International Journal of Innovative Scientific Research
2025, Vol. 3, Issue 3, pp. 1-8

International Journal of
Innovative Scientific Research

Journal homepage: https://ijisr.net

Research paper

Geo-Spatial Analysis of Landslides and Flood Hazards Driven by Climate Change and Quarrying in the Southern Western Ghats

Sanjay Sukumaran *[1], **Dr. Giriprasad C.** [1]

[1] *Department of Geology, Mansarovar Global University, Billkisganj, Sehore, Madhya Pradesh, India*

KEYWORDS

Climate Change

Landslides

Flood Hazards

Quarrying

Western Ghats

Remote Sensing

ABSTRACT

This study investigates the influence of climate change and quarrying activities on landslides and flood hazards in the southern region of the Western Ghats, utilizing remote sensing and GIS data for comprehensive geo-spatial analysis. The Western Ghats, a UNESCO World Heritage site, is characterized by its biodiversity and fragile ecosystems, making it highly vulnerable to natural hazards such as landslides and floods, which are exacerbated by both climatic factors and human activities. The study specifically focuses on the interaction between changing climate patterns, quarrying, and their collective impact on the region's vulnerability to these hazards.

Remote sensing data, including satellite imagery from Landsat and MODIS, combined with GIS-based analytical tools, were employed to map the land use/land cover (LULC) changes, identify landslide and flood susceptibility zones, and assess the spatial distribution of quarrying operations. The study also included the application of hydrological models and rainfall intensity analysis to understand the relationship between extreme rainfall events and the occurrence of landslides and floods.

Results from the study indicate a significant correlation between quarrying activities and an increased frequency of landslides, particularly within 500 meters of quarry sites. Additionally, the findings reveal that the southern Western Ghats are experiencing higher flood risks due to intensified rainfall patterns linked to climate change, with the most vulnerable areas being those with reduced vegetation cover and increased human-induced land disturbances. The analysis further highlights a clear trend of vegetation loss and increased built-up areas over the past two decades, particularly around active quarries.

This study emphasizes the urgent need for integrated land-use management and policy interventions to mitigate the impacts of quarrying and climate change on the region's natural hazards. The findings offer valuable insights for environmental conservation efforts, disaster risk management, and sustainable development strategies in the Western Ghats, advocating for the promotion of eco-friendly mining practices, stricter regulations on land use, and adaptive measures to combat climate-related hazards.

***Corresponding author**: Sanjay Sukumaran

DOI 105281/ijisr-2130425

1. Introduction

Landslides and floods are among the most destructive natural disasters, frequently exacerbated by human activities and climatic variations (Kanwar and Kuniyal, 2022). Landslides involve the movement of soil, rock, or debris down a slope and can range from minor rockfalls to large-scale flows of mixed materials. Often, these events are closely linked to floods, forming part of a multi-hazard scenario. In the southern parts of the Western Ghats, an ecologically sensitive and topographically diverse region, landslides and floods are increasingly influenced by two significant factors: climate change and quarrying activities. These interconnected drivers amplify the frequency, intensity, and impact of such hazards, posing severe risks to local ecosystems, infrastructure, and communities (Ali et al., 2021).

Climate change is a global phenomenon with profound implications for weather patterns, biodiversity, and natural landscapes (Dey et al., 2020; Das et al., 2022). In the context of the Western Ghats, rising temperatures, altered precipitation patterns, and extreme weather events are triggering more frequent and severe landslides and floods (Pathak, 2016). Over the past two decades, global average temperatures have risen significantly due to greenhouse gas (GHG) emissions from activities such as deforestation and fossil fuel use. The Inter-governmental Panel on Climate Change (IPCC) predicts further warming of up to 4.8°C by the end of the century, with cascading effects on regional rainfall intensity and soil stability. These climatic shifts have increased the vulnerability of the Western Ghats to landslides and flood events, especially during monsoon seasons.

1.1 Landslides: An Overview

A landslide is a downward and outward movement of slope-forming materials such as rock, soil, and debris under the influence of gravity. Landslides can be categorized into various types, including debris flows, rockfalls, slumps, and translational or rotational slides, depending on the material involved and the mode of movement. In hilly and mountainous terrains like the Western Ghats, landslides are a common geomorphological process, especially during the monsoon season (Rai et al., 2014).

1.1.1 Landslides in the Southern Western Ghats

The southern part of the Western Ghats, due to its steep gradients, fractured bedrock, deep weathering zones, and heavy seasonal rainfall, is highly prone to landslides. Regions in Kerala (e.g., Idukki, Wayanad), Tamil Nadu (e.g., Nilgiris), and Karnataka (e.g., Kodagu) have witnessed frequent and often devastating landslide events. These incidents not only result in the loss of life and property but also lead to soil erosion, sedimentation of rivers, and habitat destruction.

1.1.2 Climatic Influence

The increasing frequency and intensity of extreme rainfall events associated with climate change have become a critical trigger for landslides in this region. Prolonged heavy rains saturate the soil, increase pore-water pressure, reduce shear strength, and ultimately cause slope failure. Moreover, changing rainfall patterns—such as short-duration, high-intensity storms—intensify surface runoff and accelerate mass movements (Adjei-Darko, 2017).

1.2 Human-Induced Triggers: The Role of Quarrying

Unscientific and excessive quarrying has emerged as a major anthropogenic factor aggravating landslide risks. Blasting operations, removal of overburden, road cutting, and unregulated slope modification destabilize the already fragile hill slopes. Quarrying also disrupts the natural drainage, creating waterlogging or diversion that increases erosion and subsurface seepage. In many instances, landslides have occurred in close proximity to active or abandoned quarries, highlighting the spatial and causal link between these activities.

1.3 Importance of Remote Sensing and GIS in Landslide Studies

Modern tools such as Remote Sensing (RS) and Geographic Information Systems (GIS) provide effective methodologies for analyzing landslide-prone zones. These technologies enable:

- Mapping and monitoring of land use/land cover changes over time.
- Terrain analysis, including slope, elevation, and aspect, derived from DEMs.
- Integration of multi-criteria datasets (e.g., rainfall, geology, proximity to faults/quarries) for landslide susceptibility zonation (LSZ).
- Post-disaster assessments to identify the extent and impact of past landslide events.

The use of satellite imagery, geospatial modeling, and field-based validation allows for the creation of predictive maps and risk models, aiding planners and disaster management authorities in implementing early warning systems and mitigation strategies (Sholihah et AL., 2020).

To evaluate community perceptions and adaptive responses to flood hazards, with a focus on understanding the socio-economic impacts on lives, livelihoods, and resilience mechanisms in the southern parts of the Western Ghats.

To examine the primary triggers of landslides by analyzing spatiotemporal rainfall patterns and correlating them with fluctuations in groundwater and surface water levels, aiming to identify critical thresholds for slope failure.

To analyze the lithological, geomorphological, and soil characteristics of the study region in order to understand the geophysical conditions contributing to landslide susceptibility and hazard intensification.

2. Literature Review

N. Arif (2022) underscores the critical role of vulnerability mapping in mitigating the impacts of natural disasters. The research highlights how remote sensing and GIS tools can effectively analyze vulnerabilities in dynamic landscapes prone to environmental risks. By focusing on parameters like land-use types, terrain slopes, and built-up density, the methodology provides insights relevant to areas impacted by climate-induced landslides and floods, as well as anthropogenic activities such as quarrying.

Using Landsat 8 OLI satellite data, techniques like the Normalized Difference Built Index (NDBI) were employed to assess structural density and land-use distribution. GIS layering further enabled the spatial visualization of at-risk zones. The findings demonstrated that densely built regions are particularly vulnerable, with 26% of the study area classified as very high vulnerability, followed by high (29%), moderate (29%), and low (16%). While the study focuses on urban centers like Yogyakarta City, its approach offers a valuable framework for evaluating vulnerabilities in the Western Ghats, where climatic variability and quarrying exacerbate the risk of landslides and floods. Integrating similar remote sensing and GIS methodologies can help identify priority zones, ensuring targeted interventions and improved disaster resilience in ecologically sensitive regions.

Kansal et al. (2022) explored the disaster-prone geography of Uttarakhand, a Himalayan state characterized by its fragile ecosystem and frequent calamities like floods, cloudbursts, and landslides. The study examined both natural and human-induced causes of these events, emphasizing the role of increasing urbanization since the state's formation in 2000. Additionally, the research discussed the implications of climate change, such as intense rainfall, and proposed an effective flood management framework to mitigate these impacts while protecting lives and infrastructure.

Ali et al. (2018) evaluated morphometric parameters to understand flood and soil erosion risks in Kashmir's Sukhnag watershed. Using DEM data, the study classified areas into high, medium, and low vulnerability zones. Findings indicated that unstable slopes, dense lineaments, and unsustainable development exacerbated erosion and flooding risks. This research emphasized targeted soil conservation and flood management strategies for sub-watersheds to minimize damage.

Mahyat Shafapour et al. (2017) conducted a comparative study to evaluate the effectiveness of three flood prediction methods: Frequency Ratio (FR), Logistic Regression (LR), and Weight of Evidence (WoE). Their research, focusing on flood-prone areas in China, revealed that the WoE model outperformed the other techniques, achieving an impressive 90.36% prediction accuracy when used independently. This finding highlights the capability of the WoE method in accurately mapping regions vulnerable to flooding. The study emphasizes the model's potential for broader application in disaster preparedness and risk mitigation. In the context of landslides and floods influenced by climate change and quarrying in the southern Western Ghats, the integration of the WoE method with remote sensing and GIS data could provide critical insights for identifying high-risk zones and enhancing resilience in this environmentally sensitive region.

3. Materials And Method

This study employs an integrated geospatial approach to assess the impact of climate change and quarrying activities on landslide and flood hazards in the Ooty region of the southern Western Ghats, Tamil Nadu. The methodology involves data acquisition, spatial analysis, hazard mapping, and field validation.

3.1 Study Area Delineation

The area of interest (AOI) is Ooty and its surrounding hilly terrain in the Nilgiris district, characterized by steep slopes, high rainfall, and extensive anthropogenic pressure. Administrative boundaries and topographic features were derived from Survey of India maps and extracted using shapefiles of the Western Ghats ecoregion. A 30-meter resolution SRTM DEM was used to define elevation, slope, and physiographic details.

3.2 Data Sources

Multi-temporal satellite imagery (Landsat 8, Sentinel-2, and IRS LISS-III) was used for land use/land cover (LULC) analysis for the years 2000, 2010, and 2022. Climate data including rainfall and temperature from 1990 to 2020 were collected from the India Meteorological Department (IMD) and local AWS stations. Geological and soil data were obtained from the Geological Survey of India (GSI) and NBSS&LUP. Quarry data were mapped using high-resolution imagery, field GPS surveys, and mining department records. Historical disaster data were compiled from NDMA, district disaster records, and satellite-based change detection.

3.3 Analytical Techniques

Supervised classification using the Maximum Likelihood Algorithm was conducted on satellite images to generate LULC maps. DEM was used to derive slope, aspect, flow direction, and drainage networks using ArcGIS and QGIS. Rainfall trend analysis was performed using the Mann-Kendall test and Sen's Slope Estimator. Landslide susceptibility mapping was carried out using Multi-Criteria Evaluation (MCE) through Analytic Hierarchy Process (AHP), incorporating factors such as slope, LULC, lithology, proximity to roads and quarries, and rainfall intensity. Flood hazard mapping involved DEM-based hydrological modeling and identification of low-lying zones.

3.4 Change Detection and Impact Analysis

LULC change was analyzed through post-classification comparison, revealing forest loss, quarry expansion, and increased impervious surface. NDVI and Land Surface Temperature (LST) were derived to evaluate vegetation loss and thermal changes, particularly near quarry sites.

3.5 Field Validation and Statistical Analysis

Ground truthing was conducted using GPS and UAV surveys to verify landslide scars, quarry locations, and flood zones. Statistical models, including Logistic Regression and Random Forest, were applied to assess the influence of variables on landslide occurrence and flood frequency.

3.6 Mapping and Visualization

Thematic maps were generated for landslide susceptibility, flood hazard zones, LULC changes, and quarry hotspots using ArcGIS, QGIS, and ERDAS Imagine. These outputs supported the development of risk mitigation strategies for ecologically sensitive and hazard-prone areas in the Ooty region.

4. Results

Table 1 Amount of Annual Rainfall, in Millimetres, for the Decade (2012-2021).

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Rainfall in mm	1069	1720	1700	1560	1730	1615	1860	1511	1531	1279

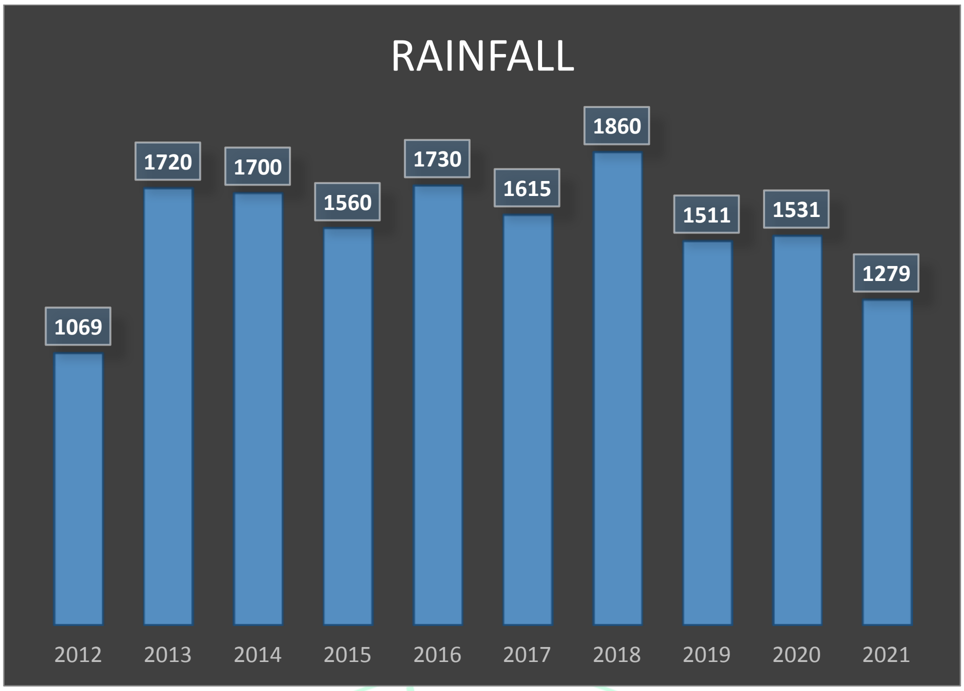

Fig. 1 Rainfall Variations during the Time Frame (2012 – 2021)

The research, conducted from 2012 to 2021, explored the impact of climate change and quarrying activities on landslides and floods in the southern parts of the Western Ghats, utilizing Remote Sensing and GIS data. During this period, the region experienced significant fluctuations in rainfall, with 2012 recording the lowest levels and 2018 experiencing the highest, as depicted in Figure 1 and Table 1. The precipitation pattern exhibited a distinct wavelike trend across the years, reflecting the influence of varying climatic conditions.

Table 2 Yearly Seasonal Rainfall Averages (in millimetres) over the Decade (2012-2021)

Stations	Post-Monsoon season	Pre-Monsoon season	Southwest monsoon	Northeast Monsoon	Yearly Average
Adarly	45.42	131.67	138.97	317.83	633.88
Avalanche	27.5	172.68	2467.05	902.4	3569.63
Coonoor	110.79	358.2	385.44	1018.95	1873.38
Coonoor (RLY)	96.1	340.86	449.23	1075.17	1961.36
Devala	7.7	278.3	2923.36	511.9	3721.26
Ellamanna	9.97	234.17	1723.92	371.43	2339.48
Emarald	32.17	216.57	1173.27	469.77	1891.77
Glenmorgan	6.2	243.99	1049.96	358.21	1658.36
Govermersola	15.83	243.07	825.97	411.33	1496.2
Gudalore	9.32	204.84	1465.51	284.85	1964.52
Gurrency	25.72	158.53	191.35	459.77	835.37
Hillgrove	113.26	292.83	331.34	663.37	1400.8
Kallatti	1.08	71.54	202.69	142.34	417.65
Kethi	38.44	436.32	737.91	830.93	2043.6
Kinnakoraai	38.17	110.83	124.92	370.08	644
Kodanadu	47.09	338.31	325.13	687.05	1397.58
Kothagiri	56.85	381.66	357.8	676.04	1472.35
Kundah	50.8	228.79	484.5	586.53	1350.62
Kunshola	94.6	293.48	386.02	759.15	1533.25
Naduuvattam	6.11	192.37	1886.97	348.22	2433.67
Ooty	12.11	258.15	545.92	507.82	1324
Ooty_SCR	17.73	254.89	679.16	391.36	1343.14
Runnyymedu	128.5	323.34	307.39	995.37	1754.6
Upperbhavani	30.17	194.67	2219.75	479.77	2924.35
Valvewoodes	60.33	155	214.87	368.92	799.12
Annur	9.04	121.59	139.7	210.63	480.96
Karamadai	16	136	56	289	497
Mettupalayam	44	217	162	439	862
Pnpalayam	29	109	161	379	678

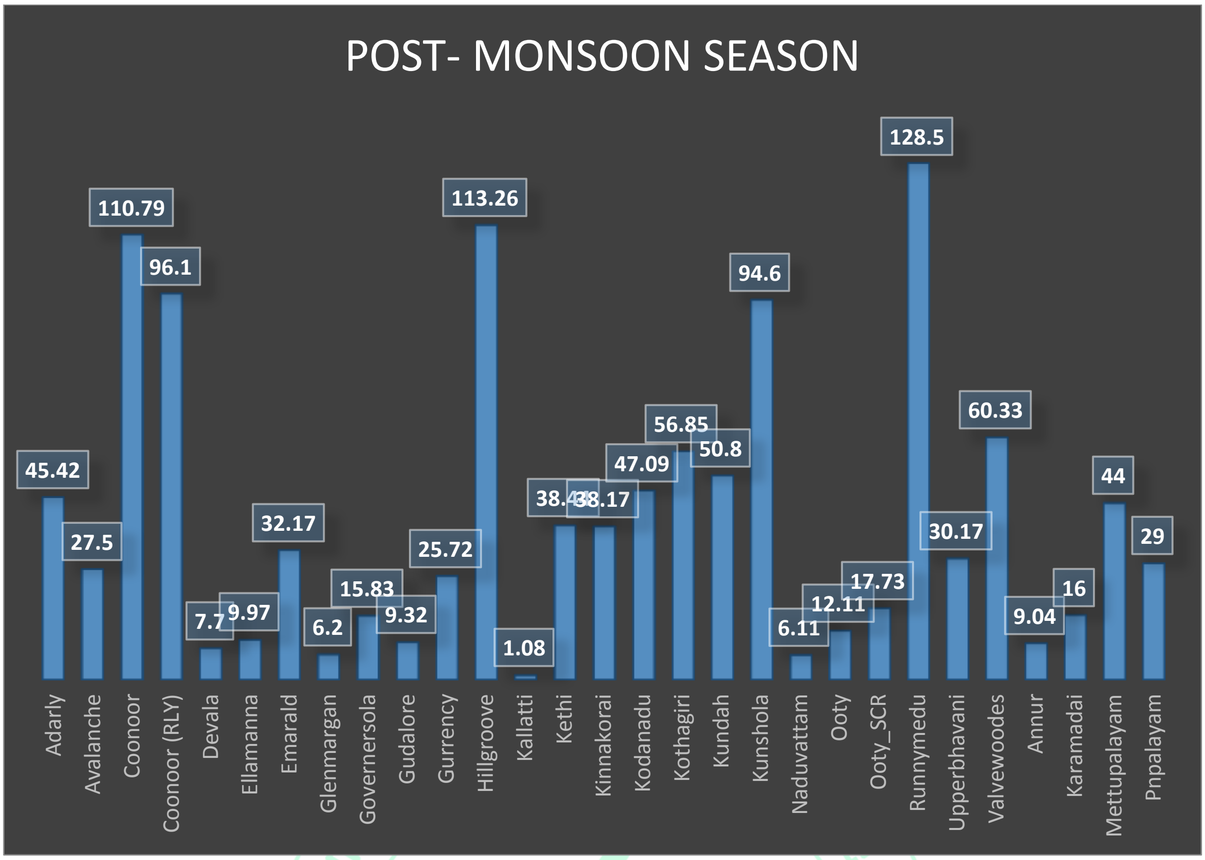

Fig. 2 Rainfall variation of Post-Monsoon – 2012-2021

Figure 2 highlights significant changes in rainfall across six different regions. The graph clearly illustrates the extremes, with the peak representing the highest rainfall and the trough the lowest.

5. Discussions

The data presented in Table 1 and Table 2 offer valuable insights into the variability of annual rainfall over the decade (2012-2021) and its seasonal patterns, as observed in the southern parts of the Western Ghats. These figures provide a foundation for understanding the broader impacts of climate change and quarrying activities on natural disasters like landslides and floods (Ramachandra et al., 2012)

Figure 1, which captures the rainfall variations over the decade, demonstrates a distinct pattern of fluctuations. The region experienced notable changes in precipitation, with 2012 recording the lowest levels and 2018 marking the highest rainfall. These fluctuations are likely influenced by both global climate change and local anthropogenic factors, such as quarrying activities (Putri et al. 2013).

The trend shows a wavelike pattern, which can be linked to the irregular climatic conditions, possibly attributed to the influence of El Niño and La Niña cycles, which often bring erratic rainfall to the region. This irregularity, particularly the extremes in 2012 and 2018, may reflect the increasing unpredictability of weather patterns in the context of changing global climates.

In Table 2, the yearly seasonal rainfall averages provide additional context by breaking down the annual precipitation into distinct seasonal patterns. These seasonal averages are critical in understanding how rainfall is distributed across the monsoon and post-monsoon periods, as these have direct implications for the region's hydrological dynamics and the frequency of natural disasters like landslides and floods (Savith et al., 2021).

The higher rainfall levels observed in some years may indicate an over-saturation of the soil, making it more susceptible to landslides. On the other hand, the lower rainfall levels, particularly in 2012, may have contributed to reduced vegetation cover, further exacerbating soil erosion and making the terrain more vulnerable to flooding in subsequent years. The variability in these seasonal averages highlights the need for adaptive water resource management strategies that account for fluctuating rainfall patterns.

Figure 2 delves into post-monsoon rainfall variations, where the graph clearly shows extremes, with peaks representing higher rainfall and troughs indicating drier periods. These post-monsoon months are critical in understanding the cumulative impact of rainfall during the entire year. The variation observed could be due to shifts in the monsoon's duration and intensity, which might have been influenced by long-term climate trends (Seddon et al., 2020).

Such rainfall patterns are of particular importance when examining the region's susceptibility to floods and landslides. Excess rainfall during the post-monsoon season can lead to flash floods, while a lack of rainfall during this period may hinder the replenishment of groundwater levels, exacerbating drought conditions.

The fluctuations in rainfall, particularly during the monsoon and post-monsoon periods, are closely linked to landslide and flood risks in the Western Ghats. In years with above-average rainfall, the saturated soil conditions increase the likelihood of landslides, particularly in regions with steep slopes and disturbed landscapes due to quarrying activities. Conversely, in years with below-average rainfall, while the risk of landslides may decrease, the region may still face severe flooding during subsequent rain events due to reduced water absorption capacity of the soil.

6. Conclusions

The data suggests that the region's climate is experiencing increasing variability, which may be further amplified by human activities like quarrying. Both extreme rainfall years (such as 2018) and drought years (like 2012) underline the need for a comprehensive understanding of local climate patterns to predict and mitigate the risks associated with landslides and floods. The fluctuations in seasonal rainfall could inform future flood management and landslide prevention strategies, emphasizing the importance of early warning systems, land-use planning, and sustainable quarrying practices.

This analysis highlights the need for ongoing monitoring of rainfall and climate trends, using Remote Sensing and GIS data, to better understand the interplay between climate change, anthropogenic activity, and natural disasters in the region.

References

1. Kanwar, N., Kuniyal, J.C. (2022). Vulnerability assessment of forest ecosystems focusing on climate change, hazards and anthropogenic pressures in the cold desert of Kinnaur district, northwestern Indian Himalaya. J Earth Syst Sci 131, 51. https://doi.org/10.1007/s12040-021-01775-z
2. Ali, N., Alam, A., Bhat,M.S. et al. (2021)Developing a Hazard Profile of The Kashmir Valley Through Historical Data Analysis For The Period 1900-2020, 16 December 2021, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-1148421/v1]
3. Dey, M., Mazumder, M., Sarkar, A.K., Ghosh, S., Sarkar, D., Rahaman, R. (2020). Floristic composition and fodder availability in Patlakhawa Forest patches under Cooch Behar Forest Division, West Bengal, India. NeBIO 11(3): 220-233.
4. Das, B., Mandal, S., Sarkar, K., Mazumdar, I., Kundu, S. and Sarkar, A K. (2022) Contribution of Ethnic and Indigenous people in the Conservation of Plant Biodiversity in India. Adv. Biores. 13(3):209-229.
5. Pathak, D. (2016). Remote sensing and GIS application in landslide risk assessment and management. Nepalese Journal on Geoinformatics. 15. 52-57.
6. Rai, P.K., Kshitij Mohan, K., and Kumra V.K. (2014) Landslide Hazard and Its Mapping Using Remote Sensing and GIS. Journal of Scientific Research.58:1-13.
7. Adjei-Darko, P. (2017). Remote Sensing and Geographic Information Systems for Flood Risk Mapping and Near Real-time Flooding Extent Assessment in the Greater Accra Metropolitan Area.
8. Sholihah, Q., Kuncoro, W., Wahyuni, S., Suwandi, S.P. and Feditasari, E.D. (2020). The analysis of the causes of flood disasters and their impacts in the perspective of environmental law", IOP Conf. Series: Earth and Environmental Science.437: 012056. 10.1088/1755-1315/437/1/012056
9. Arif, N., Wardhana, A., and Martiana, A. (2022). Spatial analysis of the urban physical vulnerability using remote sensing and geographic information systems (case study: Yogyakarta City). IOP Conf. Series: Earth and Environmental Science 986:012067
10. Kansal, M.L.; Singh, S. (2022). Flood Management Issues in Hilly Regions of Uttarakhand (India) under Changing Climatic Conditions. Water. 14:1879.
11. Ali, U., Ali, S.A., Ikbal, J., Bashir, M., Fadhl, M., et al. (2018) Soil Erosion Risk and Flood Behaviour Assessment of Sukhnag catchment, Kashmir Basin: Using GIS and Remote Sensing. J Remote Sensing & GIS 7: 230
12. Shafapour Tehrany, M., Shabani, F., Neamah Jebur, M., Hong, H., Chen, W., & Xie, X. (2017). GIS-based spatial prediction of flood prone areas using standalone frequency ratio, logistic regression, weight of evidence and their ensemble techniques. Geomatics, Natural Hazards and Risk, 8(2), 1538–1561. https://doi.org/10.1080/19475705.2017.1362038
13. Ray R.L., Lazzari, M. and Olutimehin, T. (2020). Remote Sensing Approaches and Related Techniques to Map and Study Landslides. In Landslides - Investigation and Monitoring. InTech Open. doi: 10.5772/intechopen.93681

14. Ramachandra, T.V, Subash Chandran, M.D, Joshi, N.V, Julka, P., Kumar, U.,. Aithal, B.H., Mesta, P., Rao, G.R., and Mukri, V. (2012). Landslide Susceptible Zone Mapping in Uttara Kannada, Central Western Ghats., ENVIS Technical Report: 28, Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012.
15. Putri, R.F., Wibirama, S., Alimuddin, I., Kuze, H., Sumantyo, J.T.S. (2013). Monitoring and Analysis of Landslide Hazard Using Dinsar Technique Applied to Alos Palsar Imagery: A Case Study in Kayangan Catchment Area, Yogyakarta, Indonesia Journal of Urban and Environmental Engineering. 7(2):308-323
16. Savith, S., Sheela, A.M. and Vineetha, P. (2021). Post landslide Investigation of Shallow Landslide: A case study from the Southern Western Ghats, India. Disaster Advances. 14: 52. 10.25303/147da5221.
17. Seddon, N., Chausson, A., Berry, P., Girardin, C.A.J., Smith, A., Turner, B. (2020) Understanding the value and limits of nature-based solutions to climate change and other global challenges. Phil. Trans. R. Soc. B 375: 20190120.