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GIS based Landslides Susceptibility Mapping using Probabilistic Certainty Factor for Hazard Zonation in Mandakini Valley

Seema Joshi, J.K. Garg, Amarjeet Kaur

Abstract*: Landslides are highly threatening a phenomenon which is very common in hilly region and mountainous regions. These landslides trigger major risks leading to heavy losses in terms of life and property. Many studies were conducted globally to determine Landslide vulnerability of different locations. In order to assess vulnerability, there were few studies around Landslides Susceptibility mapping also whose main objective is to identify high-risk vulnerable areas, there by applying measure to reduce the damage caused, if it were to happen in near future. In literature, there are many methods available for predictive susceptibility mapping of landslides. However, identification of any of the prevalent method for a specific area require utmost care and prudence because land sliding is a result of complex geo-environmental spatial factors. Mandakini valley is highly ruggedized terrain with intensive rains during monsoon season. As a result, Landslides are very common in the Mandakini River valley and its catchment area. These landslides cause severe damage to human settlements and infrastructure present in this area. In this study, we have used certainty factor method in order to generate landslide susceptibility map for the catchment area of Mandakini river. Certainty factor approach is a bi-variate probabilistic method which uses Geo-environmental parameters like elevation, slope, aspect, rainfall distance away from river, soil characteristics etc. to generate landslide susceptibility map. A Script was developed in ArcPy - a python package to design tools for generating susceptibility map. These tools can run both at desktop level and at server level and generate results in an integrated way. Esri ArcMap 10.7 is used in order to generate required data layers and thematic maps. Overall, this paper leverages GIS technology and its tools to performs Landslide Susceptibility Mapping using Probabilistic Certainty Factor and generate Hazard Zonation of Mandakini Valley using an automated script for generating Landslide Susceptibility Mapping and Hazard Risk Zonation. It was found that out of 696, total 136 villages are under high risk of landsides, total 329 villages are under moderate risks and around 231 villages are under low risk zonation impacting lives of approx. 216166 people. Also, it is worth mentioning that a GIS based script was developed to automate generation of Landslide Susceptibility Maps which can be used where the same geological and topographical feature prevails.

Keywords: GIS, Landslides, Susceptibility, mapping, Certainty factor (CF)

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***** Correspondence Author

Seema Joshi*, Esri India Technologies Ltd, University School of Environment Management, Guru Gobind Singh Indraprastha University, New Delhi, India. Email: seema.joshi@esri.in

J.K. Garg, University School of Environment Management, Guru Gobind Singh Indraprastha University, New Delhi, India. Email: gargjk@gmail.com

Amarjeet Kaur, University School of Environment Management, Guru Gobind Singh Indraprastha University, New Delhi, India. Email: amarjeet_ip@yahoo.com

I. INTRODUCTION

Landslide is a down slope movement of rock or soil, or both occurring on the surface of rapture in which much of the material often moves as a Coherent or semi coherent mass with little internal information. These landslides are the most threatening Hazard in hilly terrain which has major impact on human life and Infrastructure.

Asia is the site of highest number of landslides with substantial number of landslides along the Himalayas. According to Geological Survey of India about 0.42 million square kilometre of land that is landslide prone area which is distributed all along the Himalayan belt and Western Ghats.

The Himalayan region is most eco-fragile regions in the world (Anbalagan 1992) [1]. The region is a affected by a number of disasters like earthquakes, flash floods, Glacier Lake Outburst Floods, forest fires, hailstorms, avalanches and landslides (NDMA 2007). Among these disasters, landslides are the most frequent hazards causing adverse effects on the community (Saha et al. 2005) [9]. Active tectonic activity, heavy rainfall, unplanned development and anthropogenic activities are responsible for landslide.

The present study focuses on Mandakini Valley in the Uttarakhand state of India. This valley is well known for landslide hazards. From the reports, it was observed that since 2000 more than 350 people lost their lives and several villages were affected due to various landslides in this mountain state (Parkash 2015). In June 2013 during Kedarnath Disaster, more than 4000 people lost their lives due to flash floods which triggered landslides in and around the Mandakini Valley (Satendra et al. 2015). Creating inventory of landslides is very important step in reducing losses related to landslides. Towards this, Geological Survey of India has launched National landslide susceptibility mapping program to map create Inventory of landslide and come out with susceptibility map for landslide prone area. Once inventory is prepared, various methods and scientific techniques were used to create landslide susceptibility map.

Geographical information system (GIS) and Earth observation data provide reliable and scalable methods to create landslide susceptibility map. GIS as a tool it is very effective in managing data related to landslide. A detailed outline of methods used for creating susceptibility map has been well put out in Literature (Comparison of different models for susceptibility mapping of earthquake triggered landslides related with the 2008 Wenchuan earthquake in China). In this study, we have used certainty factor method in order to generate landslide susceptibility map for the catchment area of Mandakini river. Certainty factor approach is a bi-variate probabilistic method. This method uses Geo-environmental parameters like elevation, slope, aspect, rainfall distance away from river, soil characteristics etc. to generate landslide susceptibility map.

A Script was developed in Arcpy - a python package to design tools for generating susceptibility map. These tools can run both at desktop level and at server level and generate results in an integrated way. Further, Esri ArcMap 10.7 w used in order to generate required data layers and thematic maps.

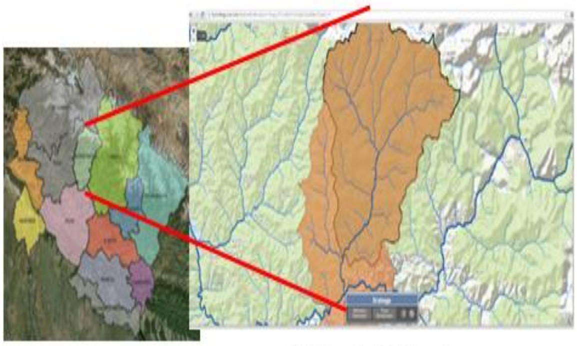
The main goal of landslide susceptibility analysis is to identify dangerous and high risk areas and prepare Landslide Hazard Zonation which can be used to suggest measures for building Risk Resiliency n the Study Area. This paper suggests how GIS can be used for building susceptibility map of landslide in Mandakini watershed using Probabilistic Certainty Factor method.

II. STUDY AREA

In the recent past, the state of Uttarakhand has witnessed a number of geo-hazards leading to various disasters. It is vulnerable to small ecological changes and hence any small disturbance in mountain ecosystem triggers a disaster. Mandakini Valley by virtue of its geographical setting, is one of the most disaster prone areas in the state. [7]

Mandakini River Valley, administratively, lies in Rudraprayag district of Uttarakhand State, covering an area of about 1982 sq. km lies between lat. 30° 12” 58.132’ – 30° 48” 27.642’ N and long. 79° 2” 58.649’ – 79° 2” 0.952’ E. Mandakini is a branch of the Alaknanda River and originates from the Chorabari Glacier near Kedarnath in Uttarakhand, India. Mandakini River joins Alaknanda at Rudraprayag. [7]

For the purpose of this paper, Rudraprayag District of Uttarakhand was selected as entire district is falling under catchment of Mandakini River Valley as shown in Fig.1. (Seema 2019 et. al) [9]. For study sites, cities/habitations adjoining Mandakini River were selected enrouting from Rudraprayag to Guptkashi. For multi-hazard vulnerability assessment, entire Mandakini Valley was considered. [7]



(a) Rudraprayag District (b)Mandakini Catchment

Fig. 1. Study Area

III. MATERIALS & METHODOLOGY

A. Model Description

Certainty Factor is commonly used probabilistic GIS model. Certainty factor was generated for each layer based on various layers and landslide inventory. A detailed Block Diagram of entire process [7] is shown in Fig.2.

Certainty factor, which is a function of probability for each pixel, is given below as (1)

$$CF = \begin{cases} \frac{ppa - pps}{ppa(1-pps)} & \text{if } ppa \geq pps \\ \frac{ppa - pps}{pps(1-ppa)} & \text{if } ppa < pps \end{cases} \quad (1)$$

Where CF is certainty factor. This ranges between -1 to 1. Positive values indicated an increase in certainty and negative value indicates decrease in certainty. Value 1 means it is very certain that landslide will happen and value -1 means landslide will not happen at all. [7]

ppa is conditional probability of having a number of landslide in a class

pps is the prior probability of having total number of landslide in the whole area

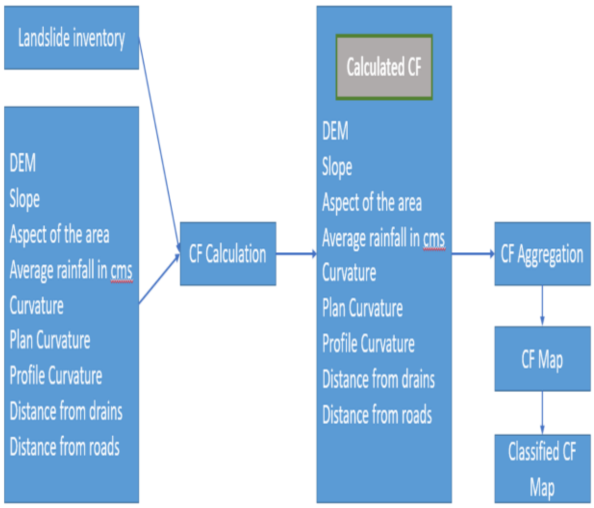


Fig 2 – Approach & Methodology - Block Diagram

Once CF is generated for all layers using the CF formula (1), these CFs are combined pairwise using integration rules.

Hence CF (z) of 2 layers, x and y is given by formula

$$z = \begin{cases} x + y - xy, & x, y >= 0 \\ \dfrac{x + y}{1 - \min(|x|, |y|)} & x, y \text{ opposite sign} \\ x + y + xy, & x, y < 0 \end{cases} \quad (2)$$

Where :

z is the aggregated CF value

x,y are 2 CF rasters

Final CF is generated by combining CF of all 9 input layers. This CF raster is then classified based upon Table I below [10]

Table I: CF Classification

Sl. no.	Description	Susceptibility class	Range of certainty factor
1	Very low certainty–stable	Very low	−1–0.5
2	Low certainty–moderately stable	Low	−0.5–0.05
3	Uncertain	Uncertain	−0.05–0.05
4	High certainty–moderate instability	High	0.05–0.5
5	Very high certainty–high instability	Very high	0.5–1

B. Preparation of Data

Following 9 parameters were taken to generate Landslide Susceptibility Map using **Probabilistic Certainty Factor:**

a. DEM
b. Slope
c. Aspect of the area
d. Average rainfall in cms
e. Curvature
f. Plan Curvature
g. Profile Curvature
h. Distance from drains
i. Distance from roads

- As revealed in various studies, in gradually undulating terrain, elevation values of Cartosat-DEM are lower than SRTM-DEM, whereas the stream parameter values of Cartosat-DEM are higher than SRTM-DEM. As per ISRO-Bhuvan also, CartoDEM products are extremely useful in contour generation; drainage network analysis; quantitative analysis of run-off and soil erosion; volume-area calculations; design of hydraulic structures; design of new road, rail and pipeline alignments; watershed planning; urban utility planning; landslide zonation; river configuration studies and flood proofing; and fly through visualization; etc. Hence, for this study Cartosat-1 DEM was considered.
- Using same DEM, different inputs required towards "Curvature" like Plan curvature, Profile curvature were drawn using ArcGIS Spatial Analyst extension.
- Other layers like Slope, Aspect were also calculated from this DEM using ArcGIS Spatial Analyst extension.
- For Average rainfall, TRMM and relevant data was taken from NASA website https://neo.sci.gsfc.nasa.gov/). Monthly average rainfall of the area was taken for 15 years from 2001 to 2015
- Distance from drainage network was calculated using "Euclidean Distance" tool.
- Similarly, layer representing distance from roads was also generated using "Euclidean Distance" tool in ArcGIS.
- To integrate in this model, Landslides locations were required in raster format. This was generated by converting Landslide point feature class to raster using Feature to Raster tool. As pixel size of the raster is generally taken somewhere between 60 to 100 meter. So landslide raster that we have used has pixel size of 100 meter.

C. Classification of Data

In order to work on certainty factor model, we were required to generate conditional probability of having number of landslides in every class of the input data and also probability of having total number of landslides in the study area. Hence, to get conditional probability of the classes, we classified all input data into desired classes.

- **Calculating CF for all the Rasters**

For calculation of CF, we have used equation (1)
For Study area, calculated pps is **0.006785**.
Same was used for generation of "ppa" for all classes of all layers.
This code also aggregates the CF and gave final CF for the regions. To aggregate the CF formula (2) has been used.
CF calculations for all the raster is given in the Table 3. For aggregated CF, we required all these CF of each parameter and aggregation done using formula (1). The aggregated CF is again classified into following 5 class as shown in Table 2 below. Detailed Results generated for all Rosters during this process are shown in Table III.

D. Design of Re-usable Script for Automation

To simplify, one script was written to automated the entire process using ArcPy.

This re-usable python Script was used to automate entire process of generation of different data layers with desired classification.

Under this Script, following Tools were developed:
Tool 1 : Classification Tool for Landslide Data
Tool 2 : Certainty Factor
Tool 1 Fig. 3 was used for classification of data related to landslide

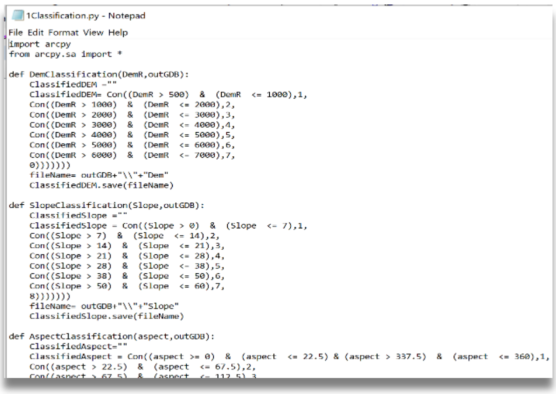


Fig. 3 Classification Script

Tool 2 as shown in Fig.4 was used to calculate CF factor individually and then give aggregated Certainty Factor Susceptibility map as shown in Fig 5.

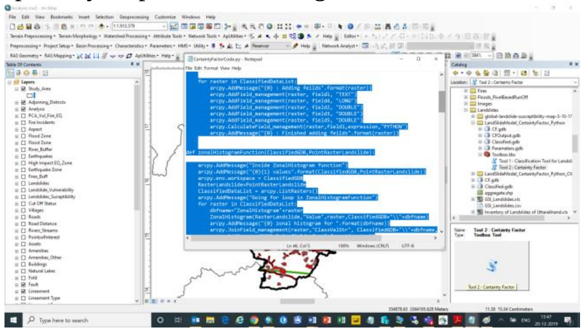


Fig. 4: Script for Calculation of Certainty Factor

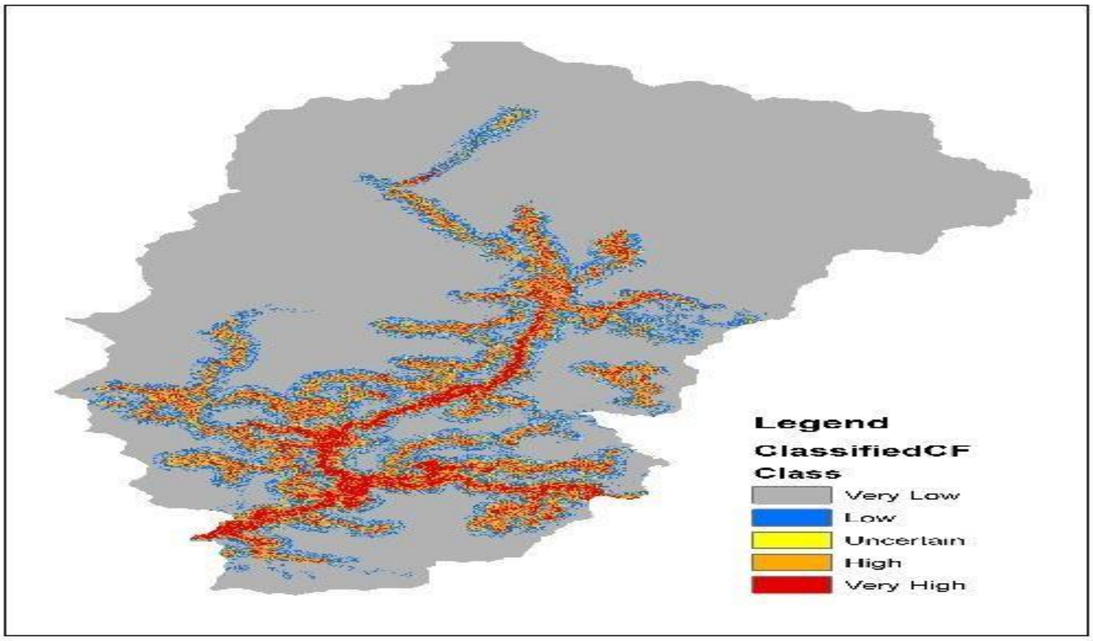
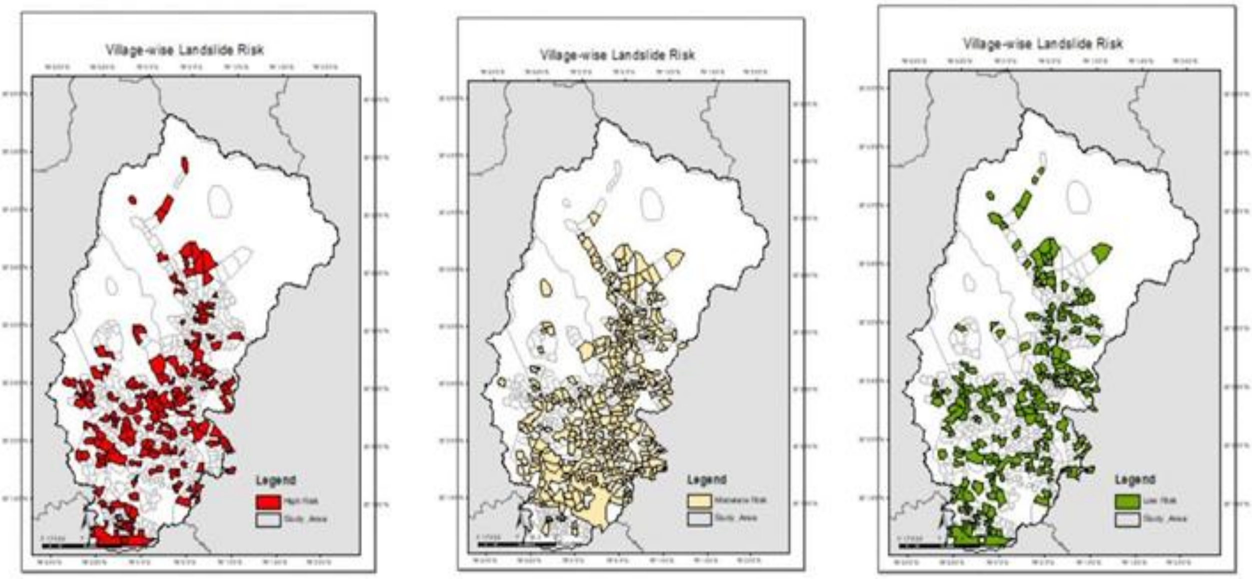


Fig 5: Landslides Susceptibility Map



(a) High Risk **(b) Moderate Risk** **(c) Low Risk**

Fig. 6: Village-wise Landslides Hazard Risk Zonation

Table II: Landslide Hazard Zonation

Hazard Impact	Total Villages Affected	Total Area (Sq.km.)	Total Area of Affected Villages under Risk (%)	Total Affected Population
High	215	16.42	6.47	92092
Moderate	329	32.53	7.63	117376
Low	231	18.69	6.83	92092
Total	605	93.32	3.70	216166

E. Outputs & Results

Generated Landslide Susceptibility Map was overlaid with Village-wise demographic map of the area for Landslide Risk Zonation. Villages were categorized under Very High Risk, High Risk, Moderate Risk and Low Risk and Very Low Risk as shown in Fig. 5 below. All these five categories of Hazard Risk were further aggregated in three categories – High, Moderate and Low Risk as shown in Table II below.

Table III – Generated CF of all different parameters

Layer	Class Value	Count	Landslides in each class	ppa	pps	CF
Aspect	-1	282955	153	0.000541	0.006785	-0.9208
	2	291459	160	0.000549	0.006785	-0.9196
	3	287215	217	0.000756	0.006785	-0.88932
	4	321728	303	0.000942	0.006785	-0.86201
	5	312091	254	0.000814	0.006785	-0.88077
	6	310685	209	0.000673	0.006785	-0.90146
	7	276611	275	0.000994	0.006785	-0.85432
	8	259507	194	0.000748	0.006785	-0.89049
DEM	1	131572	276	0.002098	0.006785	-0.69228
	2	837995	901	0.001075	0.006785	-0.84244
	3	713535	300	0.00042	0.006785	-0.93843
	4	345765	265	0.000766	0.006785	-0.88772
	5	254688	24	0.000094	0.006785	-0.98621
	6	58558	0	0	0.006785	-1
	7	7742	0	0	0.006785	-1
General Curvature	1	1215670	787	0.000647	0.006785	-0.90517
	4	1134185	979	0.000863	0.006785	-0.87354
Plan Curvature	1	1256458	882	0.000702	0.006785	-0.89717
	4	1093397	884	0.000808	0.006785	-0.88155
Profile Curvature	1	1260962	1071	0.000849	0.006785	-0.87556
	4	1088893	695	0.000638	0.006785	-0.90651
Rain	1	4308	0	0	0.006785	-1
	2	148553	0	0	0.006785	-1
	3	1518584	149	0.000098	0.006785	-0.98564
	4	3279088	1527	0.000466	0.006785	-0.9318
	5	443102	90	0.000203	0.006785	-0.97026
Distance from River	1	980929	848	0.000864	0.006785	-0.87334
	2	551678	470	0.000852	0.006785	-0.87518
	3	265927	179	0.000673	0.006785	-0.9014
	4	121049	50	0.000413	0.006785	-0.93951
	5	84338	29	0.000344	0.006785	-0.94965
	6	263012	13	0.000049	0.006785	-0.99276
	7	418344	3	0.000007	0.006785	-0.99895
	8	2761451	174	0.000063	0.006785	-0.99078
Distance from roads	1	182390	311	0.001705	0.006785	-0.74997
	2	165883	224	0.00135	0.006785	-0.80206
	3	171359	191	0.001115	0.006785	-0.83666
	4	138434	119	0.00086	0.006785	-0.87406
	5	141693	96	0.000678	0.006785	-0.90076
	6	606338	243	0.000401	0.006785	-0.94131
	7	950997	131	0.000138	0.006785	-0.97983

	8	8751434	451	0.000052	0.006785	-0.99246
Slope	1	39961	29	0.000726	0.006785	-0.89369
	2	162236	103	0.000635	0.006785	-0.90701
	3	355528	225	0.000633	0.006785	-0.9073
	4	490619	327	0.000667	0.006785	-0.90237
	5	718840	557	0.000775	0.006785	-0.88649
	6	465970	432	0.000927	0.006785	-0.86416
	7	92810	85	0.000916	0.006785	-0.86581
	8	16287	7	0.00043	0.006785	-0.93706

IV. CONCLUSIONS & RECOMMENDATIONS

In this paper, GIS was used to generate Hazard Risk Zonation of Villages. For this Probabilistic certainty factor was used for estimation of Landslide Susceptibility in the study area. The relationship between a landslide occurrence and the identified 9 causative factors such as slope angle, aspect, general curvature, plan curvature, profile curvature, altitude, distance to rivers, distance to roads and rainfall was evaluated using CF method. The selection of the 9 critical landslide factors which are responsible for Landslides are based on relevance, availability, and scale of data that was available for the study area. These parameters are relative and subjective, and can be improved in future research.

About 1893 landslides observed in the study area were used in this model and outputs were validated using historical hazards and their severity. The susceptibility maps was then generated by CF method, which divided study area into five different susceptibility classes such as very low, low, moderate, high, and very high. These were further consolidated in three categories. Finally, this map was integrated with various administrative boundaries and demography of the area to generate Landslide Hazard Zonation. It was found that out of 696, total 136 villages are under high risk of landsides, total 329 villages are under moderate risks and around 231 villages are under low risk zonation impacting lives of approx. 216166 people.

The output results of the present study can help the decision makers and disaster managers to manage slopes and choose susceptible locations to implement mitigation measures. It can further help in developing disaster risk reduction strategies and in disaster management

Also, it is worth mentioning that a GIS based script was developed to automate generation of Landslide Susceptibility Maps which can be used where the same geological and topographical feature prevails.

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REFERENCES

1. Anbalagan.1992. Landslide hazard evaluation and zonation mapping in mountainous terrain. Engineering Geology: 32, pp 269-277.
2. Asthana, A.K.L. and Sah, M.P. 2007. Landslides and Cloudbursts in the Mandakini Basin of Garhwal Himalaya. Himalayan Geology, Vol.28 (2).pp.59-67. Printed in India
3. Carrara, A., M. Cardinali, R. Detti, and F. Guzzetti., (1991), GIS techniques and statistical models in evaluating landslide hazard: Earth surface process, Landform v. 16(5), pp 427445.
4. Carrara, A., F. Guzzetti, M. Cardinali, and P. Reichenbach., (1999), Use of GIS technology in the prediction and monitoring of landslide hazard, Natural hazards, 20, pp 117- 135.
5. Garg, J.K; Murthy T. V. R; Kimothi, M. M Singh, T. S. (2001). Environmental Hazard Zonation and Optimal Resources Use in the Alaknanda Valley, Garhwal Himalaya using Remote Sensing and GIS Techniques.
6. Gupta, Peeyush and Kimothi. M.M. 2012. Slope instability and Landslide hazard zonation mapping of the area around Nainital. Proc. National symposium on Space technology for food and environment security and annual conventions of Indian society of remote sensing and Indian society of geomatics, 5-7 Dec, ICAR, New Delhi.
7. Joshi S, Garg J.k., Kaur A. 2020. Multi-Hazard Risk Zonation based on functions responsible for Hazards like Landslides, Floods, Forest Fires and Earthquakes in Mandakini Valley – Under Publication
8. Joshi V; Naithani AK, Negi. GCS 2001. Study of Landslides in Mandakini River Valley, Garhwal Himalaya, India. GAIA, 16, 87-95.
9. Saha AK, Gupta RP, Arora MK,(2002), GIS – based landslide hazard zonation in a part of the Himalayas, Int. Jrn. Remote Sens, 23, pp 357-369.
10. Wang Qiqing, Li Wenping, Chen Wei and Bai Hanying, October 2015 GIS-based assessment of landslide susceptibility using certainty factor and index of entropy models for the Qianyang County of Baoji city, China, J. Earth Syst. Sci. 124, No. 7, October 2015, pp. 1399–1415

AUTHORS PROFILE

Seema Joshi
Research Scholar – USEM, GGSIPU, New Delhi
A passionate GIS Professional with 24+ years of experience in Geo-spatial Technologies, Enterprise GIS Solutions, Handling Strategic Initiatives, Solutions, Trainings & Capacity Building.
Education: MBA (Disaster Management) from USEM, Guru Gobind Singh Indraprstha University (GGSIPU), New Delhi
Working with Esri India as General Manager – Technology & Solutions
Worked at LBSNAA, Mussoorie as GIS Consultant

***Specialisation* :**

- Conceptualising & Designing Domain Specific Enterprise GIS Solutions. Domain Expertise: Disasters Management & Emergency Response, eGovernance, Urban Development, Hydrology, Forestry and Natural Resources
- Advanced Spatial Analytics & GIS based Modelling
- Strategic & Technical Consulting - Trusted Technical Consultant of a number of key organisations like NDMA & SDMAs for Disaster Management initiatives
- Solution Architecture & Designing Technology– Esri ArcGIS Enterprise, Cloud GIS Platform, Location Analytics, Web GIS, Mobile GIS, Open Source, Remote Sensing & Image Processing, Customisation, AI & ML Integration, GIS based Simulations & Modelling etc.
- Esri Authorised Trainer – Visiting Faculty at Premier Institutions Designed & Executed Domain Specific Capacity Building Modules for Senior Executives (IAS / IFS / Defense / CRPF / DM etc.)
- Organized a series of Sessions in National / International Conferences https://www.linkedin.com/in/seema-joshi-bb3184a/

Prof. J.K. Garg
University School of Environment Management
Guru Gobind ingh Indraprastha University, New Delhi
Education M.Phil., Ph.D
He is M. Phil. (Environmental Science) from Jawaharlal Nehru University, New Delhi and Ph.D. in the area of Wetland Conservation and Management from Gujarat University, Ahmedabad.

Field of Interest
Geospatial techniques for Aquatic and Wetland Ecosystems Management, Climate change and ecosystem response, Biodiversity Conservation, Ecosystem Restoration, Disaster Management, Environmental Impact Assessment.

Teaching Experience
Senior Fellow – TERI School of Advanced Studies
Adjunct Professor National Institute of Advanced Studies, Bengaluru
Governing Body Member, Wetland International - South Asia, New Delhi
South Asia Lead, Global Observation of Forest Cover and Land Dynamics
Formerly with Guru Gobind Singh Indraprastha University, New Delhi and Space Applications Centre (ISRO), Ahmedabad
Prof. J.K. Garg has 40 years of research experience. Dr. Garg has joined Space Applications Centre (ISRO), Ahmedabad in 1976 and has pioneered the research pertaining to use of remote sensing and GIS for environmental applications in the country. He has completed successfully 12 research projects sponsored by the Ministry of Environment, Forest, and Climate Change, Ministry of Agriculture, Department of Space, and GNCTD in various spheres of bio-resources and environment using geospatial techniques. His main endeavour has been to develop techniques for environmental appraisal of developmental activities, wetland conservation and management, biodiversity conservation, wildlife habitat suitability analysis, landslide hazard assessment, forest fire etc. besides natural resources census using RS and GIS techniques. He was also Project Manager (Landslides) from India in International Charter on Space and Disasters. Prof. Garg has more than 160 publications which include research papers in international/national journals, book articles, and reports etc. His current areas of research include emission and modelling of GHGs, climate change and ecosystem response, hyperspectral remote sensing of wetlands, Urban Heat Island Effect, Riverine ecosystems and landscape dynamics, environmental hazards and developmental planning, biodiversity conservation, EIA of major developmental activities, river valley projects, ecosystem analysis and management, and natural hazards assessment etc. using geospatial techniques and other contemporary analytical tools. Prof. Garg has been in the selection committee of various universities such as Central University of South Bihar, Nalanda University, Rajgir, TERI University etc., and also National Centre for Antarctic and Oceanic Research, Goa, Ministry of Earth Sciences, DRDO etc.

Prof. Amarjeet Kaur
Director, CDMS, Guru Gobind ingh Indraprastha University, New Delhi
Education M.Sc., Ph.D
Field Of Interest1) Remote sensing/ GIS application in Environment (2) Environment microbeal technology.
Teaching Experience Dr. (Mrs.) Amarjeet Kaur did M.Sc. from Kurukshetra University and Ph.D. from Haryana Agriculture University, Hisar. She has more than 25 years of experience in research and training. Her areas of specialization are applications of Remote Sensing Technology in Environmental Management, Disaster Management, and Environmental Biotechnology. She has worked as Principal/Co-Principal Investigator of various international/national projects related to Environment Management. She has visited USA, UK and Japan in connection with study exchange programmes and conferences. She was also involved in Environmental Management Plan of Delhi using Remote Sensing Technology and GIS.