models such as landslide hazard models and the landslide vulnerability model. The different GIS techniques were also applied to get the outcome of these models.

4. RESULTS

The existing algorithm based landslide risk model is comprised into three: (1) existing algorithm based landslide risk model, (2) existing algorithm based landslide hazard model and (3) existing algorithm based landslide vulnerability model.

4.1 The Existing Algorithm Based Landslide Risk Model

The existing algorithm based landslide risk model was obtained into five classes such as very high, high, moderate low and no risk as presented in Fig. 4.

4.1.1 The Existing Algorithm Based Landslide Hazard Model

The landslide hazard model was generated based on the existing landslide formula utilizing its developed parameters and criteria with five categories: very high, high, moderate, low and no hazard as presented in Fig. 5.

4.1.2 The Existing Algorithm Based Landslide Vulnerability Model

The five classes of vulnerability model based on the existing landslide algorithm were generated which are; very high, high, moderate low and no as presented in Fig. 6.

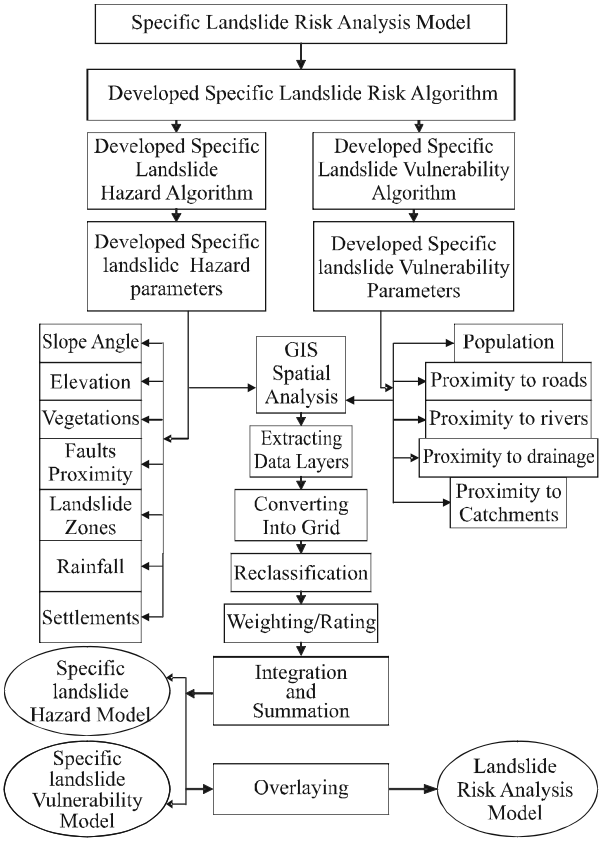

FIG. 3. METHODOLOGY FOR MODIFIED ALGORITHM BASED LANDSLIDE RISK MODEL

The modified algorithm based landslide risk model is comprised of three outcomes such as (1) Modified

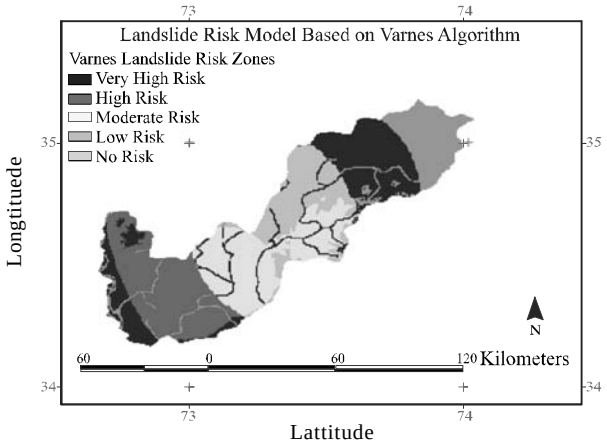

FIG. 4. EXISTING ALGORITHM BASED LANDSLIDE RISK MODEL

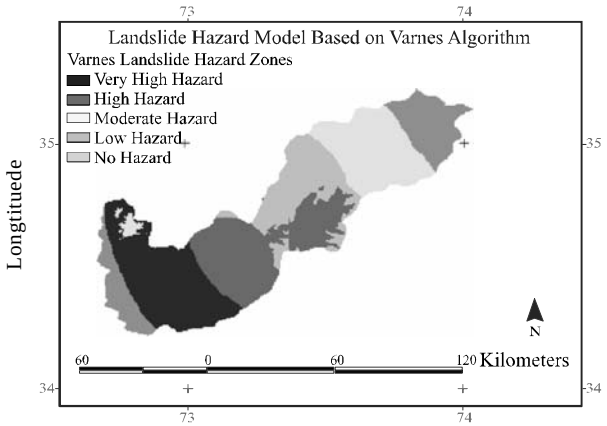

FIG. 5. EXISTING ALGORITHM BASED LANDSLIDE HAZARD MODEL

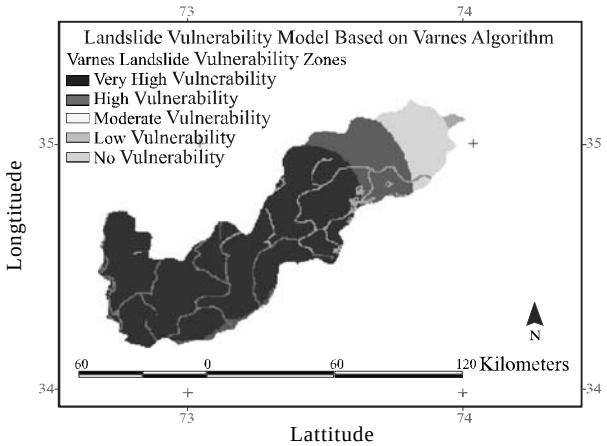

FIG. 6. EXISTING ALGORITHM BASED LANDSLIDE VULNERABILITY MODEL

algorithm based landslide risk model, (2) Modified algorithm based landslide hazard model and (3) Modified algorithm based landslide vulnerability model which are mentioned in the following sections.

4.2 Modified Algorithm Based Landslide Risk Model

The modified algorithm based landslide risk model was obtained into five classes as very high, high, moderate, low and no risk as presented in Fig. 7.

4.2.1 Modified Algorithm Based Landslide Hazard Model

The modified algorithm based landslide hazard model was obtained into five classes as very high, high, moderate, low and no risk as shown in Fig. 8.

4.2.2 Modified Algorithm Based Landslide Vulnerability Model

The modified algorithm based landslide vulnerability model was obtained into five classes as very high, high, moderate, low and no risk as shown in Fig. 9.

The both models were compared using one of the statistical test known as 2- tailed, two paired "T" test which presented the result with the value of P as 1.00 which proved the difference between these two models. Except that, the statistical test as log difference showing the marginal difference and the variation in these models were also studied as shown in as shown in Fig. 10.

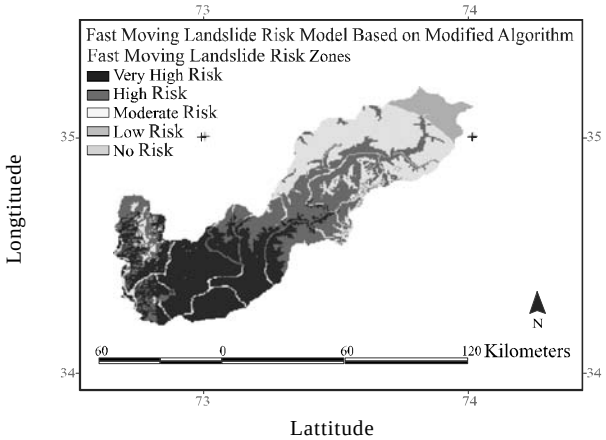

FIG. 7. MODIFIED ALGORITHM BASED LANDSLIDE RISK MODEL

The variation in the graph showing the value of Log 10 in various predicted regions between these models proved the significant difference between the existing and the modified algorithm based two different developed landslide risk models.

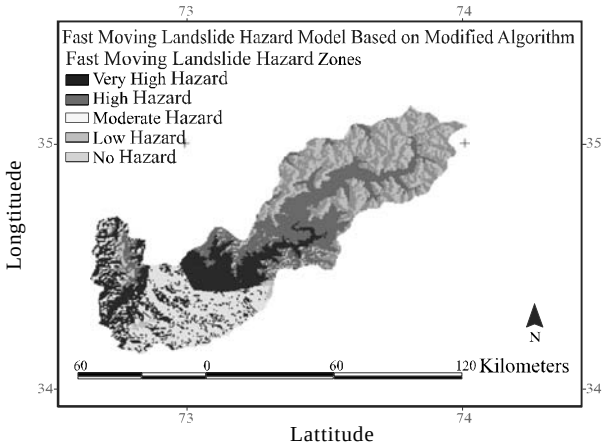

FIG. 8. MODIFIED ALGORTHM BASED LANDSLIDE HAZARD MODEL

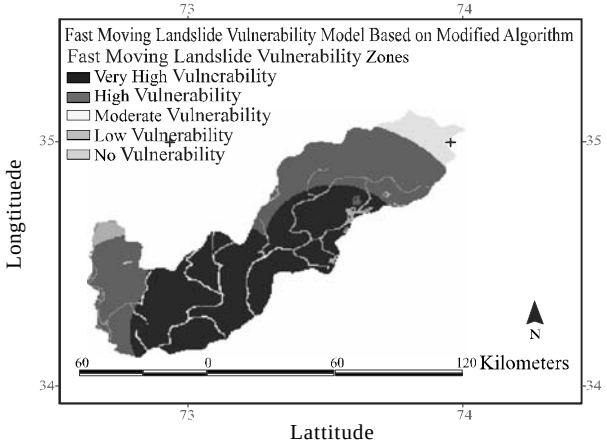

FIG. 9. MODIFIED ALGORITHM BASED LANDSLIDE VULNERABILITY MODEL COMPARISON OF MODELS

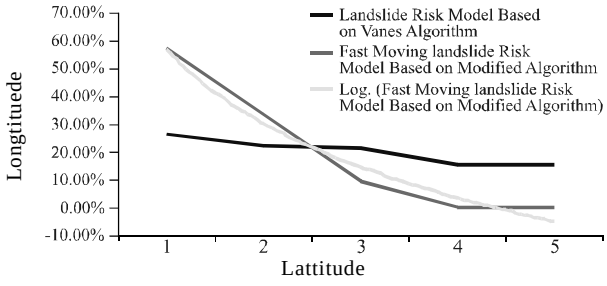

FIG. 10. THE LOG DIFFERENCE GRAPH BETEEN TWO MODELS

5. DISCUSSIONS

The very high predicted region in the modified landslide risk algorithm was almost more than 50% while in the old algorithm based landslide risk model was about 25% area. Such significant difference in the previous landslide risk algorithm showed the inefficiency and inaccuracy in the quantification of the landslide risk in the study area. Furthermore the low risk area was predicted with 16% and no risk with 14 % , while in the modified landslide risk algorithm, there is not as such prediction in such areas. This marginal difference in these two different models shows the significant difference during the quantification of the risk areas which can influence accordingly to the decision makers during implementing such models in the regions.

6. CONCLUSIONS

It is clear from the results that the pervious algorithm of landslide risk proved very deficient because it lacked to consider the particular type of the slopes failures while the modified landslide risk algorithm based developed models considering the specific type of the triggering has notified the alarming threats to the various predicted regions which showed the reliability of the modified algorithm based model for the decision makers in future.

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