

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/331008711>

# Application of Artificial Hierarchy Process for Landslide Susceptibility Modelling in Rangamati Municipality Area, Bangladesh

Conference Paper · January 2019

CITATIONS

0

READS

69

5 authors, including:



**Abdulla - Al Kafy**

Rajshahi University of Engineering & Technology

26 PUBLICATIONS 14 CITATIONS

SEE PROFILE



**Lamia Ferdous**

Rajshahi University of Engineering & Technology

19 PUBLICATIONS 12 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Urban Growth And Urban Extent Of Cities In Bangladesh [View project](#)



Compact Township [View project](#)

## Application of Artificial Hierarchy Process for Landslide Susceptibility Modelling in Rangamati Municipality Area, Bangladesh

Abdulla - Al Kafy<sup>1,2\*</sup>, Mohammad Mahmudul Hasan<sup>1</sup>, Lamia Ferdous<sup>3</sup>, Md. Rahamat Ali<sup>4</sup> & Md. Salah Uddin<sup>5</sup>

### Abstract

Landslide hazards are a common threat for the community people living in the risky hill slopes in Rangamati Municipality Area (RMA) in Bangladesh. Extensive hill cutting for urban settlements and heavy rain in a short period of time are responsible for triggering frequent landslide disasters in RMA. Every year, landslides cause economic losses, human casualties, and damage. Therefore, the principal objective of this research is to develop the Landslide Susceptibility Maps (LSM) for RMA so that suitable landslide disaster risk reduction approaches can be developed in near future. In this research, Artificial Hierarchy Process (AHP) has been applied for assessing the landslide susceptible areas in RMA which is a Geographic Information System (GIS) and remote sensing-based technique. LSM has been prepared on the basis of eleven (12) relevant factor (i.e. Geology, Slope Gradient, elevation, Topographic Wetness Index, distance from road and structure, land cover, NDVI, Stream Power Index, Plan Curvature and Profile Curvature). A landslide inventory map has been prepared using field surveying data of 48 historical landslide locations. Finally, the area under the relative operating characteristics curves (AUC) has been used to validate the AHP modelling result and AUC values of AHP 76.3%. According to the results of the AUC evaluation, the produced map has exhibited good performance. This study would support decision making by relevant departments for formulating policies and planning associated with landslide disaster risk reduction in Bangladesh.

**Keywords:** Landslides, Landslide Susceptibility Mapping, Artificial Hierarchy Process, ROC curve.

### Introduction

Landslides are most hazardous incident in the history of the world and third category of natural hazard for its worldwide position (Ahmed & Dewan, 2017; Rahman, Ahmed, & Di, 2017). Bangladesh is also affected by landslides during the monsoon period (June–September), which hit Chittagong Hill Track (CHT), almost every year (Rahman et al., 2017). Vulnerability level of landslide hazard to CHT is very high with a cumulative trend of frequency and harm (Ahmed, 2015). High rainfall, rapid urbanization, increased population density, inappropriate land use, hill cutting, deforestation, and agricultural practices are provoking the landslide susceptibility in CHT (Ahmed, 2015; Khan, Lateh, Baten, & Kamil, 2012). Recently, overwhelming landslides have frequently hit Rangamati Metropolitan Area (RMA) and caused injured person, compensations and loss. According to the district administration's report at least 15,000 people from 3,378 families are living at risk from landslides in the hilly areas and 120 people killed in last year's landslides in RMA. The huge amount of natural, social and economic losses due to landslides indicate its vulnerability (Ferdous, Kafy, Roy, & Chakma, 2017) and in last few years geographic information system (GIS), remote sensing (RS) and spatial statistical techniques and tools are applied in LSM studies frequently to identify the landslide locations, condition and predictability (Ahmed & Dewan, 2017; Chousianitis et al., 2016; Scaioni, Longoni, Melillo, & Papini, 2014).

Nowadays, different landslide susceptibility calculation methods are used, i.e., analytical hierarchy process (AHP), Weighted linear combination, ordered weighted averaging, decision tree methods etc. (Nefeslioglu, Gokceoglu, & Sonmez, 2008; Pourghasemi, Mohammady, & Pradhan, 2012; Pourghasemi, Pradhan, Gokceoglu, Mohammadi, & Moradi, 2013). The analytical hierarchy process (AHP) is known to analyze landslide condition for landslide susceptibility mapping and its combinations which are multi-criteria evaluation (MCE), multi-criteria decision analysis (MCDA), spatial multi-criteria evaluation (SMCE) is used in different related researches (Demir, Aytakin, Akgün, Ikizler, & Tatar, 2013; Pourghasemi et al., 2013; Yalcin, 2008). Landslides in CHT are a complex and multi-faced problem but despite a high degree of landslide hazard and vulnerability in RMA, only a few studies have been carried out to in Chittagong, Cox's Bazar area except Rangamati area. The paper basically tries to develop the

1. Graduate Student, Department of Urban & Regional Planning, Rajshahi University of Engineering & Technology, Rajshahi.
2. GIS Analyst, Rajshahi Development Authority (RDA), Rajshahi-6203
3. Undergraduate Student, Department of Urban & Regional Planning, Rajshahi University of Engineering & Technology, Rajshahi.
4. Masters Student, Department of Urban & Regional Planning, Bangladesh University of Engineering & Technology, Dhaka
5. Masters Student, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering & Technology, Dhaka.

\*Corresponding Authors Email: [sunnykafy@gmail.com](mailto:sunnykafy@gmail.com)

Landslide Susceptibility Maps (LSMs) using publicly available data with the assistance of AHP approach so that suitable landslide disaster risk reduction approaches can be developed in near future for RMA.

### Methodology

Rangamati municipality is located at the South-eastern side of Bangladesh and it lies between 22°27' and 23° 44' north latitudes and 91°56' and 92°33' east longitudes. The total area of the RMA is 546.49 sq. km. of which 210.32 sq. km. is under forest and is one of the most landslide prone areas in Bangladesh (Bangladesh Bureau of Statistics, 2013). Based on the data from the Bangladesh Meteorological Department, the annual average temperature of this district varies from maximum 36.5°C to minimum 12.5°C and annual rainfall is 2673 mm.

The first step of LSM is identifying the contributing factors of landslide hazards and then generating the relevant factors maps. For this research purpose, eleven relative factor maps and a landslide inventory map was produced. All the raster images (30 m×30 m) were projected to 'Bangladesh Transverse Mercator (BTM)' using 'Everest Bangladesh' datum. Landsat 8 operational land imager (OLI) satellite images were used for the land cover mapping (2017) of RMA. The images dated 21 November 2015 with row (44), path (136) were downloaded from the global visualization viewer of the United States Geological Survey (USGS) for land cover mapping. Science October and November are cloud-free seasons and trees are not in leaf-off condition image collected from those two periods (Kafy, Rahman, & Ferdous, 2017; Rahman et al., 2017). A supervised image classification technique has been performed to prepare decadal land cover maps of the CHT (Ahmed & Rubel, 2013; Kafy et al., 2017). Five broad land cover types (Built-up area, Hill forest, water body, crop and shrubland, and bare soil) were identified (Fig. 1-a).

The digital elevation model (DEM) image, dated on 2011, was acquired from the advanced spaceborne thermal emission and reflection radiometer (ASTER) global digital elevation model web-portal and DEM were used for the preparation of Elevation and slope maps (Fig. 1-b). The Normalized Difference Vegetation Index (NDVI) is a standardized index that allows generating an image displaying greenness (relative biomass). In this research, the Landsat-8 OLI images from the same season (dry and summer) were acquired from the official website of the USGS. Finally, the NDVI map of RMA was prepared by analyzing band 3 and band 4 in Erdas Imagine 15 software.

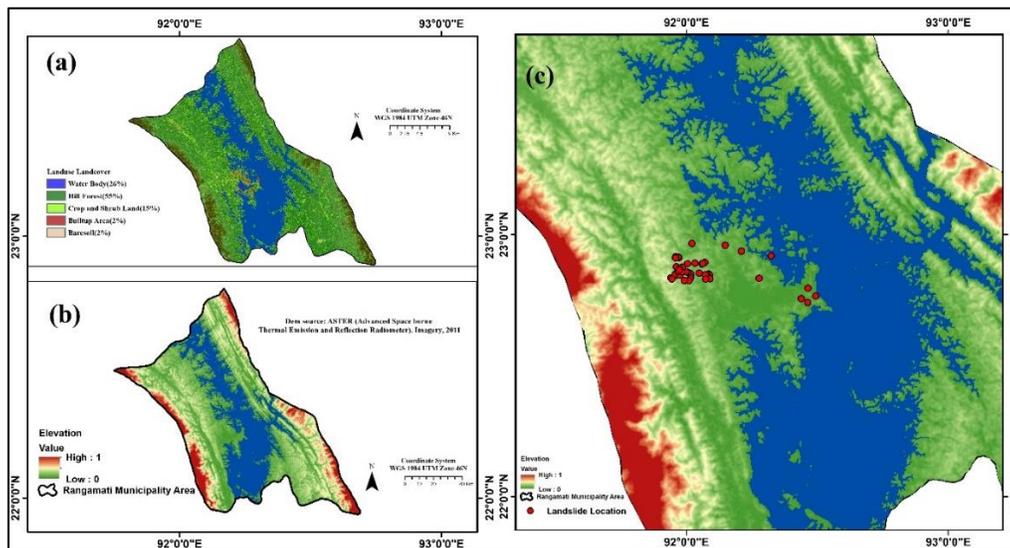


Figure 1 Rangamati Municipality Area (RMA) a) Land use of RMA, 2015 b) Elevation map of RMA c) Landslide inventory map of RMA

The effect of topography on the location and size of saturated source areas of runoff generation have been described using the topographic wetness index (TWI). Moore described the calculation of TWI under the assumption of steady-state conditions and uniform soil properties in Eq.1 (Moore, Grayson, & Ladson, 1991).

$$TWI = \ln (A_s - \tan \beta) \quad (1)$$

The stream power index (SPI) is a measure of the power of water flow based on the assumption that discharge (q) is proportional to specific catchment area ( $A_s$ ) (Eq. 2)(Moore et al., 1991).

$$SPI = (A_s \times \tan \beta) \quad (2)$$

where  $A_s$  is the specific catchment's area ( $m^2/m$ ), and  $\beta$  is slope gradient (in degrees).

The road, drainage network, and existing structure layers were collected from secondary sources and various government office. The geological, geomorphological and fault-lineaments layers were collected from the Geological

Survey of Bangladesh. Euclidean distance technique was executed to generate the distance images which calculates the distance from each raster cell to its nearest source (ArcGIS 10.2 Help, 2014).

The existing landslide inventory map is very essential for identifying the relationship between landslide distribution and the conditioning factors. To produce a comprehensive and reliable landslide inventory map, extensive field surveys and observations were performed in the study area. A total of 48 historical landslides were identified and mapped in the study area (Fig. 1-c). For each landslide hazard location, information on the soil characteristics, landslide width and length, slope angle, vegetation type, number of houses and population, and occurrence of landslide history were collected.

Saaty develops AHP method in 1977 which is used to identify the weights related with the suitability of map layers and combined the attributes of map layers. AHP is an effective tool in decision making and helps to check the consistency of attributes suggested by the decisions makers. AHP builds a hierarchy of decision criteria through pairwise comparison of the factor maps (Saaty, 1977). The weight in AHP rating monitors a 9-point continuous scale: (1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9). Here, the factor weight values greater than 1 represent more importance, less than 1 represent less importance, and 1 represents equal importance in relation to another factor (Ahmed, 2015; Eastman, 2012). The weights also undertake eigenvalues and eigenvectors calculations. If one factor has a preference, then its eigenvector component is larger than that of the other. The eigenvector values sum to unity (Reis et al., 2012). In AHP, an index of consistency have been used to determine the degree of consistency, designated as the Consistency Ratio (CR), expressed in Eq.4 (Reis et al., 2012). The consistency index (CI) of a matrix of comparisons is as Eq.3

$$CI = (\mu_{max} - n) / (n - 1) \quad (3)$$

Where  $\mu_{max}$  is the largest or principal eigenvalue of the matrix, and n is the order of the matrix (Saaty, 1977).

It is stated that CR ratings greater than 0.10 should be re-evaluated (Saaty, 1977).

$$CR = CI / RI \quad (4)$$

Where RI is the average of the resulting CI depending on the order of the matrix given by (Saaty, 1977).

The weighting value of this method was given by calculation process of analytical hierarchy process (AHP). The values were extracted based on the level of influences. Expert opinion is an important part of the AHP method because it depends on the observed physical characteristic of landslides which helps to determine the levels of the influencing factors in the hazardous area.

## Result and Discussion

As previously discussed pairwise comparison matrix for all the factors were constructed in the first step of AHP method and the factor weights were assigned based on the knowledge gathered from fieldwork and expert opinion surveying in RMA area. All factors were classified into a few groups.

Table 1 Pairwise comparison matrix for AHP

Criteria	Pairwise Comparison 9 Point Continuous Rating Scale												Eigen Value
	SP	LC	NV	GU	EV	DS	DR	DST	SPI	TWI	PC	PRC	
SP	1	3	4	5	8	4	5	7	6	7	8	9	0.267005
LC	0.333	1	3	4	8	4	5	6	6	5	8	8	0.202036
NV	0.25	0.333	1	3	7	3	5	5	5	6	7	8	0.149356
GU	0.2	0.25	0.333	1	5	0.333	1	4	3	4	5	6	0.072
EV	0.125	0.125	0.143	0.2	1	0.2	3	3	4	1	3	4	0.047428
DS	0.25	0.25	0.333	3	5	1	2	4	4	5	6	7	0.098754
DR	0.2	0.2	0.2	1	0.333	0.5	1	4	4	5	5	6	0.058815
DST	0.143	0.167	0.2	0.25	0.333	0.25	0.25	1	0.333	1	2	3	0.021889
SPI	0.167	0.167	0.2	0.333	0.25	0.25	0.25	3	1	2	3	4	0.031025
TWI	0.143	0.2	0.167	0.25	1	0.2	0.2	1	0.5	1	2	3	0.024139
PC	0.125	0.125	0.143	0.2	0.333	0.167	0.2	0.5	0.333	0.5	1	2	0.015504
PRC	0.111	0.125	0.125	0.167	0.25	0.143	0.167	0.333	0.25	0.333	0.5	1	0.012049

Consistency Ratio = 0.09 (Accepted)

SP= Slope, LC=Land Cover type, NV = NDVI, GU = geological unit, EV = Elevation, DS= Distance to Structure, DR= Distance to Road, DST= Distance to Stream, SPI= Stream Power Index, TWI= Topographic Wetness Index, PC = Plan Curvature, PRC = Profile Curvature

The first group consists of slope, elevation, plan curvature and profile curvature parameters; the second one includes distance from faults parameters which were extracted from the geological map. The next groups presenting the hydrological condition contains of distance from streams, topographical wetness index (TWI), stream power index

(SPI). The final group consists of land use and distance from roads parameters because both of these were induced by human activities. The level of influence for groups and parameters were estimated by the range of weighting and were determined by the range of weighting values between spectrums from minimum to maximum. It was found that the highest weight was assigned to slop. Land cover, NDVI and distance to structure factors were also found effective. The other layers (i.e., distance to road, stream, TWI, SPI) were identified as less important (Table 1).

The final weight values were automatically calculated by means of spatial multi-criteria evaluation in IDRISI Selva software. Based on weighting values in AHP, the levels of the influence of parameters were generated. The CR of the AHP method was found  $<0.1$  that can be considered as acceptable (Saaty, 1977). Based on total weight value, the Landslide susceptibility map for Hazard watershed was constructed in Fig. 2.

### Validation of the Landslide Susceptibility Map

To develop LSM and determination of its prediction ability Validation is an essential step. The area under the ROC curve (AUC) is a very effective approach to measure the validity of a susceptibility mapping. This method has been widely used as a measure of performance of a predictive rule (Chuvieco et al., 2010; Yesilnacar & Topal, 2005). AUC values  $\leq 0.5$  indicate no improvement, between 0.7 and 0.9 indicate reasonable agreement, and  $AUC \geq 0.9$  represents an ideal situation (Eastman, 2012). Figure 3 shows the ROC curve of the spatial multi-criteria evaluation model for the training sample. The AUC value is 0.763, indicate the good ability of a function to correctly discriminate between failed and un-failed groups in the sample used to develop the susceptibility model.

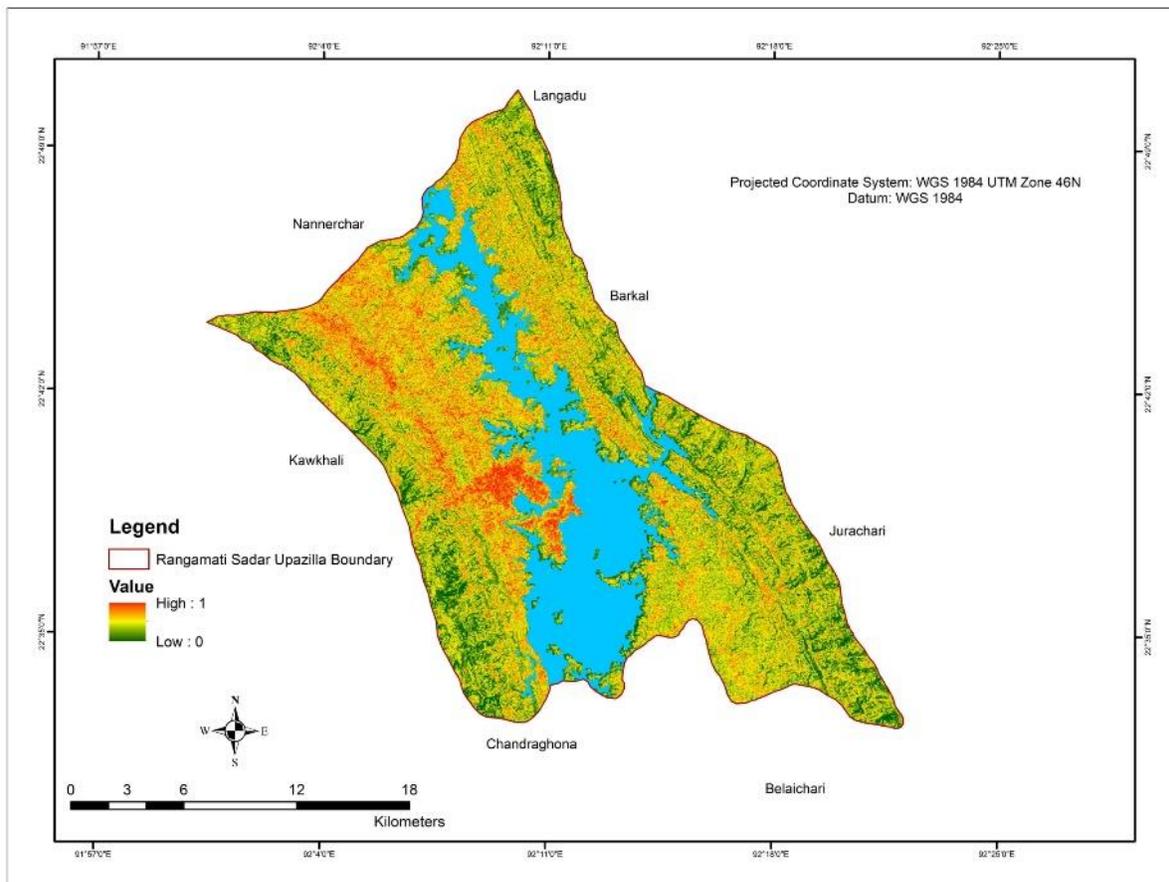


Figure 2 Landslide susceptibility map using AHP method

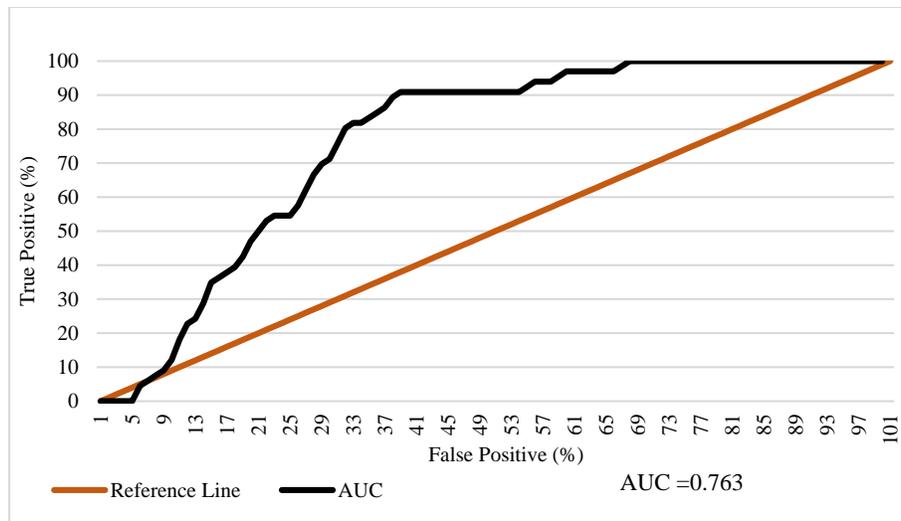


Figure 3 Assessment of the model performances based on the ROC curves

### Conclusion

Landslides are devastating phenomena causing serious casualties, economic and property loss. This situation is increased in recent year due to the manipulation of the natural formation of the hills to accommodate the living of people in the dangerous foothills region. Majority of human fatalities and costs related to landslide hazard occur in economically least-developed countries and this scenario is highly noticed for urbanized hilly areas of RMA. The aim of this article is to produce statistically valid and rational landslide susceptibility maps, using GIS- and RS based modelling techniques and freely available data sets, for the people living in the hazardous hilly gradients in RMA. The landslide susceptibility map prepared using weight-based approach (i.e. AHP) in the current study is the outcome of a combination of various factors responsible for landslide susceptibility, in which each factor has relative significance to probable landslide activity. In this study, eleven landslide-controlling parameters, namely slope, elevation, geology, plan and profile curvature, land use, NDVI, distance from streams, distance from roads, distance from structure, topographic wetness index, stream power index, were considered. The landslide inventory map of 48 observed landslides in RMA was then compared with the LSMs produced with the help of the AHP method. For the purpose of model verification, ROC curves have been produced. The AUC values for AHP was calculated as 0.763 which describe the statistically significant of the model and the produced map has exhibited promising results. The availability of higher-resolution satellite images, better base maps, and up to date data sets can help to produce better accuracies and validation results in LSMs. The research outcome will help the threaten the local community, urban planner and engineers to reduce the fatalities caused by existing and upcoming landslides by means of prevention and mitigation strategies adaptation in the hilly and vulnerable landslides occurrence regions of Bangladesh. The results will be an effective approach for explaining the driving factors of the known historical landslides, for preparing necessary emergency and risk-sensitive land use plans and for supporting activities to mitigate the future landslide hazards in RMA, Bangladesh.

### Acknowledgement

We are grateful to the Landslide experts, Rangamati Hill District Council, Chittagong Development Authority, Geological Survey of Bangladesh, Chittagong City Corporation, Bangladesh Meteorological Department, Survey of Bangladesh, Bangladesh Agricultural Research Council, U.S. Geological Survey, and the National Aeronautics and Space Administration for providing the necessary datasets.

### References

Ahmed, B. (2015). Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh. *Landslides*, 12(6), 1077-1095.

- Ahmed, B., & Dewan, A. (2017). Application of bivariate and multivariate statistical techniques in landslide susceptibility modeling in chittagong city corporation, bangladesh. *Remote Sensing*, 9(4), 304.
- Ahmed, B., & Rubel, Y. (2013). Understanding the issues involved in urban landslide vulnerability in Chittagong metropolitan area, Bangladesh.
- ArcGIS 10.2 Help. (2014). Environmental systems research institute (ESRI). Redlands, CA, USA. <http://resources.arcgis.com/en/help/main/10.2/>. Accessed 12 February 2015.
- Bangladesh Bureau of Statistics, B. (2013). District Statistics 2011, Rangamati (M. o. P. G. o. T. P. s. R. o. B. Statistics and Informatics Division (SID), Trans.) (pp. 1-137). [www.bbs.gov.bd](http://www.bbs.gov.bd).
- Chousianitis, K., Del Gaudio, V., Sabatakakis, N., Kavoura, K., Drakatos, G., Bathrellos, G. D., & Skilodimou, H. D. (2016). Assessment of Earthquake-Induced Landslide Hazard in Greece: From Arias Intensity to Spatial Distribution of Slope Resistance Demand Assessment of Earthquake-Induced Landslide Hazard in Greece. *Bulletin of the Seismological Society of America*, 106(1), 174-188.
- Chuvieco, E., Aguado, I., Yebra, M., Nieto, H., Salas, J., Martín, M. P., . . . Ibarra, P. (2010). Development of a framework for fire risk assessment using remote sensing and geographic information system technologies. *Ecological Modelling*, 221(1), 46-58.
- Demir, G., Aytekin, M., Akgün, A., Ikizler, S. B., & Tatar, O. (2013). A comparison of landslide susceptibility mapping of the eastern part of the North Anatolian Fault Zone (Turkey) by likelihood-frequency ratio and analytic hierarchy process methods. *Natural hazards*, 65(3), 1481-1506.
- Eastman, J. (2012). IDRISI Selva help system. *Clark Labs, Clark University, Worcester*.
- Ferdous, L., Kafy, A.-A., Roy, S., & Chakma, R. (2017). *An analysis of Causes, Impacts and Vulnerability Assessment for Landslides Risk in Rangamati District, Bangladesh*. Paper presented at the International Conference on Disaster Risk Mitigation., Dhaka, Bangladesh.
- Kafy, A.-A., Rahman, M. S., & Ferdous, L. (2017). *Exploring The Association of Land Cover Change and Landslides In The Chittagong Hill Tracts (CHT): A Remote Sensing Perspective*. Paper presented at the International Conference on Disaster Risk Management Dhaka, Bangladesh.
- Khan, Y. A., Lateh, H., Baten, M. A., & Kamil, A. A. (2012). Critical antecedent rainfall conditions for shallow landslides in Chittagong City of Bangladesh. *Environmental Earth Sciences*, 67(1), 97-106.
- Moore, I. D., Grayson, R., & Ladson, A. (1991). Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. *Hydrological processes*, 5(1), 3-30.
- Nefeslioglu, H. A., Gokceoglu, C., & Sonmez, H. (2008). An assessment on the use of logistic regression and artificial neural networks with different sampling strategies for the preparation of landslide susceptibility maps. *Engineering Geology*, 97(3-4), 171-191.
- Pourghasemi, H. R., Mohammady, M., & Pradhan, B. (2012). Landslide susceptibility mapping using index of entropy and conditional probability models in GIS: Safarood Basin, Iran. *Catena*, 97, 71-84.
- Pourghasemi, H. R., Pradhan, B., Gokceoglu, C., Mohammadi, M., & Moradi, H. R. (2013). Application of weights-of-evidence and certainty factor models and their comparison in landslide susceptibility mapping at Haraz watershed, Iran. *Arabian Journal of Geosciences*, 6(7), 2351-2365.
- Rahman, M. S., Ahmed, B., & Di, L. (2017). Landslide initiation and runoff susceptibility modeling in the context of hill cutting and rapid urbanization: a combined approach of weights of evidence and spatial multi-criteria. *Journal of Mountain Science*, 14(10), 1919-1937.
- Reis, S., Yalcin, A., Atasoy, M., Nisanci, R., Bayrak, T., Erduran, M., . . . Ekerin, S. (2012). Remote sensing and GIS-based landslide susceptibility mapping using frequency ratio and analytical hierarchy methods in Rize province (NE Turkey). *Environmental Earth Sciences*, 66(7), 2063-2073.
- Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of mathematical psychology*, 15(3), 234-281.
- Scaioni, M., Longoni, L., Melillo, V., & Papini, M. (2014). Remote sensing for landslide investigations: An overview of recent achievements and perspectives. *Remote Sensing*, 6(10), 9600-9652.
- Yalcin, A. (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): comparisons of results and confirmations. *Catena*, 72(1), 1-12.
- Yesilnacar, E., & Topal, T. (2005). Landslide susceptibility mapping: a comparison of logistic regression and neural networks methods in a medium scale study, Hendek region (Turkey). *Engineering Geology*, 79(3-4), 251-266.