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Advanced geo-computational techniques in natural hazards and disaster studies: monitoring, management, and mitigation

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1 Introduction

Natural hazards and disasters are observed frequently around the world due to the deleterious impacts of the unprecedented urbanisation and industrialisation process [1–3]. There is also an increase in worldwide interest to study the potential impacts of weather and climate extremes on natural hazards and disasters [4–7]. Increasing temperatures, shifts in precipitation patterns, and hastening glacier melt are profoundly accelerating the frequency, intensity, and complexity of disaster events [8, 9]. The local topography and geological settings are mainly responsible for the increasing frequency of disasters.

The hilly terrains are particularly more susceptible to such events that causes catastrophic effects on loss of human lives and infrastructure damage. The observational evidence indicates a clear ascending trend in hydrometeorological events, compound and cascading disasters [10–12]. Underprivileged communities in developing world are more susceptible because of several forms of hazards and disasters [3, 13]. It directly impacts the food security, water availability, and rural livelihoods followed by rise in climate-induced migration [3]. Exact and reliable information on the population under risk, causative factors, its patterns, and behavior can prevent many casualties and property losses. The increasing frequency, intensity, and complexity of disasters under climate change have exposed the limitations of conventional hazard assessment and risk management frameworks.

2 Evolution of geo-computational paradigms in natural hazards and disaster studies

Conventional methods largely rely on the linear models are not adequate to address complex and dynamic nature of disasters [14]. These methods are often based on static historical dataset without linking socio-economic aspects. The increasing intensity and frequency under climate change have exposed the limitations of conventional hazard assessment and risk management frameworks [7, 15]. With the advent of Geospatial technologies, disaster events can be monitored effectively to support resilience. The emergence of advanced computational methods and their effective utilization is now becoming crucial in disaster and multi-hazard studies. It remarkably shifts the paradigm from map-centric analysis to intelligent, self-learning, predictive, and cloud-based disaster management systems. The coupling of remote sensing (RS), Geographic Information Systems (GIS) with advanced computational methods such as big data analytics artificial intelligence/machine learning (AI/ML), deep learning (DL), Internet of Things (IoT), cloud and edge computing stipulates the technological foundation for building resilient and adaptive disaster risk reduction systems. These advanced Geo-computational techniques can be used effectively to model, visualize, predict natural hazards and disasters from local to global scale [6, 10, 16–18]. The real-world projection of these techniques makes it explicitly applicable for functional policies and investigation in an era of ever-increasing climate and weather extremes.

3 Summary and synthesis of published articles in this topical collection

This topical collection titled "*Advanced Geo-Computational Techniques in Natural Hazards and Disaster Studies: Monitoring, Management, and Mitigation*" mainly focuses on the state-of-the-art geo-computational methods and spatial predictive models for vulnerability and impact assessment of hazards and disasters. It includes thirty-four articles demonstrating cutting-edge applications of geospatial technologies, and advanced computational techniques such as AI/ML, DL, google earth engine (GEE) in the field of disaster management, risk reduction, and mitigation strategies. With a multifold increase in the number and volume of geospatial data, advanced computational techniques have emerged as a transformative framework that is used for modelling, visualisation, and prediction of natural hazards and disasters. This integrated framework digital tools, geospatial analytics, and real-time data ecosystems makes it more appropriate for functional policies and investigation. Based on the major disaster and hazard types, the published articles are divided into various thematic groups as given below.

3.1 Hydrological disasters

This thematic group highlights the use of geo-computational techniques in hydrological disasters and hazards studies, particularly flood events in riverine landscapes.

In the first article of this theme Arora et al. [19] analysed the contribution of climatic factors in flood event in the Middle Ganga Plain (MGP), India. Several statistical, spatial, probabilistic and trend analyses is performed on meteorological parameters to establish the link between climatic variables and flood events. It was observed that the rainfall in monsoon season correlated with major flood events. The northern part of MGP showed higher rainfall that aligned with the observed flood patterns. On the other hand, geostatistical analysis revealed that the western and eastern portions of MGP were susceptible to extreme rainfall. Also, the occurrence of strong monsoon rainfall events was confirmed based on exceedance probability analysis. This study provides valuable insights into the primary climatic factors and patterns linked with flood events.

Singh and Rawat [20] used an online computing platform Google Earth Engine (GEE) to map flood inundation in the Kangra district located in the southern Himalayan region, India. In this study, dual polarized C-band Synthetic Aperture Radar (SAR) data before and after the flood event occurred in year 2023 is utilized. Image differencing method and a threshold value of 1.25 based on experimental analysis was used to map the flooded area. Around 75 km^2 area was found to be flooded in the final inundation map. This study emphasized the strength of GEE and SAR data in mapping and monitoring flood events in real time.

Pandey et al. [21] employed four advanced artificial intelligence (AI) based ensemble models to map flood hazard in low relief riverine floodplain of Ganga, India. The flood susceptibility mapping was performed using ensemble models namely Logistic Regression-Evidential Belief Function (LR-EBF), Logistic Regression-Frequency Ratio (LR-FR), Multi-Layer Perceptron-Evidential Belief Function (MLP-EBF), and Multi-Layer Perceptron-Frequency Ratio (MLP-FR). Multicollinearity analysis was applied on twelve chosen flood conditioning factors to evaluate the bias in the modes. It was found that the LR-based ensembles models with 87.2% and 84.7% accuracies performed better in comparison to MLP-based ensembles in selected topo-climatic condition. This study highlights the reliability of LR-based ensembles for improved flood prediction and better flood management strategies.

In another article by Handique et al. [22] examined the occurrence of floods in Lower Burhi Dehing River (LBDR) in Assam, India. The Gumbel's extreme value and Log Pearson Type III method was used in this study to analyse the past and current flood events and predict future flood frequencies. For this yearly maximum peak discharge data was utilized to investigate the discharge records of LBDR during 1972–1997. The return intervals of several flood magnitudes were estimated at 2, 5, 10, 20, 50, 100, and 200 years and the probability of severe future flood events were quantified. The largest and smallest flood events were observed in 1972 (discharge of 1134.4 m^3/s) and 1997 (discharge of 214.65 m^3/s). The results of this work can guide policy for more efficient flood management and mitigation strategies.

The article by Eteh et al. [23] predicted the flood-prone areas through an integrated approach of geospatial analysis and machine learning (ML) models in the downstream regions of Nigeria during 2018 and 2024. Three ML models such as artificial neural network (ANN), support vector machine (SVM), and random forest (RF) were applied on GEE to evaluate flood dynamics from 2018 to 2024. A greater susceptibility of flood events was observed in downstream regions (78–235.1 m elevation) compared to the upstream areas (up to 1399.43 m elevation). The flooded areas extended by 10.9% and 39.8% in the month of August and October respectively. In downstream regions the flood inundation increased from 20 to 35%. This article explored the potential of satellite-based observation, spatial analysis and ML models in analysing the dynamics of flood patterns leading to effectively support flood risk management in Nigeria.

A comprehensive flood risk mapping strategy was reported by Baral et al. [24] in Gangetic interfluvial flood plain region of India. In this study, GIS based analytical hierarchy process (AHP) method was employed to evaluate flood risk in Ghatal CD Block of West Medinipur, West Bengal. The AHP based flood hazard map was validated using ROC-AUC method by incorporating flood location data with an accuracy of 75%. A risk map was developed by combining flood hazard zones and vulnerability indicators. It was found that 36% of the total area comes under high to very high-risk zones. This type of study contributes to developing flood risk assessment methods and effective decision-making in mitigating the flood risks.

Roohi et al. [25] presented a comprehensive review on the flood damage in the mountainous regions. This review article describes the obstacles, causes, and consequences of flood events. Climate change, early glacier melting, altering precipitation patterns leading to more frequent and intense flooding in mountainous regions. Apart from this complex topo-climatic characteristics of such regions requires interdisciplinary approaches to effectively assess flood risks and adopt innovative damage mitigation strategies. The flood patterns can be studied effectively at various scales through integrating advanced remote sensing techniques, LiDAR, hydrological tools, AI/ML models. It is also emphasized the importance of integrating modern technologies with community engagement through case studies from Nepal, Himalayas, and the Alps regions. Early warning systems, predictive models, and organizational collaboration can play key roles in reducing flood damage and improved flood resilience.

Jain [26] provided a systematic review on utilizing cutting-edge geo-computational techniques in enhancing flood disaster resilience. This review article explores a complex framework for flood monitoring, management, and mitigation of flood risk by combining RS, GIS, LiDAR, UAVs, and advanced geospatial big data analytics like AI/ML models. Through many case studies, it was demonstrated how well these tools and techniques can improve risk assessment preparedness, mitigation and early warning systems. This comprehensive review of case studies highlights the transformative potential of geo-computational methods in advancing flood-resistant communities. Another key insight is the need of development of inclusive interdisciplinary framework to reduce the effects of flood disasters spanning the gaps between educational organization, government bodies, public organisations, and local communities.

3.2 Geophysical disasters

This thematic group highlights the use of geo-computational techniques for geophysical disasters, particularly in hilly landscape and mountainous regions. It mainly focused on landslides, rockfall and slope instability.

The article by [27] focused on the most landslide affected region in North-Western part of Ethiopia. Landslide susceptibility mapping was conducted using modified frequency ratio model based on eight major landslide causative factors. The susceptibility maps were prepared using the relative frequency values allocated to the suitable factor groups followed by the prediction rate of appropriate causative factors. It was found that 27.5% of total area falls under very low susceptibility, while 6.0% under very high susceptibility. The performance of modified frequency ratio model was found to be exceptionally well in landslide susceptibility mapping, with 82.6% and 83.1% success and prediction rates respectively. The results can serve as a foundation for more complex models into landslide systems and mitigation strategies to tackle this problem in this study area.

Mani et al. [28] worked on the landslide hazard zonation (LHZ) mapping using RS and GIS in Doon valley, India. Various thematic layers contributing to the landslide events were produced in GIS platform. A multi-criteria analysis approach was employed to designate attribute values to thematic layers individually based on their significance. The landslide hazard zones were calculated through a combination of attribute values. It was found that 16.6% of the total area falls under high to very high hazard zone, showing frequent occurrence of landslides in this region. Furthermore, it was revealed that upper parts of the rivers in Doon valley were more susceptible to the landslides than their lower parts. This work can serve as a reliable tool for decision-makers to understand potentially risky sites and implement needed safeguards to lower the effects of landslides.

Agarwal et al. [29] evaluated landslide susceptibility along a road corridor on national highway-7 (NH-7) in Uttarakhand, India. In this work three methods, namely frequency ratio (FR), analytical hierarchy process (AHP), and information value method (IVM) were used to produce spatial landslide susceptibility maps in GIS framework. Several landslide conditioning factors were selected based on the physiography of investigated study area and experts' opinion. A multicollinearity test was done to confirm the individuality of selected factors. The ROC-AUC method was applied to assess the accuracy of the methods used in this study. The AHP delivered an accuracy of 81.9% subsequently FR (78.3%) and IVM (75.2%) in mapping landslides into five categories such as very low, low, moderate, high and very high zones. The ease and effectiveness of the methods employed in this study can be appliable for landslide susceptibility mapping in other geographical settings.

Mandal et al. [30] assessed slope stability and landslide susceptibility along a road in the lesser Himalayan region of India. Several geo-mechanical classification techniques such as rock mass rating (RMR), slope mass rating (SMR), geological strength index (GSI), and kinematic analysis were used for over 18 selected slope sites that were unstable. Landslide susceptibility mapping was conducted using frequency ratio model based on various causative factors. Out of 18 chosen slope sites, four were reported as unstable. Those slopes were located in the lower segment of the Mussoorie area and Hathi Paon-Mussoorie Road. The slopes around Junu waterfall were reported to be stable. Heavy rainfall and unstructured construction may lead to slope failure for moderately unstable slopes. The performance of the frequency ratio model was found to be reasonably good for landslide susceptibility mapping, with 61% and 78% success and prediction rates respectively. This work emphasizes the landslide concerns in Mussoorie region due to rapid infrastructure development. It shows the requirement for structured construction practices to mitigate the harmful effects of urbanization on slope stability.

Kumar et al. [31] presented a comprehensive analysis on the slope stability and displacementof a witnessed landslide event along a road corridor near Kuther in Kangra District of Himachal Pradesh, India. A surface displacement monitoring approach combined with COSI-Corr technique, rock mass rating, kinematic analysis, slope mass rating, and continuous slope mass rating was used in this study. The slope was found to be extremely susceptible to planar failure, with few occurrences of wedge failure. The types III and IV of rock mass, showing moderate stable to stable conditions. The slope is moving slowly at an average rate of 4 mm/year as per displacement analysis. There is a critical need to analyse slope stability and displacement comprehensively to safeguard the communities in vulnerable zones. The modern strategies and early warning systems should be developed to enhance resilience in such geo-environmentally sensitive hilly areas.

Hamza et al. [32] investigated slope instability in a highly vulnerable zone for landslides and debris flows in Upper Chitral District of Pakistan. Almost 60–65 acres land and 60 houses were classified being under high risk. An outward-sloping terracing and bund reinforcement were proposed as part of a slope stabilization plan to mitigate these risks. These measures reduce the risk of slope failure effectively with improvement in initial value of Factor of Safety (FoS) from 0.83 to 1.5 in this region. This study demonstrated the combined use of geotechnical testing, hazard mapping, and numerical modelling in improving FoS, indicating an extensive reduction in the slope failure risk and mitigating natural hazards. This work will be helpful to protect the population, houses, and farmland, creating a more protected and stable life in the investigated area.

Kurt [33] conducted a comprehensive investigation of lethal rockfall incidents over the past five decades in Türkiye. This investigation revealed that heavy rainfall, earthquakes, and erosion are the primary triggering factors behind the prevalent distribution of rockfalls across Türkiye. Furthermore, anthropogenic activities like uncontrolled construction and mining works have intensified the risk of rockfalls. The high-risk zones were found to be in northern, eastern, and southwestern part of the country. This study suggested the use of a multidisciplinary approach to address rockfall events. It also offers valuable insights for policymakers and researchers to tackle the rockfall hazards in Turkish communities.

3.3 Environmental disasters and natural hazards

This thematic group pertains the hazards studies using geo-computational methods. The articles are mainly focused on air pollution, soil erosion and land degradation.

Bhaduri et al. [34] examined the relationship between urban growth modes and air pollution in Kolkata Urban Agglomeration (KUA), India. In this study, the concentrations of CO, NO_2, SO_2, HCHO, and O_3 pollutants of Sentinel-5P satellite data were analysed using Google Earth Engine (GEE) platform from 2018 to 2023. Annual and seasonal variations in pollutants were analysed to map hotspots. Additionally, the impacts of various growth patterns (infilling, edge expansion, and leapfrog) of urbanization on air quality were investigated. It was observed that Leapfrog pattern significantly rises the concentrations of NO_2, SO_2, and HCHO by 28.9%, while infilling increases CO and NO_2 concentrations. Edge expansion on the other hand had a lower impact on O_3 concentration. The results showed varying contribution of different pollutant around urban growth patterns. This study underscores urban expansion and associated effects on the environment that can support more sustainable practices in urban development and foster efficient public transportation.

Gupta et al. [35] applied remote sensing and geospatial analysis to map afforestation potential in Rajasthan state of India. The work focused on the assessment of land suitability and evaluation of carbon sequestration abilities of various tree species across the study area. The optimal tree planting sites were identified by integrating remote sensing data, vegetation indices and various environmental factors. The growth patterns of individual tree species were used to estimate sequestration rates. Almost 40% of the total area of the state is suitable for afforestation, with likely carbon sequestration rates varying from 2 to 8 tons/hectare/year. Azadirachta indica (Neem) and Prosopis cineraria (Khejri) species were found to be most effective for short-term carbon sequestration, while Phyllanthus emblica (Amla) and Ziziphus mauritiana (Ber) are better efficient for the long-term scenario. This study provides a data-driven insights for improving resilience in arid ecosystems and making policies for climate adaptation.

Kumar et al. [36] used digital elevation model (DEM) derived from high resolution Cartosat-1 satellite imagery for mapping opencast mining in Jharia, an eastern coalfield region of India. The measurement of slopes is vital since its failure can cause significant loss of life and property. For this purpose, relief, aspect, and slope maps were produced for monitoring of opencast coal mining sites. These maps were validated using ground truth data collected by differential global positioning system (DGPS) survey of the study site. The results show that the eastern part have low, moderate and high reliefs. The aspect map reveals orientation of coal mines into three categories ranging from very gentle (0–5 degrees) to very steep slope (> 35 degrees). The slope (0–10 degrees) is considered as stable while the slope greater than 35 degrees is most unstable in this region. The outcomes of this work play an important role in various construction and excavation activities. It also permits early detection of slope stability to mitigate potential disasters.

Kumar et al. [37] worked on the prediction of particulate matter ≤ 2.5 micrometers ($PM_{2.5}$) concentration by applying various machine learning models based on various meteorological factors in Delhi, India. For ML based regression models such as linear, Random Forest (RF), decision tree (DT), K Nearest Neighbor (KNN), and Lasso were applied and compared in predicting $PM_{2.5}$ concentration. Out of all regression models, linear regression demonstrated the best performance, followed by RF, KNN, Lasso, and DT. This work focused on the need of accurate prediction models to effectively mitigate $PM_{2.5}$ concentration. Despite the effective and accurate predictive ML models, it is needed to use large datasets and other advanced geo-computational models for predicting the concentration of pollutants. The findings of this work can contribute to managing air quality in urban environment and enabling pre-emptive actions in handling pollution-related health hazards.

Ghosh et al. [38] employed Revised Universal Soil Loss Equation (RUSLE) model to estimate soil erosion using Google Earth Engine (GEE) platform in Damodar River Basin of India. RUSLE considers steepness factor (S), crop/cover management component (C), rainfall erosivity factor (R), soil erodibility factor (K), slope length (L), and conservation support practice factor (P) to estimate soil loss for the years 2017 and 2024. The mean soil loss declined from 12.86 t/ha/y in 2017 to 12.06 t/ha/yr in 2024. It was found that the leading soil loss area largely concentrated to the north-west and central zone of the basin which covers 36.5% of the total area in 2017. There was a slight reduction in mining activities with 35.1% of total basin area for 2024. Out of all the factors, the R factor is primarily responsible for declining soil erosion due to decrease in rainfall. The results of this work emphasize the urgent necessity for intensive soil conservation actions in this river basin.

Chowdhury and Saha [39] investigated land degradation using GIS-based advanced machine learning models in the lower Gangetic region of West Bengal, India. In this work, Multilayer Perceptron Neural Network (MLP-NN) and the Radial Basis Function Neural Network (RBF-NN) models were used to avoid bias in traditional methods. Based on the literature review and statistical evaluation, a total of eleven geophysical and environmental variables were selected for assessing land degradation. ROC-AUC and confusion matrix methods were used to evaluate the models' performance. The MLP-NN model was found to achieve better accuracy (88.9%) compared to RBF-NN (87.1%), with ROC-AUC values of 85.2% and 84.2%, respectively. Geology, elevation, rainfall erosivity, soil moisture and land use and land cover were identified as key factors by both the models. These findings were based on a data-driven method and offer action plans for sustainable land management in the lower Gangetic West Bengal.

3.4 Climatological disasters

This thematic group highlights the use of geo-computational techniques in droughts and climate extremes studies.

Tamrakar et al. [40] applied machine learning models for the analysis and prediction of drought trends from 1993 to 2023 in Chhattisgarh state of India. This study utilized the Modified Mann–Kendall test in analysing the trends of drought events. Standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI) was used for examining drought severity. A significant positive correlation was found between these two indices of different time periods using Pearson correlation coefficient. Additionally, support vector machine (SVM) and random forest (RF) ML models were employed for drought forecasting. The results were validated using several statistical measures and SVM outperformed RF in drought forecasting. There was a projected rise of 24% in seasonal drought for SPEI 06 timeframe. This work highlights a need of long-term forecasting to take preventive measures to solve the drought problems.

Abdussalam et al. [41] evaluated the climate-related road vulnerabilities in Nigeria. In this work, multivariate bias correction was applied to the ERA5 climatic data from. This corrected data has been added in existing data for assessing road vulnerability. Along with ERA5 data, daily rainfall, minimum and maximum temperature were collected during 1980 to 2015 from 40 Nigerian meteorological stations. Two multivariate bias correction methods, namely N-dimension probability (MBCn) and ranked correlation dependence structures (MBCr) were applied to calculate the replicability in ERA5 data. These methods were assessed using mean absolute error (MAE), root mean square error (RMSE), and spatial mean difference. It revealed higher uncertainty in ERA5 rainfall compared to temperature, mainly in specific portions of the Guinea savannah and swamp forest. The MBCn's performance was found to be better compared to the MBCr and MBCp in replicating minimum temperature, maximum temperature and rainfall. The outcome of this study shows the value of conducting multivariate bias correction to climate data for enhanced data consistency and support adaptation policies in transportation and infrastructure.

Minh et al. [42] predicted annual rainfall trends during a period of 45 years (1978–2022) in the Vietnamese Mekong Delta (VMD). A statistical Autoregressive integrated moving average (ARIMA) time-series model was applied for predictions based on historical rainfall data acquired from 12 meteorological stations. The autocorrelation function (ACF), partial autocorrelation function (PACF), Akaike Information Criterion (AIC) with minimum value and the Schwarz Bayesian Information (SBC) were used to select best seasonal autoregressive integrated moving average (SARIMA) models. Apart from this, Nash–Sutcliffe coefficient (Nash) and the root-mean-square error (RMSE) were used for model fitting. The SARIMA models with $(1, 1, 1)\ (2, 1, 1)_{11}$ and $(1, 1, 1)\ (2, 1, 1)_{12}$ were found to be suitable for analysing and projecting future rainfall patterns in the VMD. Such kind of study will advance the rainfall forecasting models and strengthen the understanding of dynamics and pattern of climatic conditions in the VMD.

Kafi and Ponrahono [43] presented a comprehensive review on weather and climate extreme events (WCEE). This review explores and evaluates the efficiency of four approaches: statistical, geospatial, multi-criteria decision analysis (MCDA), and AI-based modelling techniques in WCEE studies. In addition, it employed a detailed matrix to explain how each approach is relevant to various aspects of WCEE studies. Each approach had its strengths and limitations in specific applications. Machine and deep learning-based methods offered supreme adaptability and integration capabilities compared to other techniques. AI based models can handle complex and large-scale datasets, enabled with advanced predictive analytics. This study highlighted the significance of developing innovative approaches and tools in ever changing climate and disaster events and risk reduction policies.

3.5 Geological hazards

This thematic group includes anthropogenic geological hazards or engineered disasters studies in urban infrastructure.

Shrestha and Zhihou [44] used ground-penetrating radar (GPR) to identify and categorise subsurface cavity diseases beneath the surfaces of urban roads in China. The underground cavities were classified in 2D and 3D forward modelling by using GprMax simulation program. The morphological categorisation of cavity was enhanced up to 90.5% by utilizing AlexNet algorithm in convolutional neural networks (CNN). Four types of subsurface cavities were identified, such as hollow bodies, empty bodies, loose bodies, and water-rich bodies. These classes are vital for estimating voids and subsidence risks in the roads. Using GPR accurate detection of underground cavities are dependent on dielectric properties, layer thickness measurement, and time-depth conversion. Automated analysis techniques were conducted since manual examination of 3D GPR data is still laborious and ineffective. This study highlighted the need for detection and assessment of subsurface cavity infections to ensure the dependability and safety of urban transportation infrastructure.

Karunathilake et al. [45] applied a permanent scatterer (PS) Interferometric Synthetic aperture radar (SAR) (PS-InSAR)-based technique to investigate tunnel-induced ground surface subsidence in the Greater Tokyo Area, Japan. Repeat-pass SAR data from the Sentinel-1 satellite acquired in ascending and descending orbits were used to estimate interferograms. The monitoring and detection of tunnel-induced land subsidence was performed based on interferograms. It also confirmed long-term stability along the tunnel excavation path. A high-phase consistency location using a PS interferometric stacking method was used to estimate bidirectional displacement of the ground area. It was observed that an area in central Tokyo metropolitan had 15-mm subsidence and 30-mm displacement in the east–west direction. InSAR-based estimation of displacement was correlated with the conventional level survey methods. The results of this study offer insights into land subsidence process and rate to ensure the reliability and safety in urban residential system.

Attri et al. [46] used interferometric SAR (InSAR) coherence information for improved discrimination between urban and vegetation features in the capital of Uttarakhand state of India. Decomposition and scattering parameters derived from ALOS-2 at L-band and RADARSAT-2 at C-band datasets. Urban structures and vegetated areas exhibited high and low coherence values respectively that was useful to differentiate them. The RF and CNN models are used in urban land cover classification. The RADARSAT-2 data worked better by reaching an overall accuracy of 85.8% using the RF method. In addition, Gram-Schmidt fusion technique was employed to fuse Landsat data with SAR parameters for higher classification accuracy. It significantly improved the classification and achieved 94.5% accuracy by using CNN algorithm. The findings demonstrate the effectiveness of combining polarimetric SAR and optical datasets for improving urban land-cover classification.

Fatoye et al. [47] evaluated the functionality of a dam located in the University of Ilorin, Kwara state, Southwestern Nigeria, to prevent any probable hazards. This study aimed to uncover the structural trends of the dam site through geological field mapping, remote sensing, and aeromagnetic techniques. Based on the processed geological data and rosette diagram, it was observed that the structural trends were in the NE-SW direction of the study site. The dam, using remote sensing data, was found to be located between major and minor fault lines trending in the NE- SW direction. The magnetic susceptibility of geologic materials differed from low to medium magnetic strength around the dam site. Based on the tilt derivative map, the dam was found to be placed in a geologically unstable region, which could lead to subsurface structural stress. The results of this work established that the structural integrity of dam has been put in jeopardy. Consequently, the dam's stability is at risk in long-term scenario.

It is therefore needed to conduct collaborative efforts to ensure the dam's stability by mitigating the risks of collapse. It is also recommended to incorporate advanced geophysical techniques in dam inspection practices in the future.

3.6 River basin degradation, water quality and coastal hazards

The articles under this thematic group are related to the degradation in river basins, water quality and coastal regions.

Mani et al. [48] developed watershed management strategy using morphometric parameters and Land Use Land Cover (LULC) changes in Nayar River located in Uttarakhand state of India. This study involved the assessment of various factors, namely drainage network, surface water flow, and other topographical features. To understand the topographical and morphological characteristics, satellite image, DEM data, and Survey of India (SOI) toposheets were used. The parallel and dendritic drainage patterns was found with high relief in this watershed. The changes from agricultural land and Forest Cover to Wasteland was found to be 57.60 km^2 and 57.15 km^2, respectively. These changes are intended to increase the risks of landslides and erosion in this area. The findings revealed that alterations in linear, areal, and relief aspects affect erosion potential and watershed stability. It may also be crucial for developing strategies to reduce environmental hazards and retaining the longstanding sustainability of the watershed.

Sahu et al. [49] used satellite datasets for monitoring drainage network through analysis of the morphometric parameter of Palar River basin situated in the Tamil Nadu state of India. A fifth order stream network was detected with a drainage density of 0.40 km/km^2. Also, dendritic to rectangular drainage pattern was found as a structural pattern, affecting the distribution and water flow in the basin. By using DEM data aspect, relief, and slope maps were produced. Various indices such as normalized difference vegetation index (NDVI), normalized difference water index (NDWI), and soil adjusted vegetation index (SAVI) were utilized for characterising the surface features in the study area. Water bodies were found to have major changes in area among land use/land cover categories during 2005 and 2020. A positive high correlation was observed between morphometric parameters and spectral indices. Results of this study is useful in developing policies for risk management of drought, floods, and soil erosion.

Chatrabhuj et al. [50] demonstrated the integrated use RS, GIS and AI in understanding river dynamics and the importance of recording slight variations in river conditions accurately. This review highlighted the novel integrated approaches to overcome the problems of data accessibility, analysis, and authentication. Rivers provide fresh water for drinking, agriculture, and industrial purposes followed by maintaining ecological balance. An effective river management system is essential for environmental sustainability, and for developing and maintaining flood control infrastructures. Preparing emergency response plans in case of flooding and extreme weather events is recommended. Apart from this riverine ecosystem is an important indicator for changing climate scenarios. The big geospatial data analytics coupling with unmanned aerial vehicles (UAVs), IoT, LiDAR (Light Detection and Ranging) facilitates for making well-informed decisions in environmental issues and climate change effects on river ecosystem.

Kumar et al. [51] analysed various physicochemical parameters and compared groundwater suitability for drinking with BIS standards. This study was conducted on the Aik watershed located in the Jammu and Kashmir, India. A groundwater quality index was computed to assess its drinking suitability. Most of the groundwater samples were suitable for drinking apart from 19% that were highly impacted by fertilizers and industrial activities such as pollutants and waste. For example, bicarbonate exceeded the recommended limit of 200 mg/L according to the drinking water standards. The identification of excess concentrations of fluoride, nitrate, iron, sulphate, and chloride recognized the natural and human impacts like industrial discharge. Groundwater chemistry was found to be mainly controlled by rock-water interactions followed by some concerns about magnesium hazard and soluble proportion of sodium. Groundwater was mostly appropriate for drinking, irrigation, and industrial purposes in this area which was confirmed by the corrosivity ratio analysis. The findings were essential to ensures the integrity of water resources and avoid probable damage from corrosion.

Vijay et al. [52] conducted a detailed mapping of the shorelines and estimated spatial erosion/deposition during 1972–2022 for the Vedaranniyam region of Tamil Nadu, India. Multispectral Landsat images were used to demarcate the boundary between the land and water surfaces. It was observed that the land area increased by 1.27 km^2 in the centre of study site. On the other hand, the decrease in land area or erosion was found in the northern and southern parts. The areal extent of land expansion was visualised for every 500 years viz. 2500, 3000, 3500, 4000 AD and so on. The prevailing littoral current dynamics and the seabed topography observed from GEBCO data indicated that the land between the Vedaranniyam nose (India) and Jaffna peninsula (Sri Lanka) will likely be connected by a land bridge for transportation in next 10,000 or 12,000 years. This study highlighted the dynamic interface between coastal morphology and littoral currents which is crucial for shaping shorelines.

4 Future directions

Over the next decades, geospatial data analytics will be rapidly evolving through multidisciplinary approach by combining geosciences, computer science, AI/ML models, real-time sensing systems and decision-support systems. Physics-informed AI/ML models can improve predictive accuracy of hazards and disasters by understanding more complex environmental drivers. Real or near real time monitoring systems will be developed by combining in-situ sensors, earth observation and UAVs during disasters events like landslides, earthquakes, floods, and volcanic eruptions. Earth observation data from future satellite missions will likely integrate advanced assimilation methods for monitoring disasters at different scales. Multi-hazard coupling will provide new insights for better understanding the causative factors and connections among multiple disaster events. Advanced geo-computational methods will also be able to better integrate socio-economic and infrastructure data for policy and decision making. Other emerging trends such as reliable Explainable AI (XAI), IoT, edge computing, and operational-scale predictive models will be helpful for disaster preparedness and mitigation strategies. Next generation computing and cloud-based platforms will be able in modelling complex and dynamic disasters and hazards. It will also be effective to design research agendas with focus on the communities affected by a hazard or disaster at local level.

5 Concluding remarks

This topical collection on *Advanced Geo-Computational Techniques in Natural Hazards and Disaster Studies*: *Monitoring, Management, and Mitigation*, synthesized recent advances of geo-computational methods in disaster risk hazard analysis studies. The contributions emphasised the combined use of remote sensing, GIS, AI/ML models, big geospatial data analytics, cloud computing, and IoT-based systems to address the growing complexities of disaster events and natural hazards. The manuscripts published in this special issue reflect a paradigm shift from conventional and static methods towards data-driven, dynamic, and multi-hazard frameworks. Emerging techniques and multi-source data integration accelerated the potential of predictive modelling, and near-real-time monitoring to support well-timed risk measurement and early warning. Several manuscripts demonstrated the potential use of open-source data, cloud-based platforms, and interoperable frameworks for collaborative research and transparent application in disaster risk governance. This topical collection focuses on the advancements in geo-computational research in natural hazards and disaster studies. The contributions from diverse countries around the world enable this collection to offer valuable insights into strengthening community resilience and response strategies. It is also expected to support future interdisciplinary efforts aimed at advancing disaster risk reduction, enhancing resilience, and promoting sustainable development.

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