A Comparative GIS Framework for Multi-Hazard Risk Assessment: Floods in India and Droughts in China

Yiran Yuan*

Beijing National Day School, Beijing 100039, China

Abstract. Although GIS has been heavily applied in measuring disaster risks, disaster assessment has been restricted to only one type of disaster, and there has been no comparative evaluation on whether the GIS approaches can be used in other processes of disasters assessments. In an attempt to address this gap, this paper proposes a Comparative Case Study and selects two typical instances of calamities, which are floods (sudden-onset disaster) in Gujarat, India, and droughts (gradual-onset disaster) in Southwest China. The study has involved the application of multi-source data (environmental, meteorological, socioeconomic) and GIS spatial analysis methods and created high-risk areas spatial distribution maps. The comparative results indicate that the use of the GIS technique can be easily adjusted to support disasters of all sorts, yet the weights of the data selection and analysis processes have to rely on certain disasters. The soil distribution of the risk of flooding is rigidly loaded about the low features of topography, and the drought risk is arbitrarily distributed over time under the protracted weather patterns and the topography features. Besides authentication of such great GIS capabilities in the determination of multi-hazard risks, this study will be a transferable methodology guide and decision support for such research in addressing the hazards of the same compound calamities in other regions, due to its comparative model.

1. Introduction

Natural disasters are occurring more often in the world today and the climate is growing stronger and more drastic, which makes their consequences stronger for humankind. Such natural disasters as floods and droughts lead to the absolute destruction of human society, with terrifying threats to ruin the agricultural sector and the security of cities. Increased focus on the prediction of natural disasters is achieved through the commitment of more scholars to research and improvement. As a powerful tool of geographic information and movement tracking, the GIS technology can synthesize factors like weather and topography to examine the potential factors of risk, and that is why this technology abounds in the literature on the topic of natural disasters.

The combination of Geographic Information Systems (GIS) and remote sensing technology has already turned out to be a moderately mature technical framework in the field of natural disasters and risk analysis at the international level. The extent of its development and extensive application can be well discerned, particularly in the estimation of risks of single hazards. The literature is adequate in terms of demonstrating that GIS is a powerful weapon in the risk mapping, exposure and assessment instruments during the event of a specific disaster such as floods, drought and earthquake [1-3]. Such techniques as spatial overlay, weighted analysis, and raster calculation used in these analyses tend to create an effective combination of environmental data (e.g., topography, precipitation), ecological data (e.g., land use), and socioeconomic data (e.g., population distribution) in a comprehensive system of spatial analysis. This enables the visual identification, as well as detailed mapping of the areas of high risk [4, 5]. One such analysis is the spatial overlay analysis, which is a form of GIS analysis used in the general consideration of flood and landslide danger in specific areas, and weighted multi-criteria decision-based analysis has been used for the zoning of both agricultural drought danger [6]. These applications refer to the fact that GIS technology, as one of the significant tools, has already prepared a solid base of applications and even accumulated a flood of case experience in supporting the planning of personal hazard risk zoning, the disaster management planning, and the optimization of resource allocation.

The current academic agenda, though, lies primarily in the concentration of different types of disasters in case studies [7], instead of systematic comparison and synthesis of the applicability of the GIS techniques to the situation of this or that disaster mechanism (sudden-onset or gradual-onset disasters) [8]. The fact that such research space exists poses some challenges in extrapolating the existing methodologies to multi-hazard compound scenarios.

The proposed research will address this gap by coming up with a comparative construction of a case study. Using the floods and droughts in Patan, India, and the Yunnan-Guizhou-Guangxi region of China as an example, we are

*Corresponding Author's Email Address: yuanyiran2023@outlook.com

not going to emulate a single-hazard assessment. The paper shall instead engage in comparative analysis in an attempt to discern the similarities, differences, as well as the flexibility of GIS techniques in the data processing, construction of indicators, and application of models in the event of the occurrence of disasters of different magnitudes. It is, in its turn, hoped that the given study might make a contribution to the theoretical resources and methodological framework of the evolution of the GIS application as the mechanism of single-hazard assessment up to the paradigm of the comparative approach to risk assessment.

2. Data and GIS Methods

2.1 Data and Preprocessing

The assessment of the risk of natural disasters is done using unified multi-source information, which, as a rule, consists of three major groupings: environmental factors of risk, land use and ecological data of risk and socioeconomic data of risk. The digital elevation models, distribution of precipitation, the nature of soil, and information on vegetation cover are the common environmental factors. Data that is considered land use and ecological consists of the distribution of the cultivated land and the forest cover. Such dimensions as population density and distribution of the infrastructure are a part of socioeconomic statistics [9]. The sources of such data are varied and they are, in general, not consistent in their spatial resolutions and coordinate systems. Therefore, a systematic integration and standardization of the GIS platform is needed. The most associated preprocessing operations include coordinate projection transformation, data clipping and resampling, interpolation of the spatial precipitation to the meteorological stations, reclassification of the land use types and normalization of various evaluation indicators to eliminate the dimension disparity [10]. By the use of the processes, initially differentiated multi-source data will be absorbed in one spatial unit, upon which ultimately further suitable risk estimations will be carried out.

2.2 GIS Analysis Methods

Disaster risk analysis is usually proposed as the three components, namely the hazard, exposure and vulnerability [11]. GIS enables discovering findings in the research with the aid of the combination of the data and indicators on one spatial platform, which permits later overlaying, calculations, and visualization of analytical findings, resulting in more precise and easier-to-interpret findings.

On the above three factors considered as a whole. To obtain a quantitative method for measuring disaster risk, pertaining to GIS, most of the studies adopted a linear combination model, on the foundation of the classical hazard-exposure-vulnerability model. The underlying principle is based on the classical framework of natural disaster risk, where risk (R) is determined by hazard (H), exposure (E), and vulnerability (V), expressed as:

$$R=H\times E\times V \quad (1)$$

Spatial overlay analysis, raster operations and weighted analysis, spatial interpolation and hotspots, buffering and proximity analysis, and risk grading mapping are some of the widely used GIS techniques. Spatial overlay enables the combination of more than two natural disaster datasets or other respective raster layers that indicate the hazard, exposure and vulnerability to a single spatial object that has the strength to provide a holistic risk index [12]. This analytical device was employed in conducting the analysis process of the susceptibility of archeological sites to the occurrence of natural disasters in the South Sulawesi Province of Indonesia. It was later able to develop the vulnerability information about archeological sites in the region through overlaying the flood risks with landslide risks [13]. Raster operations, weighted analysis, and computational GIS raster data processing techniques are some of the techniques involved in weighted decision-making using multiple factors. Raster data is a regular grid of square grid cells with each grid cell having a numerical value that can be used to be computed and processed. Some common raster operations can include local operations, local neighbor operations and local global operations. Multi-criteria decision-making is also based on weighted analysis that usually employs such methods as AHP or entropy weighting to provide weights, and by means of which one can calculate the overall risk indices. The appropriate analysis of the point data is the spatial interpolation and hot spot analysis, which should be included in the disaster analysis along the territory of the fluoride acid area (continuous)[14]. Spatial interpolation investigates the unexplored areas based on the known ones, analyzing the probing of the likelihood of infection or risk in the areas surrounding the known locations of the known risk natural catastrophes. The hotspots analysis identifies large clusters of high or low values at a spatial scale, which are often used in the study of the risks posed by natural disasters as a way of identifying those regions that are associated with a significantly high risk, in contrast to the areas surrounding them. Buffer zones and proximity analysis determine buffer zoning around an object and determine the distance relations among spatial objects. This is normally used in identifying the risk of exposure of structures or residential areas with respect to sources of hazards. Risk analysis and mapping entail categorizing levels of risk based on a number of ways (natural breakpoints, equal-interval, or numerical classification), and the amount of the classification on the maps [15].

The methods have multi-faceted natural hazard risks through wholesome multi-factor analysis and can thus be intuitively represented as a spatial distribution. However, most of the GIS methods rely on the quality of data and weighting parameters to a great extent, which introduces a certain amount of subjectivity. Thus, a lack of excess data gaps or unrealistic preferences in weighting could decrease the accuracy of the results. Despite these shortcomings, they are cross-disaster applicable when it comes to the natural hazard threat assessment and analysis. They can be utilized in the study of various disasters such as floods, droughts and earthquakes, which will prove very significant in relevant studies [16].

3. Case Studies

3.1 Case Selection

The two sample case studies are presented in the given paper to show how Geographic Information Systems (GIS) can be applied in risk assessment of natural disasters. The analysis of both flood risk analyses is carried out on the District of Patan, located in Gujarat, India, which is a typical agricultural region that is occasionally hit by downturns [17]. The second is the risk of drought in the Yunnan-Guizhou-Guangxi region of southwest China, in which the agricultural productivity hinges on rainfall extensively, and the phenomenon of droughts is common, jeopardizing food security [18]. These are instantaneous disasters (floods) and slow-building disasters (droughts) and assist in comparison of the adaptability of the GIS approach to the hazard scenarios. The two articles integrate both hazard factors and vulnerability factors with spatial models, which provide methodological data of risk zoning of other regions.

3.2 Case 1: Flood Risk in Patan, India

The Patan district is a divided area that is relatively flat in the western Indian state of Gujarat and where the monsoon climate has a significant contribution to the district. The frequent downpours experienced in the annual monsoon period tend to cause terrible floods that occur as a deadly occurrence to the local farming and the livelihoods of the population dwelling in it. There is also the issue of flood risk assessment that has taken its turn in this region because the fields of agriculture that are present in the area are accustomed to being in the lowlands, prone to floods very easily.

In the current study, the authors conducted a spatial evaluation of the flood risk with the aid of multi-source data, including remote sensing images, digital elevation model, land-use type, soil characteristics, and precipitation data [17]. The weight solution was provided using the Analytic Hierarchy Process (AHP) under different factors that influence it. The assessment tool was added with such factors as the terrain inclination, the drainage density, the soil permeability, the condition of the land, and the rain intensity. They consisted of standardization and overlaying activities that are performed in a GIS platform. The full flood risk index was the resultant, and it indicated that there were regional variations in terms of exposure in the area.

As it was discovered, most high-risk regions within the Patan District were in the lowlands with high river catchments and low drainage rates. These areas used to be found in agricultural areas, and, notably, the agricultural production systems were quite sensitive to floods. Moderate to low-risk areas were mostly associated with relatively higher terrain or better-drained terrain, as well as areas that have fewer probabilities of flooding. There is no evenly distributed flood hazard since it is spatially distributed but has clustering forms that directly make space-specific directions to the local governments in preparing disaster prevention and mitigation measures and land use plans.

This example demonstrates that the multi-factor integrated analysis that is based on GIS could be useful in terms of identifying the high-risk zones of the flood and providing scientific information that could help to manage the risk of agricultural lands. As has been demonstrated by the experience of the Patan District, even after having land use characteristics and considering the natural environmental factors in the spatial modelling, it is viable to derive practical implications to evaluate the risk of flood in other regions in which there is the monsoon influence and agriculture is employed as a sector.

3.3 Case 2: Drought Risk in Southwest China

Precipitation is highly active in agriculture in the Yunnan-Guizhou-Guangxi region of south-western China, with the karst topography and imbalanced occurrence of the spatiotemporal distribution of precipitation. The local precipitation patterns are uneven as the East Asian monsoon was never stable and intense droughts occurred very often in history, which leads to low agricultural production. To identify the drought risks that occur annually, the researchers have collected the data of the meteorological stations (1961–2020) and contrasted it with the Standardized Precipitation Index (SPI) to determine the risks [1]. They also analyzed the data on the local locations of the farming planting and the history of the losses to provide the whole analysis of the drought risks. To establish the relationship between agricultural yield reduction rates in relation to the severity of droughts, they have used the local precipitation data with the comparison in the form of the SPI, to orient the vulnerability curves. Finally, GIS incorporated agricultural vulnerability and drought risk assessment, that allow providing an overall drought risk distribution map to the area of Yunnan-Guizhou-Guangxi. The type of index which is computed by the researcher is that of a fraction of the crop area which has been lost due to drought and the area lost due to planting on the farm crops in the study area that year. The conclusion was reached that 8.6 percent was the expected value of the DLR.

It was discovered that the high-risk and the medium-high risk areas where the values of the indexes of risk are above 0.60 are in the center of Guizhou and in the north of Guangxi, and the cause of this is mostly the recent shortages of precipitation and the large degree of the agricultural dependence (see Fig. 1). These hotspots have the highest risk index of drought that is about which is approximately 0.85 and above than 20 percent of grid cells of a high risk will be found in these hotspots. Medium risk areas (risk index 0.400. 60) were more common in Guizhou, well in the center and north, and eastern Guangxi, and this implies that there were constant droughts and the entire region depended on the presence of precipitation to support agriculture. It is seen that the geomorphology is correlated with the spatial distribution of the risk levels in the Yunnan-Guizhou-Guangxi region. The anomalies of the spatial risks of rugged areas serve to add to the predicament of managing drought-related disasters by the local governments.

As observed in the present case, drought disaster risk assessment both incorporates long-term information on climate and on the agricultural vulnerability and extensively deploys it. The GIS applications can also incorporate different data within a specific area, which leads to the discovery and presentation of the spatial variation of drought risk at a large scale.

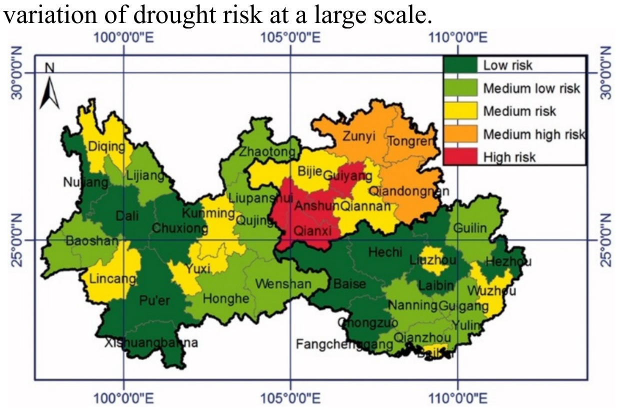

Fig. 1. Comprehensive risk zoning results for drought in the study area [16].

3.4 Comparison and Discussion

The case study on drought risk assessment in the Yunnan-Guizhou-Guangxi region in China is similar and different at the same time as the one on the assessment of flood risk in Patan District, India. In terms of methodology, the two cases came up with a mechanism of disaster risk and agricultural vulnerability indicator, in which GIS spatial analysis maps the disaster risk. The findings of both studies were utilized to narrow the high-risk area of disasters when it came to spatial location, and this helped immensely in assisting the local policy of disaster prevention and mitigation.

In these two cases, there also exist differences. First, the nature of the disasters, as the floods are short-run, abrupt, whilst drought is long-run, gradual. The two catastrophes are two disasters that require varied techniques of data collection and research analysis. The variables that were put into consideration to examine the risk of flood in the Patan case were the availability of local topography, precipitation and drainage, whereas in the Yunnan-Guizhou-Guangxi case, the correlation that was seen was associated with the time of precipitation and agricultural exposure. The indicator systems applicable, too, in both cases, were completely different. Finally, the analysis of the research revealed that the risks of flooding are low-density, whereas the risks of drought are quite diffuse and irregular, which highly depend upon the topography of the land and the weather conditions in the place. The two examples demonstrate that GIS tools may be utilized to study not only some sort of disaster, but also a specific type as well. Furthermore, GIS would be applicable in both instances of applying to one-disaster studies, as well as provide similar results with multi-disaster studies.

4. Conclusion

In these two cases, there also exist differences. First, the nature of the disasters, as the floods are short-run, abrupt, whilst drought is long-run, gradual. The two catastrophes are two disasters that require varied techniques of data collection and research analysis. The variables that were put into consideration to examine the risk of flood in the Patan case were the availability of local topography, precipitation and drainage, whereas in the Yunnan-Guizhou-Guangxi case, the correlation that was seen was associated with the time of precipitation and agricultural exposure. The indicator systems applicable, too, in both cases, were completely different. Finally, the analysis of the research revealed that the risks of flooding are low-density, whereas the risks of drought are quite diffuse and irregular, which highly depend upon the topography of the land and the weather conditions in the place. The two examples demonstrate that GIS tools may be utilized to study not only some sort of disaster, but also a specific type as well. Furthermore, GIS would be applicable in both instances of applying to one-disaster studies, as well as provide similar results with multi-disaster studies.

Although the proposed method is quite universal, this framework does have manifest drawbacks. The accuracy of the data and subjectivity in weighting the models may impact the findings of the research. The latest uses of the GIS tools involved in the study will also include the emerging sources of data (e.g., high-frequency remote sensing, social media big data), as well as the machine learning approaches. It will be promoted in such a way that not only the dynamic monitoring option will be promoted, but predictive accuracy of the model and an opportunity to expand the model to identify the risks of more complex chains of complex disasters will also be offered. These new technologies will be better placed to manage the more complicated issues of climate change, which shall arise.

References

1. Lapietra, I., Colacicco, R., Rizzo, A., Capolongo, D.: Mapping Social Vulnerability to Multi-Hazard Scenarios: A GIS-Based Approach at the Census Tract Level. Geoenvironmental Disasters 7, 35 (2020)
2. Debele D A, Tessema I. Geospatial evaluation of flood susceptibility and vulnerability for sustainable urban planning in Sululta town, Oromia region, Ethiopia: A GIS and remote sensing perspective. Scientific African 30, e03070 (2025)
3. Alasgah A A, Ahmad I, Dar A M, et al. Integrating GIS–Fuzzy logic framework and remotely sensed climate data for drought vulnerability assessment across Africa. Environmental Monitoring and Assessment 197(10), 1110 (2025)
4. Park W J. An Analysis of the Capacity of Outdoor Earthquake Evacuation Sites in Daegu, South Korea: Assessing De Facto Population Dynamics and Accessibility Through the Geographic Information System (GIS). Sustainability 17(5), 2129 (2025)

5. Čech V, Klamár R, Krokusová J, et al. Multi-Hazard Assessment in Post-Mining Landscape and Potential for Geotourism Development (On the Example of the Central Spiš Region in Slovakia). Land 14(5), 1000 (2025)
6. Hameed M H, Suleimany S M J, Rasul A. Integrating GIS and remote sensing for spatial distribution assessment of Drought Vulnerability Index. Environmental Monitoring and Assessment 197(8), 970 (2025)
7. R Ciurean, J Gill, H J Reeves, S O'Grady, T Aldridge.: Review of environmental multi-hazards research and risk assessments. British Geological Survey Open Report, OR/18/057(2018)
8. Hochrainer-Stigler, S.: Toward a framework for systemic multi-hazard and multi-risk assessment and management (2023)
9. Arrighi, C., Tanganelli, M., Cristofaro, M.T., Cardinali, V., Marra, A., Castelli, F., De Stefano, M.: Multi-risk assessment in a historical city. Natural Hazards 119, 1041–1072 (2023)
10. Kurniawan, A.A., Sunardi, S., Hendarmawan, H., Ridwansyah, I.: Flood Management on GIS-Based Multicriteria Evaluation in Developing Countries: A Systematic Literature Review. Preprints 2024051163 (2024)
11. Deepak, S., Rajan, G., Jairaj, P.G.: Geospatial approach for assessment of vulnerability to flood in local self governments. Geoenvironmental Disasters 7, 35 (2020)
12. Osman, S.A., Das, J.: GIS-based flood risk assessment using multi-criteria decision analysis of Shebelle River Basin in southern Somalia. SN Applied Sciences 5, 134 (2023)
13. Sirajuddin, K.: Advanced Technology by Using Geographic Information System (GIS) to Measure the Level of Natural Disaster Vulnerability of Archaeological Heritage in South Sulawesi, Indonesia. Social Science Research Network 11(6), 764–773 (2020)
14. Abebe, S.A., Price, R.K., Vojinovic, Z., Weesakul, S.: Flood vulnerability assessment using GIS at Fetam watershed, upper Abbay basin, Ethiopia. Journal of Hydrology: Regional Studies 44, 101255 (2022)
15. El-Mewafi, M., Soliman, M., El-Mewafi, M.M., Mansour, M.M.: Exploring a GIS-based analytic hierarchy process for spatial flood risk assessment in Egypt: a case study of the Damietta branch. Arabian Journal of Geosciences 14, 2650 (2021)
16. Dilawara, A., Chen, B., Ashraf, A., Alphonse, K., Hussain, Y., Ali, S., Jinghong, J., Shafeeque, M., Boyang, S., Sun, X., Hussain, S.: Development of a GIS based hazard, exposure, and vulnerability analyzing method for monitoring drought risk at Karachi, Pakistan. Natural Hazards 119, 1700–1720 (2023)
17. Gahalod, N.S.S., Rajeev, K., Pant, P.K. et al. Spatial assessment of flood vulnerability and waterlogging extent in agricultural lands using RS-GIS and AHP technique—a case study of Patan district Gujarat, India. Environ Monit Assess 196, 338 (2024).
18. Zhong, S., Wang, C., Yang, Y., Huang, Q.: Risk assessment of drought in Yun-Gui-Guang of China jointly using the Standardized Precipitation Index and vulnerability curves. Natural Hazards 92, 892–918 (2018)