GIS-Based Fast Moving Landslide Risk Analysis Model Using Qualitative Approach: A Case Study of Balakot, Pakistan

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ABSTRACT

The innovation of this research is the development of new model called fast moving landslide risk analysis model by modifying one of the previous prominent landslide risk algorithms focusing on the fast moving type of the landslides (such as mudslides, mud flows, block slide, rock fall and topple) based on the qualitative approach using Heuristic method in GIS (Geographical Information Systems). The different event controlling parameters and criteria were used for fast moving landslide predictive risk model. The pair wise comparison method was used in which the parameters of landslide hazard and vulnerability were compared by their assigned weights. The drawback of the used approach was justified by the standard value of consistency ratio, which proved the assigned weight of the parameters as reasonable and consistent. The model was validated by using the occurred landslides inventory data and correlation coefficient test, which showed the positive relationship between the landslide risk predicted regions and the occurred landslides locations. The various landslide events occurred on 8th October, 2005 were accumulated as landslide inventory by the interpretation of satellite imagery. The validation of the model was justified by using one of the statistical two paired, "t" test, and the amount of the predicted risk in the different regions. It is believed that this modified model will prove beneficial to the decision makers in future.

Key Words: Fast Moving landslides, Risk Model, Hazard, Vulnerability.

1. INTRODUCTION

Landslide being the activity of rock falls towards down slopes [1] is severe natural catastrophe triggering in the terrain hills should be considered in advance to mitigate its losses for the future [2]. The multidisciplinary people in the world have significantly focused the landslide hazard and risk [3]. The variety of models have been developed in past such as heuristics approach based models with the combination of either field data based on direct geomorphological analysis or indirect combination of qualitative maps [4] using the comparison matrix method [5], deterministic based on the physical parameters [6] and probabilistic approach based models [7]. These approaches based models were entitled as subjective, inaccurate and limited [8]. The trend for the development of the landslide risk models has been considered based on the either event controlling

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significant parameters [9] or the combination of the some of the types of the landslides. Few practices have been done for the specific class of the landslide modeling as some researchers worked [10] on the slow moving type of the landslides. The landslide classes have never been considered for the modeling while it has the strong impact on the selection of the criteria and the factors for the best output. As there are many categories of landslides which must be studied categorically.

The landslide risk analysis approaches need special awareness for the various type of landslides with respect to their speed, level of expansion and moment [11]. The landslide hazard assessment approaches vary with respect to fast moving and slow moving type of landslides [12] as each class of landslide has different threats based on their individual types. The few practice of the landslide risk assessment approaches in connections of the GIS using the qualitative approach called heuristic methods have been used in past [13].The landslide risk algorithms are the basis to generate the landslide risk modeling and have been developed by the various researchers in past [14] for developing the landslide risk models. Various researchers have ignored the specific type of the landslide classification for risk modeling by underestimating it. Some researchers suggested the specific type of landslide risk model study in that perspective. The study of risk models in past were lacking the complete combination in terms of their sub-components such as hazard, vulnerability including the amount of the elements simultaneously. The product of hazard and vulnerability results as the landslide risk model. This study has been based on the different steps. In the first step, we modified the old and famous landslide risk algorithm [15].

1.1 The Reasons for Modification of the Existing Landslide Risk Algorithm

The reasons to select such type of algorithm for modification is that it is prominent algorithm and has been utilized to develop the landslide hazard, susceptibility and elements at risk for the landslide risk models by the various researchers [16] in past but it possesses various drawbacks in its essence which has adversely influenced on the development of the quality of the landslide risk models which are discussed as:

- This algorithm focuses on sub groups of risk as hazard and vulnerability as well with the risk for risk modeling while the other algorithms were lacking the consideration of the combined risk group.
- This algorithm lacks the information of landslides specification, types, classes, mechanism, speed, soil and inherent properties during presenting the risk modeling parameters. So it needs to be reviewed and reworked on it for the possible better outcomes.
- It focuses on the traditional parameters and exposes the scarcity of the new factors to be considered for the landslide risk modeling.
- The extent of the sub.-groups e.g. hazard and vulnerability with its types and amount have not been specified in this algorithm so it lacks such type of information during the practical application of landslide risk model development.
- Due to described deficiencies it develops the adverse impacts on the development of the criteria and parameters for the over all landslide risk modeling so that this deficient algorithm based developed landslide risk models can not be called as accurate and reliable.

We developed the hypothesis for rejecting this algorithm: "The Varnes algorithm is deficient and should be modified based on the specific type of the landslides for fast moving type of landslide risk modeling with its sub components such as fast moving type of hazard and vulnerability".

This hypothesis encouraged for developing the fast moving type of the landslide risk model. The majority of the landslides [17] occurred in Balakot Pakistan in October 2005 were entitled as fast moving type of landslides [18] .The overall categories of the landslides have been classified [19] into three classes based on the velocity:

- Extreme rapid to rapid moving landslides range from 5 meter/sec to 3 meter/min.
- Extreme fast to fast moving range from 8 meter/ hour to 13meter/month.
- Extreme slow to slow moving range from 13 meter/ month to 16 meter/year.

In the second step of our research, we developed a new model entitled as fast moving type of landslides risk model based on the modified landslide risk algorithm considering the fast moving type of landslides. In the last step, we validated the developed model using statistical test and various occurred landslides locations data [20] received by global position systems in Balakot region at the various latitude and longitude points known as ground control points which have been given in Appendix-1.

It is believed that this modified algorithm-based fast moving landslide risk model will be very useful not only in Balakot, for rehabilitation and mitigation but also can be utilized in various regions where terrain conditions generate the fast moving types of landslides in the world.

2. STUDY AREA AND LANDSLIDE INVENTORY

The study area Balakot as shown in Fig. 1 is one of the urban cities of district Mansehra in north Pakistan currently known as Khyber Pakhtoonkhwa province.

The earthquake induced landslides disaster's epicenter was located at 34°29'35" N and 73°37'44"E. The whole city was ruined. Balakot topography is a part of the Himalayan mountains known as fold and thrust belt with 15 km fault line around the region [21]. The peak of the mountains reaches to 4800 m above sea level in Balakot.

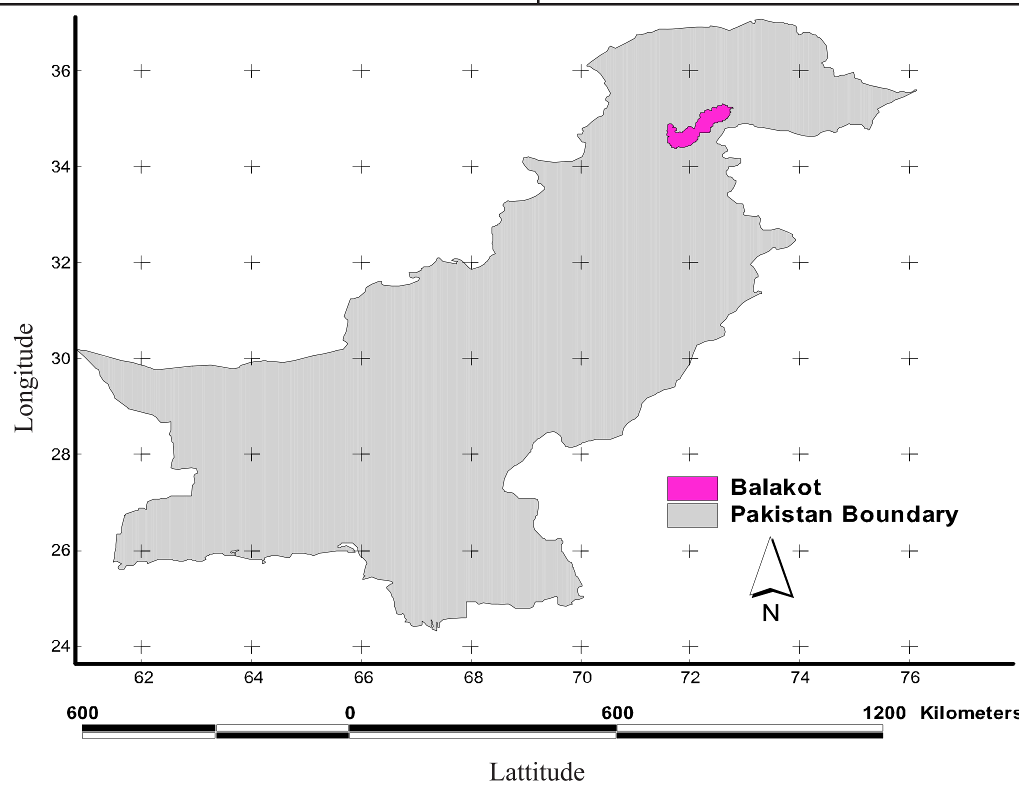

FIG. 1. BALAKOT STUDY AREA FROM PAKISTAN MAP

The Kunhar river is main river draining into the center eroding the toe of the slopes of the rocks. The population is almost on the plane lands on river terraces. The majority of the triggered landslides were lying within elevation of 1000-2000 m at asl (above sea level). Some of the triggered landslides located within the elevation of 3967-4947m, asl were along the rivers and the roads as shown in Fig. 2.

3. METHODS

3.1 Modified Landslide Risk Algorithm

The existing landslide risk algorithm as mentioned in Equation (1) was considered to modify.

$$R_\tau = (E)(R_s) = (E)(H \times V) \quad (1)$$

Where R_τ is the total risk, H is the Hazard, V is the vulnerability, E is the elements at risk Rs is the specific risk. The Equation 1 has been modified by Equations (2-4):

$$TR_{fml} = \Sigma(H_{fml} \times VA_{fml}) \quad (2)$$

$$H_{fml} = \Sigma(P_{fml} \times W) \quad (3)$$

$$V_{fml} = \Sigma(P_{fml} \times W) \quad (4)$$

Where TR_{fml} is the total risk for the fast moving type of the landslides, H_{fml} is the hazard occurred from the fast moving type of landslides, VA_{fml} is the vulnerability of the all amount of the elements, P_{fml} is the parameters of the fast moving landslides and W is the weight of the parameters.

The existing Equation (1) has been modified and replaced in the Equation (2) with its auxiliary modified Equations (3-4) explaining as total risk occurred from the fast moving type of landslides is the outcome of entire hazard and vulnerability. While the hazard as a sub group of the landslide risk in Equation (3) is the product of its specific parameters and their weights. In addition, the vulnerability in the Equation (4) has been declared as the entire result of its definite factors and their ranks.

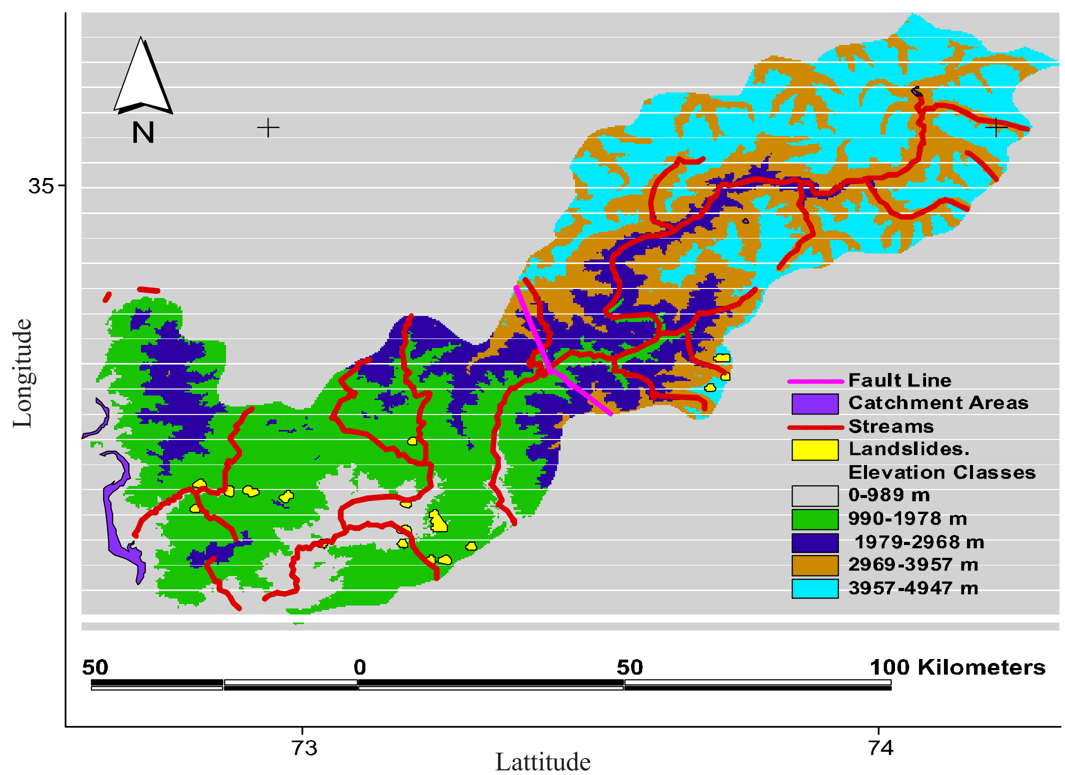

FIG. 2. BALAKOT TOPOGRAPHY WITH LANDSLIDE INVENTORY

3.2 Parameters for the Fast Moving Landslide Hazard and Vulnerability

The fast moving landslide hazard criteria were modified and the parameters were selected by the various supplementary sources such as previous research done, experts suggestions, landslide inventory data occurrence in past, field visit, photography, and contributory approach of the local residents of the study area. The criteria and the parameters for the fast moving type of landslides are described in Table 1.

The criteria and parameters have been developed for the fast moving type of the vulnerability is given in Table 2.

3.3 Comparison of the Weights Methods

This method is used by different researchers in past for the decisions making [22]. This method is done by the experts based on individual approach, subdividing the parameter into certain classes, assigning weight to them. This method utilizes the 9 weighing scales to differentiate the inclination of the different pairs for the certain criteria as shown in Table 3 [23].

The results of the pair wise comparison for the parameters for the modified fast moving landslide hazard are shown in Table 4. In this scale, the criterion accuracy and reasonability is justified through the CR (Consistency Ratio) which is between the consistency index and the random index and ranges from 0-1. The acceptable value of CR after calculating the different mathematical operations using weight comparison matrix method should be less than or equal to 0.01 [24]. The CR in our hazard study for the fast moving type of landslide hazards parameters weight is 0.025 that is less than 0.1 which proved our criteria reasonable. The potent parameter in our landslide hazard study is the landslides zone, which has been given strongly importance while slope angle and fault are in between from strong to the moderate importance comparatively to the landslides zones. The elevation,

TABLE 1. FAST MOVING LANDSLIDE HAZARD CRITERIA AND PARAMETERS

No.	Fast Moving Landslide Hazard Criteria	Fast Moving Landslide Hazard Parameters
1.	Landover	Forest, Vegetations etc.
2.	Land use	Scellements, commercial and résidentiel proximités
3.	Topography	Elevations, slope angle
4.	Landslide inventory data	Présent landslide zones
5.	Rain Threshold	Rainfall, precipitation
6.	Water Bodies	Rivers ,streams, catchments, water drainage
7.	Seismicity	Fault , Earthquake data

TABLE 2. FAST MOVING LANDSLIDE VULNERABILITY CRITERIA AND PARAMETERS

No.	Fast Moving Landslide Vulnerability Criteria	Fast Moving Landslide Vulnerability Parameters
1.	Human bodies	Population proximities
2.	Transportation	Roads, major and minor roads
3.	Supply system	Hospitals, schools, sport complexes
4.	Proximity to elements at vulnerability	Proximity to roads, rivers, catchments, streams
5.	Infrastructure	Residential and commercial

TABLE 3. THE PAIR WISE COMPARISON SCALE

No.	Weight	Definition
1-3.	Equal to moderate importance	Moderate rated on another
4-6-8.	Transitional values	Transitional values between extreme and light
5	Strong important	Strongly favored on the other parameters
7	Very strong important	Preferred very strongly
9	Extreme important	Utmost rate of declaration

rainfall, vegetations and settlements have been considered equally important.

The results of the pair wise comparison for the parameters for the modified fast moving landslide vulnerability are shown in Table 5.

The CR for the fast moving type of landslide vulnerability parameters weight is 0.03 which is less than 0.1 which also proved that our criteria is reasonable. The potent parameter in our study for the fast moving type of the vulnerability is road proximity, which has been given very strong importance while rivers posses' strong importance, and population density proximity and the catchments' areas are in the range of moderate to strong importance.

4. RESULTS

4.1 Fast Moving Landslide Risk Model

The development of the fast moving landslide risk model is a series of combinations of two different procedures e.g. development of fast moving landslide hazard model and fast moving landslide vulnerability model .The modified Equations (2-4) have been used for the fast moving type of landslide risk model.

4.1.1 Fast Moving Landslide Hazard Model

The fast moving landslide hazard model has been developed using modified Equation (3). The various parameters have been used such as vegetation, population, elevation, slope angle, rainfall, river, and fault and landslide zones. We utilized various GIS techniques such as extracting the study area as boundary theme from the huge data of Pakistan boundary, after that we clipped and overlaid the other themes in the GIS shape files in vector format (such as faults, landslides and elevation) using the GIS software with datum WGS-84, UTM projection, zone 43. We prepared the grid files for the spatial analysis and reclassified them into 10 classes. After that we set those classes in five categories for landslide hazard zones. Then we used the geo-processing wizard by applying the map calculation technique in GIS by calculating the sum of all layers and dividing them with the total number of layers. Finally, we got the map calculation result into new layer with many classes. We made five classes of that map calculation as a new layer according to our criteria and developed the landslide hazard model. The five categories were prepared as very high hazard, high hazard, moderate hazard, low hazard and no hazard as shown in Fig. 3.

TABLE 4. PAIR-WISE COMPARISON FOR FAST MOVING LANDSLIDE HAZARD PARAMETERS WEIGHT

Factors	Elevation	Vegetation	Rainfall	Slope Angle	Fault	Landslide Zones	Settlements	Factors Weight (λ)
Elevation	1	1	1	4	4	5	2	6.975
Rainfall	1	1	1	4	4	5	2	6.975
Vegetation	1	1	1	4	4	5	2	6.975
Slope Angle	¼	¼	¼	1	1	5/4	1/2	7.017
fault	¼	¼	¼	1	1	5/4	1/2	7.017
Landslide zones	1/4	1/5	1/5	4/5	4/5	1	2/4	7
Settlements	1/2	1/2	1/2	2	2	2.5	1	8.479

TABLE 5. PAIR-WISE COMPARISON FOR FAST MOVING LANDSLIDE VULNERABILITY PARAMETERS WEIGHT

Factors	Catchments Proximity	Rivers Proximity	Population Proximity	Road Proximity	Factors Weight (λ)
Catchments proximity	1	5	4	7	3.995
Rivers proximity	1/5	1	4/5	1.4	4.397
Population proximity	1/4	5/4	1	7/4	4
Road proximity	1/7	5/7	4/7	1	4.012

The buffering technique was used in GIS for analyzing the proximity of the fault, river and the landslide zones. Furthermore the criteria was used for fast moving landslide hazard model and utilized for the various parameters which have been shown in shown in Table 6.

4.1.2 Fast Moving Landslide Vulnerability Model

The fast moving landslide vulnerability model has been developed using modified Equation 4 considering the fast moving landslide vulnerability parameters such as population proximity, roads proximity, rivers, catchments and stream proximity by multiplying the criterion assigned weights with the parameters and dividing them with the total number of the parameters. The fast moving landslide vulnerability criteria have been given in Table 7.

The various techniques of GIS were used for the moving landslide vulnerability model and the five categories were set as very high vulnerability, high vulnerability, moderate vulnerability, low vulnerability and no vulnerability which have been shown in Fig. 4.

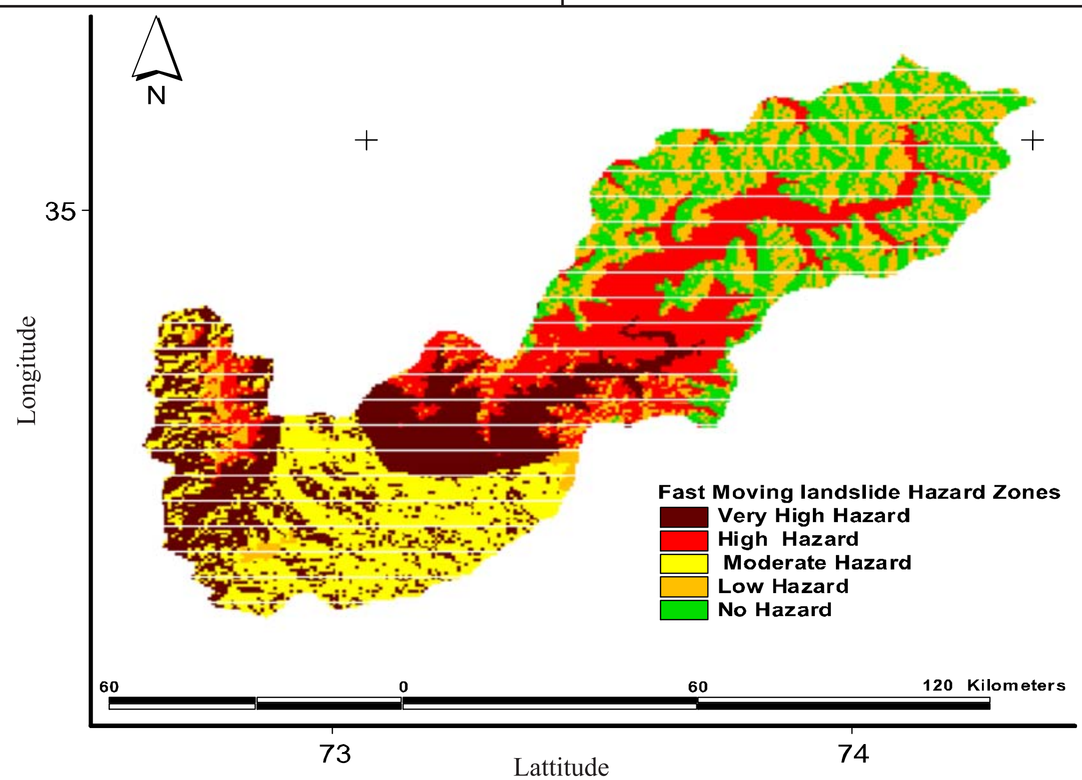

FIG. 3. FAST MOVING LANDSLIDE HAZARD MODEL

TABLE 6. FAST MOVING LANDSLIDE HAZARD CLASSES

Parameters	Very High Hazard	High Hazard	Moderate Hazard	Low Hazard	No Hazard
Slope Angle	30-45°>	20-30°	10-20°	5-10°	0-5°
Elevation	0-2000m	0-1500m	1500-3000m	3000-4500m	>4500m
Forest/Vegetations	No Density	Very Less Density	Moderate Density	High Density	Very High Density
Population	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m
Faults	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m
Landslide Zones	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m

4.1.3 Fast Moving Landslide Risk Model

Finally the various parameters of the fast moving landslide hazard model (such as slope angle, elevation, forest/ vegetation, faults, landslide zones, rainfall) and fast moving landslide vulnerability (population, proximity to roads, proximity to rivers, proximity to drainage, proximity to the catchments) were overlaid using map calculation technique in GIS. The landslide risk model as shown in Fig. 5, was developed with five categories as very high risk , high risk , moderate risk, low risk and no risk. We developed fast moving landslide risk model as shown in Fig. 5, using the modified Equation 2 with its auxiliary Equations (3-4).

4.2 Validation of Results

This model based on the modified Equations (2-4) has been validated by using the occurred landslide data in the various predictive regions as shown in Fig. 6.

The correlation coefficient test r^2 resulted as 0.882 shown in Fig.7, proving the correlation as strongly positive justified prediction of the various landslides region as true with the occurred landslides.

The total predicted areas in the modified fast moving landslide risk model with the extent of the landslides have been given in Table 8.

TABLE 7. FAST MOVING LANDSLIDE VULNERABILITY CLASSES

Parameters	Very High Vulnerability	High Vulnerability	Moderate Vulnerability	Low Vulnerability	No Vulnerability
Population Proximity	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m
Roads Proximity	0-300m	300-600m	600-1500m	1500-200m	>2000m
Rivers Proximity	0-50m	50-100m	100-200m	200-500m	>500m
Catchments proximity	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m

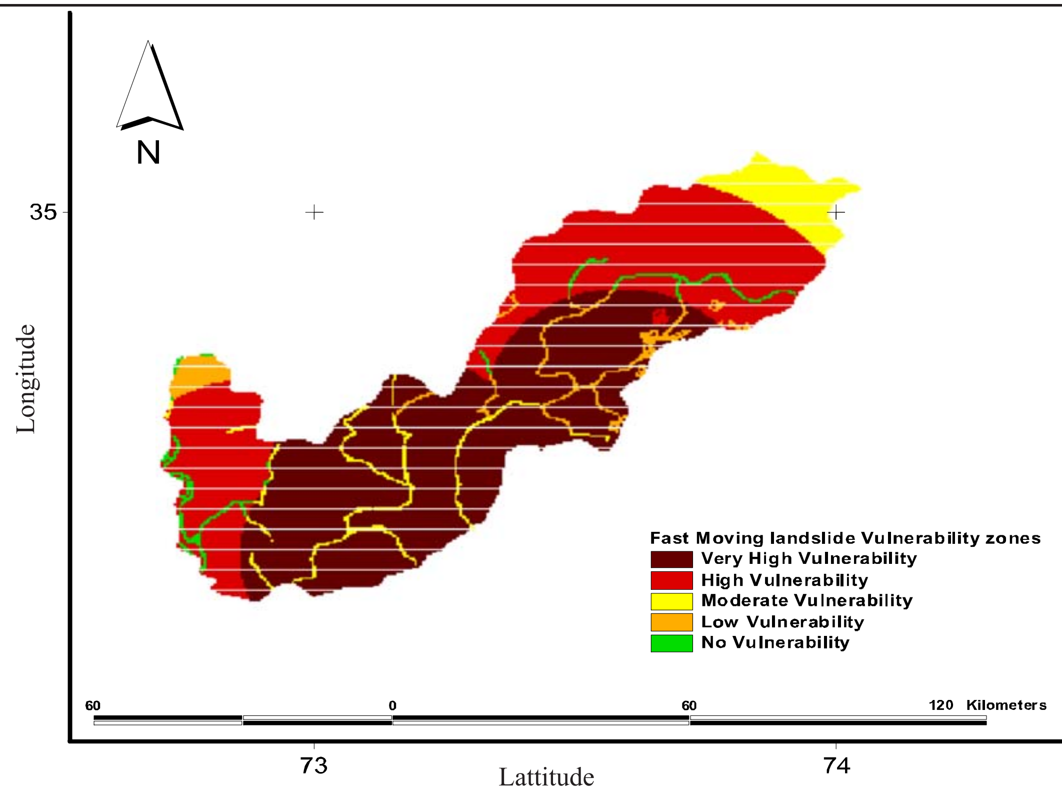

FIG. 4. FAST MOVING LANDSLIDE VULNERABILITY MODEL

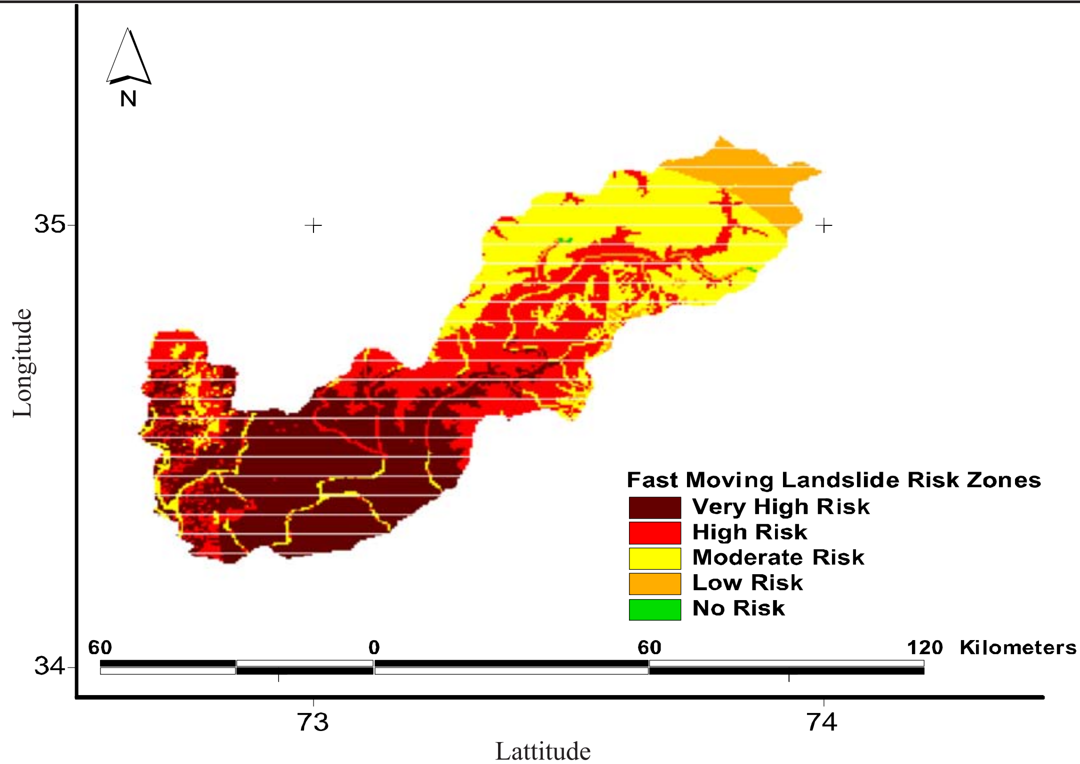

FIG. 5. FAST MOVING LANDSLIDE RISK MODEL

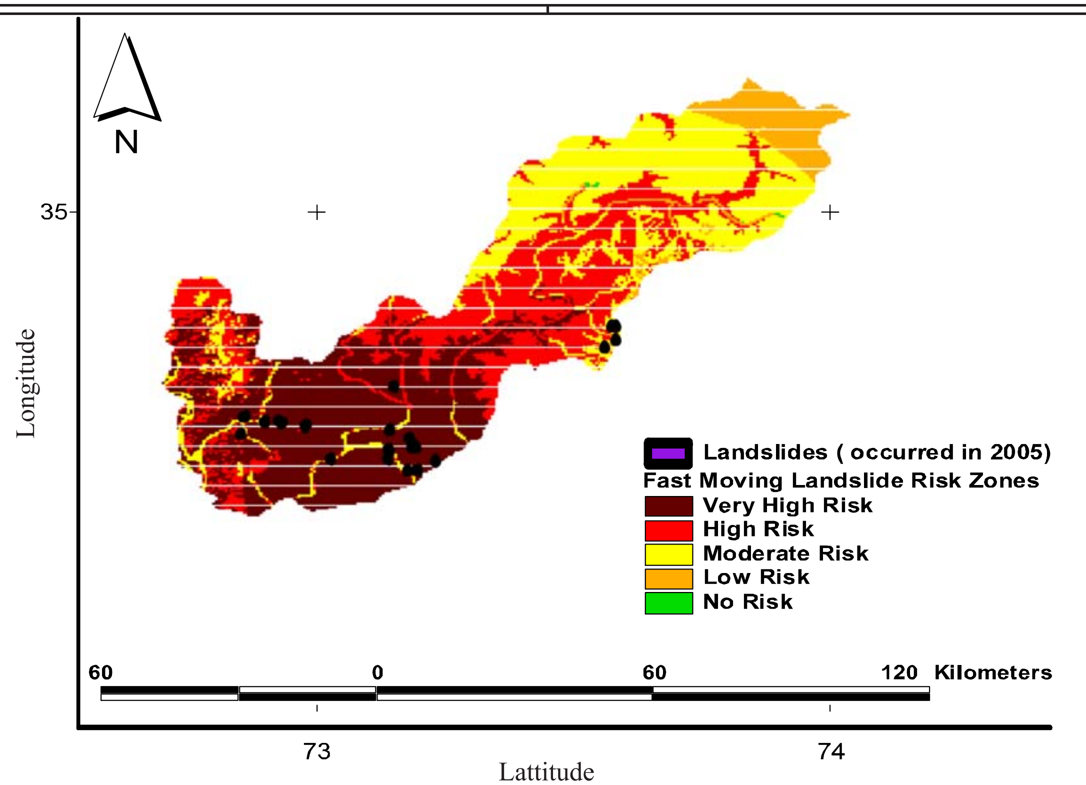

FIG. 6. FAST MOVING LANDSLIDE RISK MODEL WITH LANDSLIDES OCCURRENCE

The validity of the modified model in terms of utilizing the modified algorithm with appropriate criteria and the parameters was statistically tested using the (2- tailed) "t" test, while "P" value of the model resulted as 0.99 which is greater than the value of ? which is 0.05. The value proved that the landslides occurred are not the significantly different with the predicted regions and they have the similarity which confirmed our predictions as true with respect to the landslide inventory data.

4.3 Discussions

Landslide classes possessing different levels of natural intensity and damaging impacts have different effects on the development of landslide hazard, vulnerability and risk models. The Varnes landslide risk algorithm was therefore needed to be reviewed and reworked on it for the possible better outcomes of the landslide risk modeling as its scope is too limited by considering the very few traditional parameters. The specific class oriented landslide risk model based on the appropriate required parameters and criteria can save time, money, skills and the issues of inaccuracy by developing landslide risk modeling.

This research paper has provided the new information regarding to the class of the landslides for the landslide risk modeling. So in future the various researchers can develop the landslide risk models not only for the rest of the classes such as rapid and slow but also even in the case of the fast moving type of landslides modeling, the various approaches can be applied, compared and tested for further comparative studies.

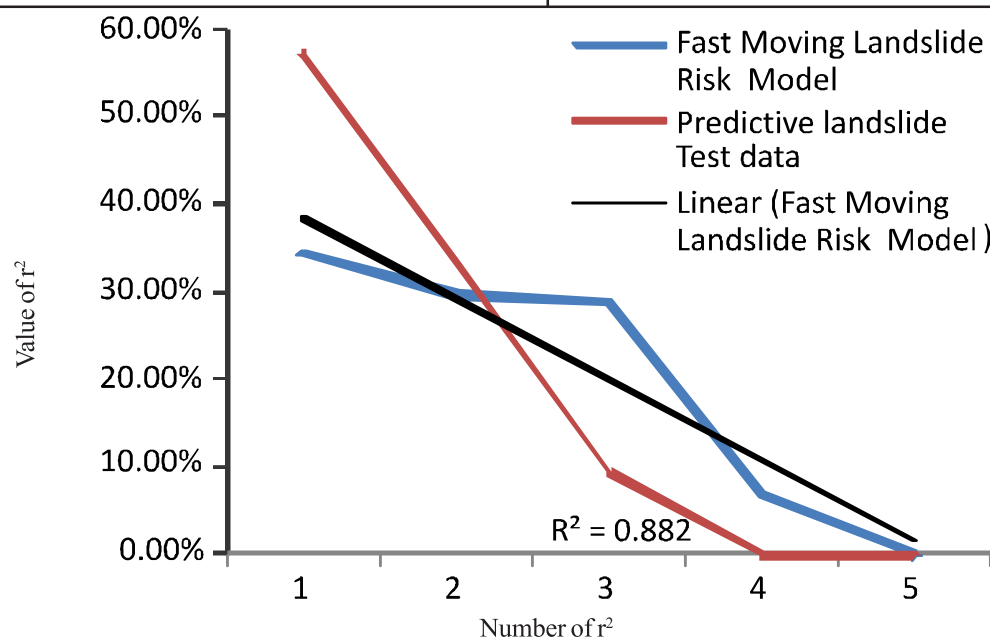

FIG. 7. THE CORRELATION BETWEEN FAST MOVING LANDSLIDE PREDICTED ZONES AND OCCURRED LANDSLIDES

TABLE 8. FAST MOVING LANDSLIDES PREDICTED REGIONS WITH OCCURRED LANDSLIDES

No.	Fast Moving Predicted Regions	Total Area	Triggered Landslides
1.	Very High Risk Zones	57.14	20%
2.	High Risk Zones	33.34	13.32%
3.	Moderate Risk Zones	9.53	16.7%
4.	Low Risk Zones	00	00
5.	No risk Zones	00	00

5. CONCLUSIONS

The landslide algorithms are the basis to develop the landslide risk modeling. These algorithms can help to understand the mechanism, criteria and parameters of the model and prove to be helping to develop the accurate, suitable and .reliable models. The prominent algorithms even used since years need to be renovated to make it more fruitful for the next generations. The different types, intensities, and class of landslides also need the different merged class based landslide risk modeling using the various type of the approaches. Even in the single or appropriately merged classified landslides needs to be adopted, checked and compared on the scope of various techniques so as to be benefited their accuracies and fruitfulness. The Varnes algorithm with its sub groups hazard and susceptibility denoted the generalization in landslides considerations. The vulnerability extent in varnes algorithm is general and has not been not specified whether it is suitable for human, physical or both While in the modified algorithms, the specific class of landslides has been considered for the expected losses from hazard and vulnerability with significant parameters, which influence on the quality of the risk models.

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APPENDIX-1. LANDSLIDE INVENTORY SUPPLEMENTARY DATA

No.	Northing (Degree, Minute, Second)	Easting (Degree, Minute, Second)	Slope (Degree)	No.	Northing (Degree, Minute, Second)	Easting (Degree, Minute, Second)	Slope (Degree)	No.	Northing (Degree, Minute, Second)	Easting (Degree, Minute, Second)	Slope (Degree)
1.	N 34 37 27 4	E73 32 068 0 0	80°	23.	N 34 23 40 34	E 73 29 51 50	50°	45.	N 34 20 13 41	E 73 31 9 43	80°
2.	N 34 37 48 47	E73 29 51 58	32°	24.	N 34 23 54 50	E 73 29 35 31	29°	46.	N 34 13 15 14	E 73 32 37 8	80°
3.	N 34 39 32 24	E73 29 18 11	335°	25.	N 34 24 0 4	E 73 29 19 55	15°	47.	N 34 11 4 44	E 73 33 53 24	325°
4.	N 34 39 38 35	E73 28 37 26	352°	26.	N 34 24 4 23	E 73 29 18 32	-	48.	N 34 10 56 53	E 73 33 56 31	255°
5.	N 34 31 42 18	E 73 28 17 6	250°	27.	N 34 24 26 46	E 73 28 40 8	270°	49.	N 34 10 52 19	E 73 34 49 8	95°
6.	N 34 21 55 5	E 73 28 2 42	320°	28.	N 34 24 20 2	E 73 28 39 22	60°	50.	N 34 10 49 12	E 73 35 9 40	310°
7.	N 34 21 53 28	E 73 22 28 12	-	29.	N 34 24 43 37	E 73 27 27 22	110°	51.	N 34 10 15 0	E 73 35 33 54	85°
8.	N 34 21 58 8	E 73 23 7 59	-	30.	N 34 24 47 56	E 73 27 12 0	100°	52.	N 34 10 30 4	E 73 37 22 30	10°
9.	N 34 25 6 36	E 73 23 31 37	50°	31.	N 34 25 0 40	E 73 27 4 5	035°	53.	N 34 10 34 37	E 73 41 58 59	90°
10.	N 34 21 59 10	E 73 24 51 32	057°	32.	N 34 26 15 47	E 73 26 43 41	360°	54.	N 34 10 16 30	E 73 26 55 19	115°
11.	N 34 21 54 4	E 73 25 13 23	20°	33.	N 34 26 22 55	E 73 26 34 48	360°	55.	N 34 9 25 19	E 73 27 6 50	242°
12.	N 34 21 43 52	E 73 25 39 18	345°	34.	N 34 26 41 20	E 73 26 20 13	30°	56.	N 34 7 30 47	E 73 37 20 53	245°
13.	N 34 21 46 41	E 73 27 8 2	12°	35.	N 34 26 55 23	E 73 26 16 16	25°	57.	N 34 6 34 19	E 73 40 56 38	65°
14.	N 34 21 51 50	E 73 27 30 22	300°	36.	N 34 26 52 12	E 73 26 13 30	17°	58.	N 34 37 27 4	E 73 41 3 32	310°
15.	N 34 22 2 10	E 73 20 50 46	30°	37.	N 34 27 23 56	E 73 25 32 42	-	59.	N 34 37 48 47	E 73 41 36 0	335°
16.	N 34 21 37 8	E 73 30 30 25	-	38.	N 34 27 27 14	E 73 28 15 14	10°	60.	N 34 39 32 24	E 73 41 36 50	10°
17.	N 34 21 53 10	E 73 30 24 0	70°	39.	N 34 27 26 24	E 73 29 6 22	60°	61.	N 34 39 38 35	E 73 44 52 16	160°
18.	N 34 23 5 42	E 73 30 21 14	305°	40.	N 34 27 25 5	E 73 29 11 24	345°	62.	N 34 31 42 18	E 73 45 56 20	40°
19.	N 34 23 9 43	E 73 41 58 59	298°	41.	N 34 27 13 55	E 73 29 6 54	24°	63.	N 34 21 55 5	E 73 46 3 32	310°
20.	N 34 23 12 47	E 73 30 0 4	-	42.	N 34 26 33 58	E 73 29 44 35	360°	64.	N 34 21 53 28	E 73 46 58 12	345
21.	N 34 23 21 50	E 73 30 8 6	282°	43.	N 34 25 6 40	E 73 29 54 54	270°	65.	N 34 21 58 8	E 73 49 48 22	340°
22.	N 34 23 26 35	E 73 30 32 49	275°	44.	N 34 20 14 17	E 73 30 44 10	-	66.	N 34 25 6 36	E 73 52 1 16	10°
								67.	N 34 21 59 10	E 73 53 16 37	55°

REFERENCES

[1] Chen, H., and Lee, C.F., "A Dynamic Model for Rainfall-Induced Landslides on Natural Slopes", Geomorphology, Volume 51, pp. 269-288, Elsevier Publishers, Germany, 2003.

[2] Dahal, R.K., Hasegawa, S., Nonomura, A., Yamanaka, M., Masuda, T., and Nishino, K., "GIS-Based Weights-of-Evidence Modeling of Rainfall-Induced Landslides in Small Catchments for Landslide Susceptibility Mapping", Environment Geology, Volume 54, pp. 311-324, Springer Publishers, Germany, 2008.

[3] Aleotti, P., and Chowdhury, R., "Landslide Hazard Assessment: Summary Review and New Perspectives", Bulletin Engineering Geology Environment, Volume 58, pp. 21-44, Springer Berlin/Heidelberg, Germany, 1999.

[4] Van-Westen, C.J., Van-Asch, T.W.J., and Soeters, R., "Landslide Hazard and Risk Zonation-Why is it Still so Difficult", Bulletin Engineering Geology Environment, Volume 65, pp.167-184, International Association for Engineering Geology and the Environment, Springer Verlag, Italy, 2006.

[6] Xie, M., Esaki, T., and Zhou, G., "GIS-Based Probabilistic Mapping of Landslide Hazard Using a Three-Dimensional Deterministic Model", Natural Hazards, Volume 33, pp. 265-282, Springer, Netherlands, 2004.

[5] Kamp, U., Growley, B.J., Khattak, G.A., and Owen, L.A., "GIS-Based Landslide Susceptibility Mapping for the 2005 Kashmir Earthquake Region", Geomorphology, Volume 101, pp. 631-642, Elsevier Publishers, Germany, 2008.

[7] Saha, A.K., Gupta, R.P., Sarkar, I., Arora, M.K., and Csaplovics, E., "An Approach for GIS-Based Statistical Landslide Susceptibility Zonation with a Case Study in the Himalayas", Landslides, Volume 2, pp. 61-69, Elsevier Publishers, Germany, 2005.

[8] Günther, A., Reichenbach, P., Guzzetti, F., and Richter, A., "Criteria for Identification of Areas at Risk of Landslides in Europe: The Tier-1 Approach, Expert Meeting on Guidelines for Mapping Areas at Risk of Landslides in Europe", JRC Ispra, pp. 23-24, Europe, 2007.

[9] Komac, M., "A Landslide Susceptibility Model Using the Analytical Hierarchy Process Method and Multivariate Statistics in Perialpine Slovenia", Geomorphology, Volume 74, pp. 17-28, Elsevier Publishers, Germany, 2006.

[10] Mansour, M.F., Morgenstern, N.R., and Martin, C. D., "Expected Damage from Displacement of Slow-Moving Slides", Landslides, Elsevier Publishers, Germany, 2010.

[11] Chacon, J., Irigaray, C., Fernandez, T., and El-Hamdouni, R., "Engineering Geology Maps: Landslides and Geographical Information Systems", Bulletin Engineering Geology Environment, Volume 65, pp. 341- 411, Springer Berlin/Heidelberg, Germany, 2006.

[12] Guzzetti, F., Carrara, A., Cardinali, M., and Reichenbach, P., "Landslide Hazard Evaluation: A Review of Current Techniques and Their Application in a Multi-Scale Study, Central Italy", Geomorphology, Volume 31, pp. 181-216, Elsevier Publishers, Germany, 1999.

[13] Castellanos, A.A., and Van-Westen, C.J., "Qualitative Landslide Susceptibility Assessment by Multicriteria Analysis: A Case Study from San Antonio del Sur, Guantánamo, Cuba", Geomorphology, Volume 94, Issues 3-4, pp. 453-466, Elsevier Publishers, Germany, 2008.

[14] Peduzzi, P., Dao, H., Herold, C., and Mouton, F., "Assessing Global Exposure and Vulnerability Towards Natural Hazards: The Disaster Risk Index", Natural Hazards Earth System Society, Volume 9, pp. 1149-1159, Copernicus Publications, Italy, 2009.

[15] Varnes, D.J., "Landslide Hazard Zonation: A Review of Principles and Practice", International Association of Engineering Geology, Natural Hazards Series, No. 3, pp. 63, UNESCO, France, 1984.

[16] Catani, F., Casagli, N., Ermini, L., Righini, G., and Menduni, G., "Landslide Hazard and Risk Mapping at Catchment Scale in the Arno River Basin", Landslides, Volume 2, pp. 329-342, Elsevier Publishers, Germany, 2005.

[17] Kamp, U., Owen, L.A., Growley, B.J., and Khattak, G.A., "Back Analysis of Landslide Susceptibility Zonation Mapping for the 2005 Kashmir Earthquake: An Assessment of the Reliability of Susceptibility Zoning Maps", Natural Hazards, Springer Netherlands, 2009.

[18] Hungr, O., Evans, S.G., Bovis, M.J., and Hutchinson, J.N., "A Review of Classification of Landslides of the Flow Type", Environmental and Engineering Geoscience, Volume VII, No. 3, pp. 221-238, Association of Environmental & Engineering Geologists and the Geological Society of America, 2001.

[19] Nagarajan, R., "Landslide Disaster: Assessment and Monitoring", New Delhi, India, 2004.

[20] Owen, L.A., Kamp, U., Khattak, G.A., Harp, E.L., Keefer, D.K., and Bauer, M.A., "Landslides Triggered by the 8th October 2005 Kashmir Earthquake", Geomorphology, Volume 94, pp. 1-9, Elsevier Publishers, Germany, 2008.

[21] Zaré, M., Karimi-Paridari, S., and Mona, L., "An Investigation on Balakot, Muzaffarabad (Pakistan) Earthquake, 8th October 2005, Mw 7.6; Geological Aspects and Intensity Distribution", Journal of Seismol, Volume 13, pp. 327-337, Springer Publishers, Germany, 2009.

[22] Ayalew, L., Hiromitsu, Y., and Ugawa, N., "Landslide Susceptibility Mapping Using GIS-Based Weighted Linear Combination, The Case in Tsugawa Area of Agano River, Niigata Prefecture, Japan", Landslides, Volume 1, pp. 73-81, Elsevier Publishers, Germany, 2004.

[23] Malczewski, J., "GIS and Multi Criteria Decision Analysis", pp. 183, NewYork, 1999.

[24] Saaty, T.L., "The Analytic Hierarchy Process", New York, 1980.