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Implementation Case Study

Implementation of Geodesign Framework for Development of Flood Resilient Hill Town: A Case Study

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Abstract Flooding is a natural disaster characterized by the inundation of land areas due to the overflow of water from its usual channels. Various natural and man-made factors are responsible for the occurrence of floods and the damage caused by them. Floods have become more dangerous in the Himalayan region because of complex topographical features and extreme climatic conditions. In recent years, the Kullu district of Himachal Pradesh has experienced a number of devastating floods due to its proximity to the Beas River and the hilly terrain which caused collective damage to man-made as well as natural resources, leading to loss of lives and property. Recognizing the urgent need for flood resilience, the present study aims to develop a flood-resilient town through a geodesign framework that will reduce the impact of floods in hilly areas. The study uses a three-stage geodesign framework that involves data collection, data analysis, and geodesign-based flood-resilient plan modeling. In the first stage, the data pertaining to historical floods and geospatial data of the study area was collected. In the second stage, flood susceptibility mapping was done to identify vulnerable communities and assess critical infrastructure at risk based on the analytical hierarchy process (AHP). In the third stage, interactive three-dimensional (3D) modeling was done in ESRI CityEngine to develop a flood-resilient model for the study area which integrates geospatial data, flood simulation, land-use planning, and stakeholders' engagement. The results of this study show that by focusing on flood resilience, this model offers a valuable insight and practical approach for shaping the development in hilly areas that can withstand and adapt to the challenges of increasing flood occurrences.

Keywords: flood, geodesign framework, GIS, AHP, ArcGIS CityEngine, flood resilient model

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1. INTRODUCTION

Floods cause damage and disruption to communities worldwide. Accurate flood forecasting and risk assessment are difficult tasks worldwide due to the increasing complexity of natural weather patterns, scarcity of resources, unexpected occurrences of floods, and unplanned development. Floods have become more dangerous in the Himalayan region of India because of its complex topography. The state of Himachal Pradesh (HP), India which forms a part of the north-western Himalayas is vulnerable to about 25 types of disasters/hazards such as flash floods, landslides, cloud bursts, etc. with varying intensities (Ruiz-Villanueva et al., 2017; Rawat, 2013; Sah & Mazari, 2007). In HP, water-induced flash floods are very frequent and are accelerated by seasonal hydro-meteorological conditions of the state (Nibanupudi & Shaw, 2015; Paul et al., 2000; Sharma, 2006). Flash floods result from substantial surface runoff on smaller geographic regions during a short period of time. The hills of HP, specifically Kullu, Mandi, Shimla, Kangra, Chamba, Kinnaur, Sirmaur, and Una, are susceptible to flash floods. Unfortunately, flash floods have become frequent in recent years, leading to the loss of property and human lives. The reason for flash floods can be traced back to the increasing human intervention in the eco-sensitive Himalayan region.

In recent years, the impact of natural disasters in the Himalayan region has substantially increased because of the increasing population and extension of human activity on fragile land or hazardous locations (Kahlon, 2014). The younger geologically formed mountains are tectonically very active and the rugged landscape elevates the risk of hazard events which holds back socio-economic development opportunities for remote and vulnerable communities (Ruiz-Villanueva et al., 2017).

Over the last two decades, cloudburst-induced floods have also increased in the Himalayan region (Singh & Lal Kansal, 2022). In the year 2022, the monsoon season in HP saw a 121% increase in cloudbursts compared to 2020 (Singh & Lal Kansal, 2022). Floods have increased in frequency and intensity due to climate change, which can lead to infrastructure failures due to the correlation between carrying capacity and flood occurrence (Acuña-Coll & Sánchez-Silva, 2023; Linnerooth-Bayer & Hochrainer-Stigler, 2015). The weather and climate are heavily influenced by the Himalayan Mountain range's unique geographical location. It forms a strong barrier to the circulation pattern, serving as a heat source in the summer and a heat sink in the winter. Moreover, the monsoon rainfall is affected by the variable snow cover and vegetation, which further leads to flash floods with heavy damage to the people of the Himalayan region.

The analysis of flash floods in Himachal Pradesh, India is critical due to their destructive impact on the region's economic and ecological fabric. Researchers have conducted studies on the causes of flash floods, hydrological issues, and vulnerability assessment for local flash floods. Different researchers have employed different techniques for flood vulnerability assessment and create flood-resilient modeling which includes hydraulic and hydrological modeling, Geographic Information System (GIS) and remote sensing, machine learning and

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data analytics, community engagement, and participatory techniques. Most of these methods have some weaknesses when applied individually as mentioned in Table 1.

Table 1. Methods used by researchers and their limitations

Methods	Limitations
Hydraulic and Hydrological Modelling	• Insufficient data quality and availability frequently impact hydraulic and hydrological models, reducing simulation accuracy. • The scalability and implementation of these models may be limited by computational difficulty and high demand for resources. • Predictions can vary significantly because of unidentified model parameters and inputs, which lowers reliability.
Geographic Information Systems	• Limitations on spatial resolution affect the quality and accuracy of data. • Difficulties in combining multiple sources of data could result in inaccurate analyses.
Remote Sensing	• Detailed investigation of some environmental features is limited because of the inadequate spectral resolution of sensors. • It is difficult to reliably extract surface details from remote sensing data due to atmospheric interference.
Machine Learning and Data Analytics	• Difficulty in understanding complex models makes it difficult to figure out how decisions originate. • Effective analysis and generalization are hindered by inadequate data availability and quality.

The present study explores flood resilience through interdisciplinary approaches, including geospatial technology surveys, statistical analysis, and focus group discussions. Geodesign provides a systematic framework for integrating and analyzing the spatial data, design and planning concepts, and expert opinion to support decision-making in the planning and designing of towns by incorporating flood resilience (Kapoor & Bansal, 2023; Eikelboom & Janssen, 2017). Geodesign assists in flood resilience by integrating spatial data for effective flood risk management, and flood vulnerability assessment, implementing flood resilience technologies, and enhancing the decision-making processes (Naumann & Golz, 2018).

The most important step for flood resilient planning is to do flood vulnerability mapping of the area. By incorporating flood vulnerability into local planning, the risk associated with flood exposures can be minimized. Though the concept of resilience is widely known, decisions that might enhance resilience are complex and involve a range of stakeholders (Mulia & Handayani, 2024; Gerges et al., 2022). Geodesign has been seen as a critical approach for achieving such development since resilient planning necessitates the consideration of a variety of complicated challenges (Musa et al., 2016; Kulawiak & Lubniewski, 2014). Historically, flood-control measures include the development of numerous flood-control infrastructure. However, when extreme weather events grow more often, the construction of flood-control infrastructure is no longer enough to reduce the impact of hazards (Liao, 2012). Identifying how to restore a town's activities and operations in the shortest amount of time has become a problem that all governments must address.

Resilient planning includes collecting, analyzing, and evaluating data about an area's existing overall status as well as the development of plans and designs based on the assessment results. These initiatives improve a town's ability to respond to floods in an efficient manner (Chiang & Huang, 2016; Xu & Coors, 2012). Geodesign is largely mentioned in conversations about sustainable urban development and resilient planning (Wong et al., 2011). The increased popularity of geodesign stems from the significant impact and threat of extreme climate-driven natural disasters on human lives and property; the need for long-term planning; and the need for people to adapt to and mitigate the effects of future natural disasters (Abid et al., 2016; Lei et al., 2016; Carlson & McCormick, 2015; Muis et al., 2015). Geodesign uses GIS and other visualization tools to enable the stakeholders to focus on the development patterns based on the environmental characteristics of the area under consideration (Lee & Gamez, 2017).

The current practice of flood-resilient planning in hill areas is based on the subjective judgment of the decision-makers and it lacks any scientific base. Moreover, the planning policies also lack integration of flood vulnerability in hill areas of India. The integration of GIS and the analytical hierarchy process (AHP) provides a scientific basis for identifying vulnerable areas, which are critical for flood-resilient interventions (Efraimidou & Spiliotis, 2024). The flood susceptibility assessment through the integration of GIS and AHP provides more practical solutions in comparison to the contemporary approaches. It helps in a comprehensive analysis of all the factors affecting floods, which further leads to informed decision-making (Ramdani et al., 2024). GIS facilitates spatial visualization, for enabling the identification of flood-prone areas with varying risk levels through flood susceptibility mapping, thus adding to the informed contextual decision making and AHP helps in prioritizing the factors towards flood susceptibility based on the survey results (Hossain & Adhikary, 2022; Nizamani et al., 2022). This integration provides a more practically feasible and realistic situation because the weights are derived from the experts' opinions who are working in the same field and context.

2. CASE STUDY AREA

HP experiences flash floods almost every year, which are accelerated by seasonal hydro-meteorological conditions of the state. Data underscores the growing concern about floods in the area and highlights the need for flood-resilient planning. It is also highlighted that insufficient governance mechanisms and land usage may aggravate the flood risk. This necessitates a fresh agenda for governmental measures for building flood-resistant towns. The Kullu district of HP has been the subject of interest due to its susceptibility to floods, resulting in significant loss of life and property during the monsoon season. Human activities and land use have noticeably impacted the environment in the area (Basolo et al., 2009). It is imperative to consider potential hazards and develop mitigation strategies. As climate change continues to impact the environment with more frequent extreme weather events and increased precipitation, resilient city planning, and design have become progressively important (Charak et al., 2024). The present research explores the development and implementation of the geodesign framework focused on enhancing flood resilience in Kullu district of HP. The case study area is the Indian state of Himachal Pradesh's Kullu district as shown in Figure 1. It is situated between 31° 50′ 14″ to 32° 24′ 51″ N latitude and 76° 56′ 12″ to 77° 23′ 35″ E longitude. The Kullu district has elevations ranging from roughly 600 m to over 6000 m. The topography is made up of ridges of extremely high, glacier mountain peaks and, deeply carved river valleys scattered with high mountain ridges. The upper section of the Kullu district, which makes up about 22% of the entire land, is primarily composed of vast apple and plum orchards, deodar forests, and pine forests. Kullu district has been classified as "extremely" susceptible to various calamities.

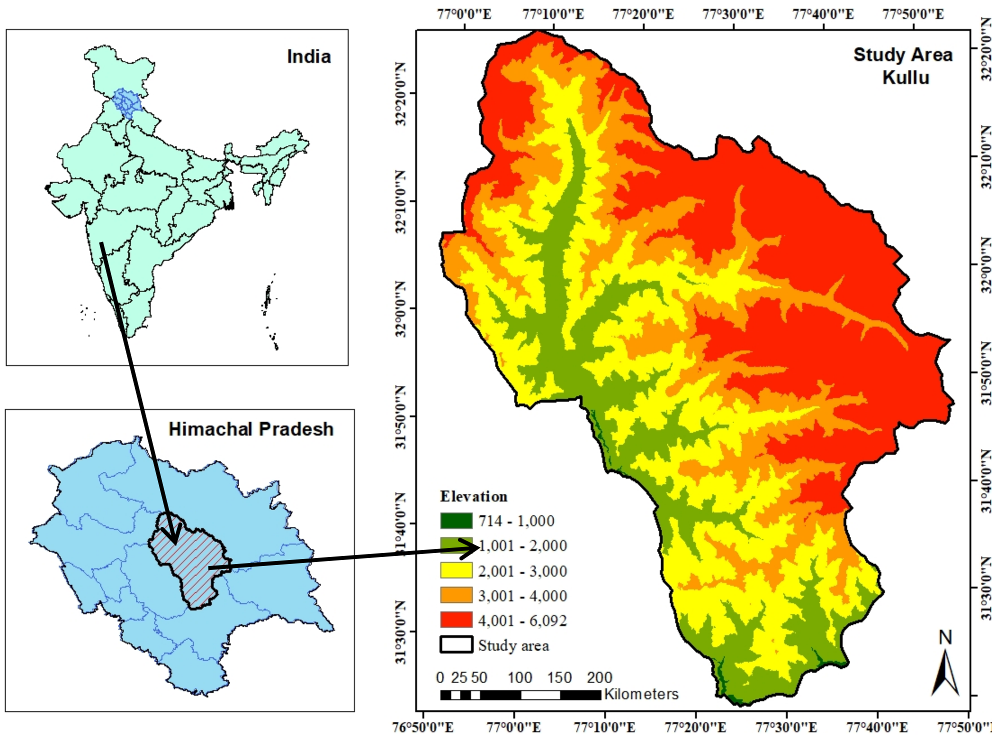

Figure 1. Location map of the Kullu district, Himachal Pradesh

3. RESEARCH METHODOLOGY

Resilient planning requires the collection, analysis, and evaluation of data about a city's existing status as well as the development of plans and designs based on the results. Geodesign has been viewed as a critical approach for achieving resilient planning, because it necessitates the consideration of a variety of complicated challenges (Gerges, 2022; Chiang & Huang, 2016; Kulawiak & Lubniewski, 2014; Liao, 2012). The conceptual Geodesign framework adapted for flood-resilient planning has three stages as shown in Figure 2.

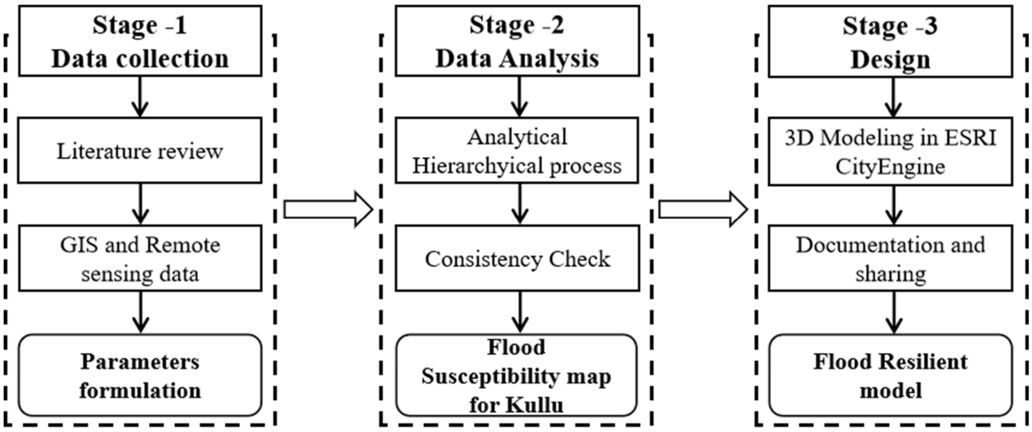

Figure 2. Conceptual geodesign framework

Stage 1: Data Collection

The detailed methodology of data collection involves a thorough collection of both historical flood data and geospatial data for the study area as shown in Figure 3. Historical flood data was obtained from newspapers and online databases. A literature review was conducted to identify the major factors affecting floods in hill areas and a matrix has been made as shown in Table 1 of the supplementary data. From the matrix, the factors considered in less than two studies were not considered for the present study. It was found that most of the existing studies on flood resilience have focused on geo-environmental factors only. Because of this reason, the scope of the study was limited to the consideration of geo-environmental factors only. Ten identified critical factors were topographic wetness index (TWI), elevation, slope, drainage density, distance from the river, distance from the road, LULC, NDVI, precipitation, and geomorphology.

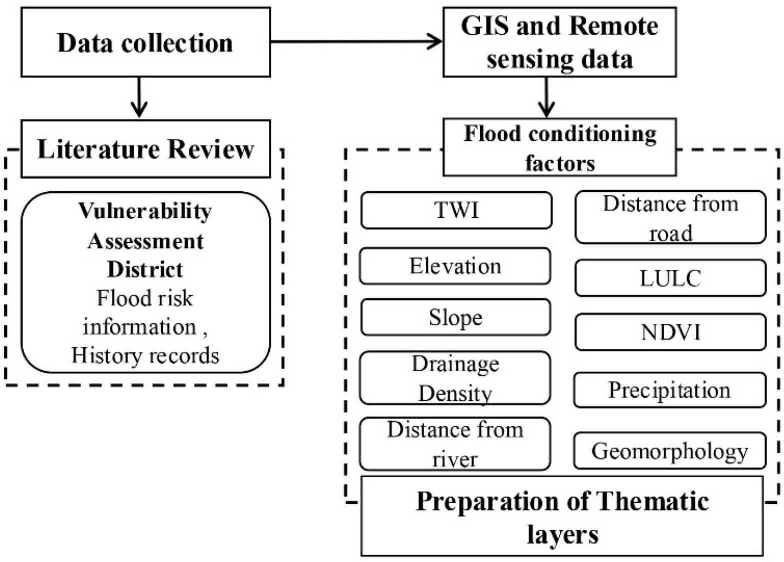

Figure. 3. Methodology for data collection

The thematic map layer corresponding to each critical factor was created and analyzed using ArcGIS. The analysis resulted in determining the patterns and correlation between various factors. Table 2 lists the specific datasets and their sources. The digital elevation model (DEM) of the case study area with a spatial resolution of 30 meters was used to produce thematic layers of TWI, elevation, slope, drainage density, and distance from the river. TWI map is widely used to determine the size and location of water-saturated regions (Sarkar & Mondal, 2020). ArcGIS 10.7.1 was used to create an elevation map of the study area. The areas with low elevation flood more quickly because surface runoff velocity is low. The thematic layer corresponding to the slope was created from the DEM by using the spatial analyst tool in ArcGIS. The ratio of the total length of streams within a watershed to its area is known as the drainage density. An area with higher drainage density increases the possibility that it will flood, which justifies why drainage density has a major influence on the occurrence of floods (Pande et al., 2021). The distance from the rivers is another important aspect that significantly raises the risk of floods. Locations where the river is less than 500 meters away are significantly more vulnerable to floods.

Landsat-8 satellite imagery was used for making the thematic layers corresponding to LULC and NDVI. In the study area, six LULC classifications have been identified: permanent snow, water bodies, built-up areas, barren ground, agricultural land, and forest. NDVI is an index of vegetation used to quantify photosynthetic activity and the density of green on a patch of land. By using the below formula in Eq. (i), the value of NDVI was determined:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \quad \ldots\text{(i)}$$

where NIR is a near-infrared band value and RED represents the red band value.

Geomorphology data was acquired from the Bhuvan thematic Map of the World which contains high-quality information on the earth's surface characteristics. The thematic layer of road proximity was developed in ArcGIS. Significant rains caused highways to flood, which made accessibility and connectivity extremely difficult (Das et al., 2017).

Stage 2: Data Analysis

The flood susceptibility maps were derived through the spatial analysis of the data acquired in Stage 1. These maps help in the assessment of potential hazards to critical infrastructure and the identification of people at risk. Weights of critical factors were determined by using AHP for the analysis of the expert survey, which was further used to identify the flood-prone areas within the case study area through weighted overlay analysis. The detailed methodology for deriving the flood susceptible map is shown in Figure 4. The ten numbers of thematic layers corresponding to ten critical factors in order to develop flood susceptibility maps were created in ArcGIS. These layers were used to determine flood-prone areas while assessing the risk to essential infrastructure. An in-depth analysis of the thematic layers is crucial for recognizing areas susceptible to floods and evaluating the risks for critical infrastructure. This further benefited in the development of flood-resilient modeling of the case study area.

Table 2. Sources of the datasets used in the research

S.No.	Data	Source	Year	Mapping Output	Selection Basis
1	Digital elevation model	https://earthexplorer.usgs.gov/ (30m spatial resolution)	2022	Topographic Wetness Index (TWI)	TWI parameter is widely used to determine the size and location of water-saturated regions. The higher this parameter is the area is more susceptible to floods.
				Elevation	Low-lying locations are more vulnerable to rain and flood damage, and elevation will influence the pressure of the urban storm flood system (Tayyab et al. 2021; Hoque et al. 2019).
				Slope	Choosing the appropriate slope is a crucial evaluation factor since it impacts the prevailing flood velocity (Hamidi et al. 2020)
				Drainage density	Drainage network is essential, which can remove floodwaters as quickly as possible during a disaster.
				Distance from river	A place is more likely to flood if it is near water bodies (Sar et al. 2015).
				Distance from road	Significant rains caused highways to flood, which made accessibility and connectivity extremely difficult (Ghosh & Kar 2018; Das et al. 2017).
2	Landsat 8	https://earthexplorer.usgs.gov/ (30m spatial resolution)	2022	LULC	Impermeable earth has a lower water absorption capacity and is more vulnerable to floods than green space (Saha & Agrawal 2020; Omran 2017).
				NDVI	The NDVI is a crucial indicator of the amount of vegetation, because plants can withstand flood damage to some extent (Sar et al. 2015).
3	Geomorphological data	Bhuvan	2015	Geomorphological map for Kullu district	The geomorphic Composition of any location has a major influence on flood conditioning. Compared to hilly terrain, low-lying floodplain areas are more vulnerable to flooding (Das et al. 2017).
4	Rainfall data	https://crudata.uea.ac.uk/cru/data/hrg/	2011-2020	Precipitation map	As a major contributing factor to flood disasters, precipitation plays a significant role as an evaluation metric.

All the factors do not hold equal importance for the occurrence of floods. Therefore, it is necessary to determine the relative weights of these factors. An expert survey was conducted for determining the relative weights of the critical factors influencing floods in hill areas. In this research, each factor in the decision matrix related to flood vulnerability was given a ranking between 1 and 9. The expert opinion was analyzed using AHP (Raj & Bansal, 2024; Zhang et al., 2009; Saaty, 1980). The process for determining the weights is described in the following steps:

Step 1: Based on each response from the expert survey, a pairwise comparison matrix of the 10 essential factors was created. The combined pairwise comparison matrix of each reply was created in Microsoft Excel.

Step 2: To create the normalized pairwise matrix, each value in the consolidated pairwise comparison matrix was divided by its column total by using Eq. (ii).

$$x_{ij} = \frac{C_{ij}}{\sum_{\{i=1\}}^{\{n\}} C_{ij}} \quad \text{...(ii)}$$

Step 3: Using Eq. (iii), each critical factor's weights were determined using the normalized pairwise matrix.

$$W_{ij} = \frac{\sum_{\{i=1\}}^{\{n\}} X_{ij}}{n} \quad \text{...(iii)}$$

Calculation of consistency ratio

Using Eq. (iv), the numerical value of CR was determined, where CI is the consistency index and RI is the random index.

$$\text{CR} = \frac{\text{CI}}{RI} \quad \text{...(iv)}$$

$$\text{CI} = \frac{(\lambda max - n)}{(\text{n} - 1)} \quad \text{...(v)}$$

To calculate CI, Eq. (v) was employed, where n is the number of elements and ⋋max represents the highest eigenvalue of the matrix. ⋋max is calculated by using the Eq. (vi).

$$\lambda = \sum_{\{i=1\}}^{\{n\}} Cv_{ij} \quad \text{...(vi)}$$

Eq. (vii) was used to calculate the value of CV. Where the value of ⋋max should always be greater than or equal to n.

$$\left.\begin{aligned} Cv_{11} &= \frac{1}{W_{11}}[c_{11}W_{11} + c_{12}W_{21} + \cdots] \\ Cv_{21} &= \frac{1}{W_{21}}[c_{21}W_{11} + c_{22}W_{21} + \cdots] \\ Cv_{31} &= \frac{1}{W_{31}}[c_{31}W_{11} + c_{32}W_{21} + \cdots] \end{aligned}\right\} \quad \text{...(vii)}$$

Finally, the expert's opinion consistency was assessed by using a consistency ratio (CR), the value of which should be less than 0.10. Insufficient consistency is represented by a CR greater than 0.10 (Kapoor et al., 2020; Kim & Wilson, 2015). In such circumstances, the values of the pairwise comparison matrix must be revised. In the present study, the value of CR is 0.089 which was less than 0.10.

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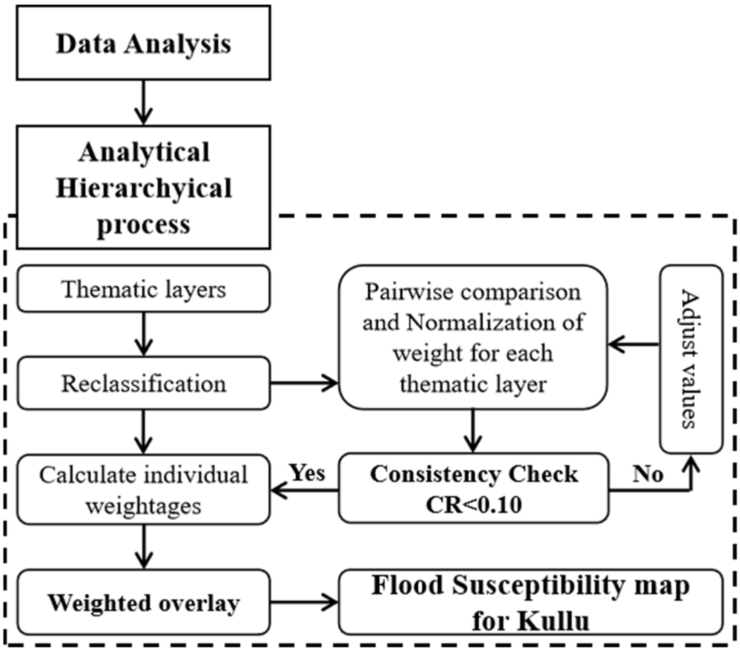

Figure 4. Methodology for deriving the flood susceptible map

Stage 3: Flood Resilient Modeling

To create a 3D model, ESRI CityEngine 2019.0 was used for creating different scenarios, which allows many design possibilities inside a scene. Comparing and editing scenarios in parallel window views may efficiently satisfy the needs of a 3D-visualized geodatabase and connect it to the design process, workflow, and associated geodesign tools (Miller, 2017; Kim & Wilson, 2015; Neuenschwander et al., 2014). It combines the geographical environment with the researched, evolving condition, changing 2D geo-based data into 3D evidence-based models of the area under consideration. Different scenarios can be simulated using CityEngine's rule-based modeling and attribute stacking, allowing the decision-makers to change presented scenarios with an elevated degree of freedom. The tool's methodical control and visual intuition help decision-makers to evaluate different planning and designing options. Furthermore, CityEngine scenarios may be instantly uploaded on the internet for sharing project models as well as evaluating findings or design recommendations with decision-makers.

GIS data was imported with precision, such as maps of elevation, slope, hydrological data, etc. 3D models of the town were generated using CityEngine's rule-based procedural modeling, incorporating features like green spaces, building height restrictions, and infrastructure that correspond to flood risk zones. Techniques for construction that are resistant to floods were incorporated, such as permeable surfaces, and well-placed buffer areas. Resilient urban design strategies were incorporated like buffer zones, and green corridors, and scenarios were developed, that were effective in flood risk. The developed scenarios were compared and updated to meet the needs of a 3D-visualized geodatabase and connect it to the design process, workflow, and geodesign-related tools (Li & Kim, 2022;

Neuenschwander et al., 2014). This helped in combining the geographical environment with the researched, evolving condition, changing 2D geographic data into 3D empirically verified city models of the physical environment. This helped planners in creating the circumstances necessary to convert 2D geospatial data into 3D, based on the city models of the study area and its surroundings in a procedural manner. A more realistic depiction of the physical and environmental characteristics of the city was made possible by this transition. The incorporation of the visualization component established the developed framework for regional intelligence toward resilient planning with the geodesign fusion (Vaz, 2016).

4. RESULTS AND DISCUSSIONS

4.1 Data Collection

Data collection involves gathering historical flood data as well as geospatial data for the study area. The thematic layers indicating TWI, elevation, slope, drainage density, distance from the river, distance from the road, LULC, NDVI, precipitation, and geomorphology were prepared in ArcGIS to determine the areas that are susceptible to floods as shown in Figure 5(a) and 5(b). It was found that the TWI value varies between 1.4 and 26 which coincides with the high flood-vulnerable range. The elevation of the study area varies from 714 to 6092 meters. The region with an elevation value of less than 714 had a substantial correlation with flooding. The slope of the study area varies from 0 degrees to 83.1 degrees. Six LULC classifications including waterbodies, permanent snow, built-up areas, barren land, agricultural land, and forest were detected in the study area. Among these waterbodies and permanent snow areas have a positive correlation with flood susceptibility. The precipitation value varied from 683 to 1930 mm, the areas with high precipitation values indicate the high potential of floods. The value of drainage density ranges between 0.02 to 1.65 km^{-1}. High value of drainage density is more susceptible to floods. Another important aspect that influences flood risk is distance from the rivers. In the areas where the river is less than 500 meters away, there was a very strong relation found for high susceptibility for floods.

4.2 Data Analysis

The study area is prone to flash floods and extreme rainfall. ArcGIS was used to construct the map of prospective flood zones in order to assess the degree to which the area is likely to experience high rainfall and be vulnerable to floods. The ten numbers of critical factors were used to calculate the possibility of flooding, risk associated was categorized as “very high,” “high,” “moderate,” “low,” and “very low”. The weightage of each factor derived from AHP has been tabulated in Table 3.

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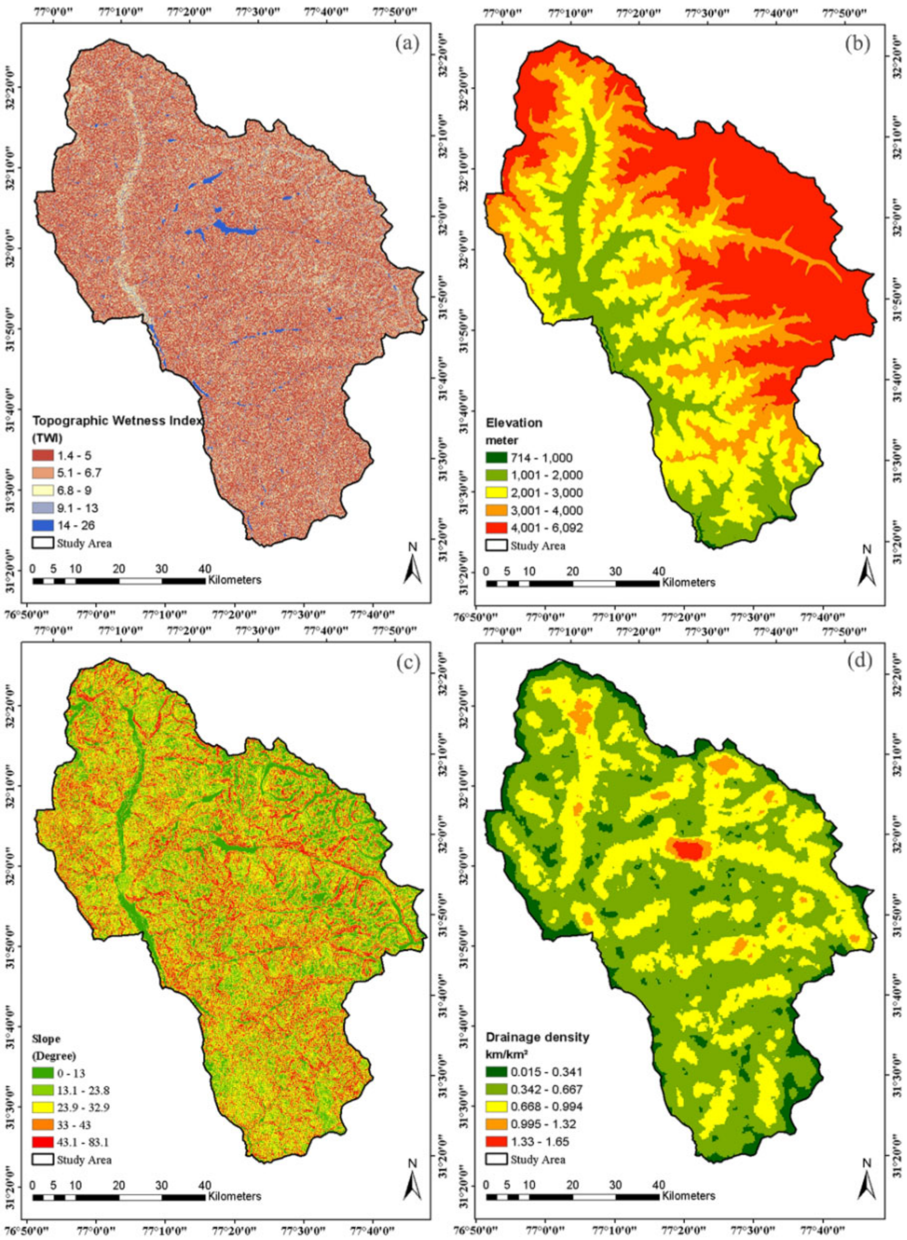

Figure 5 (a). Layers corresponding to the factors affecting flood: (i) TWI, (ii) elevation, (iii) slope, (iv) drainage density

The derived weights of the identified factors are 21% for TWI, 14% for drainage density, 13% for LULC, 12% for precipitation, 11% for distance from river, 9% for slope, 8% for elevation, 4% for distance from road, 4% for NDVI, and 4% for geomorphology. The weights were assigned to the thematic layers pertaining to the identified factors for deriving the flood susceptibility map using weighted overlay analysis. The thematic layers developed had also been used as the foundational data for 3D procedural modelling.

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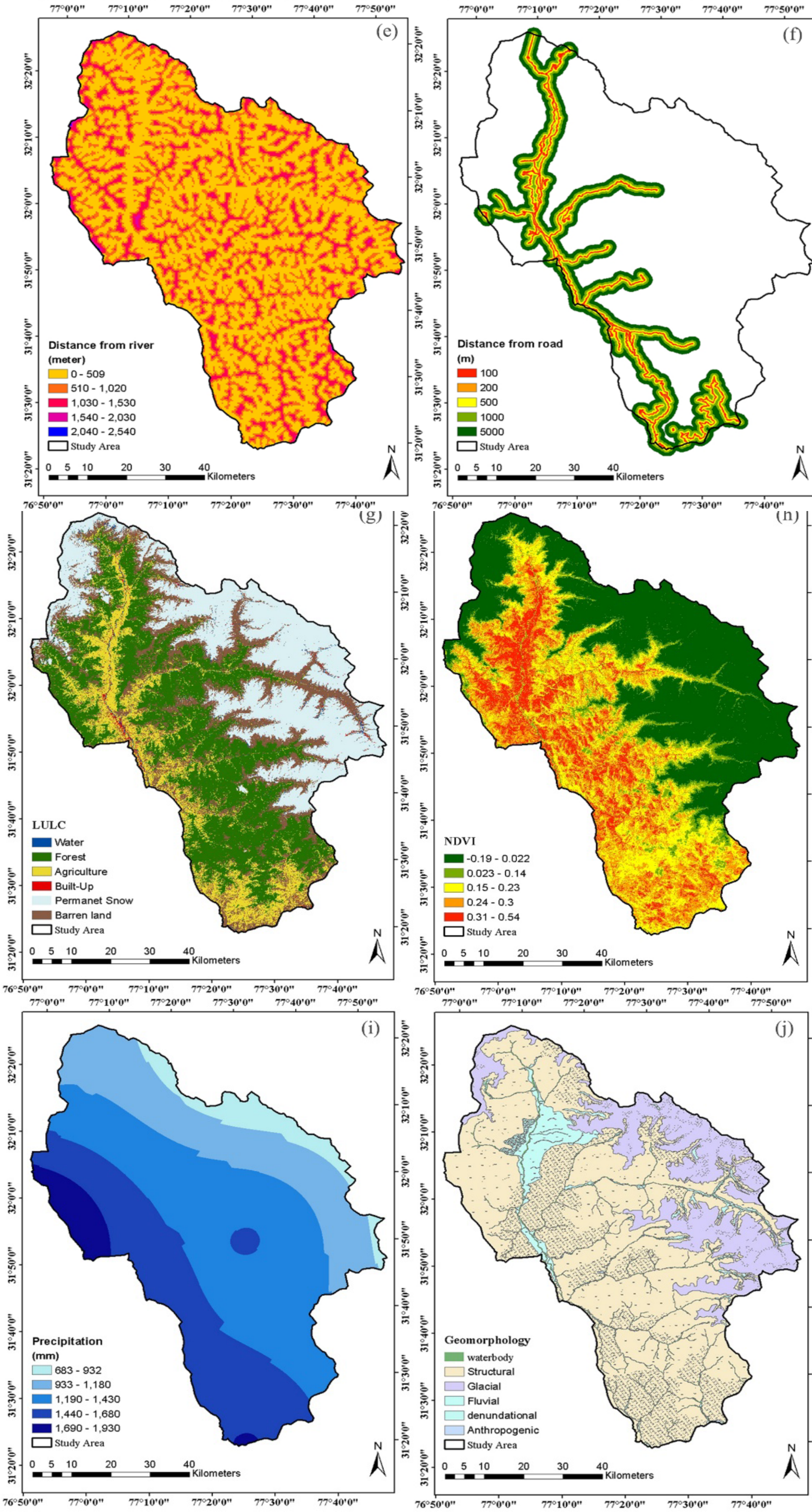

Figure 5 (b). Layers corresponding to the factors affecting flood: (v) distance from river, (vi) distance from road, (vii) LULC, (viii) NDVI, (ix) precipitation, and (x) geomorphology

Table 3. Flood susceptibility ranges and factor weightage for flood susceptibility analysis

Factors	Unit	Class	Susceptibility Class Ranges	Susceptibility Class Rating	Weightage
Topographic Wetness Index (TWI)	Level	1.4 - 5	Very low	1	21
		5.1 - 6.7	Low	2	
		6.8 - 9	Moderate	3	
		9.1 - 13	High	4	
		9 - 26	Very high	5	
Elevation	m	714-1000	Very high	5	8
		1001-2000	High	4	
		2001-3000	Moderate	3	
		3001-4000	Low	2	
		4001-6092	Very low	1	
Slope	Degree	0 - 13	Very high	5	9
		13.1 - 23.8	High	4	
		23.9 - 32.9	Moderate	3	
		33 - 43	Low	2	
		43.1 – 83.1	Very low	1	
Drainage density	km/km^2	0.015-0.341	Very low	1	14
		0.342-0.667	Low	2	
		0.668-0.994	Moderate	3	
		0.995-1.32	High	4	
		1.33-1.65	Very high	5	
Distance from river	m	0 -509	Very high	5	11
		510 -1020	High	4	
		1030 -1530	Moderate	3	
		1540 - 2030	Low	2	
		2040 - 2540	Very low	1	
Distance from road	m	100	Very high	5	4
		200	High	4	
		500	Moderate	3	
		1000	Low	2	
		2000	Very low	1	
LULC	Level	Water	Very High	5	13
		Permanent Snow	Very high	5	
		Built-Up	High	4	
		Barren land	Moderate	2	
		Agriculture	Low	3	
		Forest	Very Low	1	
NDVI	Level	-0.19-0.022	Very high	5	4
		0.023-0.14	High	4	
		0.15-0.23	Moderate	3	
		0.24-0.3	Low	2	
		0.31-0.54	Very low	1	
Precipitation	mm	683 - 932	Very low	1	12
		933 - 1180	Low	2	
		1190 - 1430	Moderate	3	
		1440 - 1680	High	4	
		1690 - 1930	Very high	5	
Geomorphology	Types	Waterbody	Very high	5	4
		Glacial	High	4	
		Denudational	Moderate	3	
		Fluvial	Moderate	3	
		Structural	Low	2	
		Anthropogenic	Very low	1	

Each thematic layer was reclassified into five classes using ArcGIS. After reclassification, the overall score for each grid square was obtained by summing up the grades for all ten factors. This score is a representation of the flood risk for that particular location on the map. Using weighted overlay analysis, the weights of the grid data were put in and classified into five classes to create the flood susceptibility map of the study area as shown in Figure 6. A close examination of the map indicates that the majority of the "high" and "very high" flood-prone regions are along the river basins. Furthermore, it is clear that locations with a combination of high TWI, higher drainage density, less slope, low elevation, close to rivers, and other flood-inducing factors are extremely susceptible to floods.

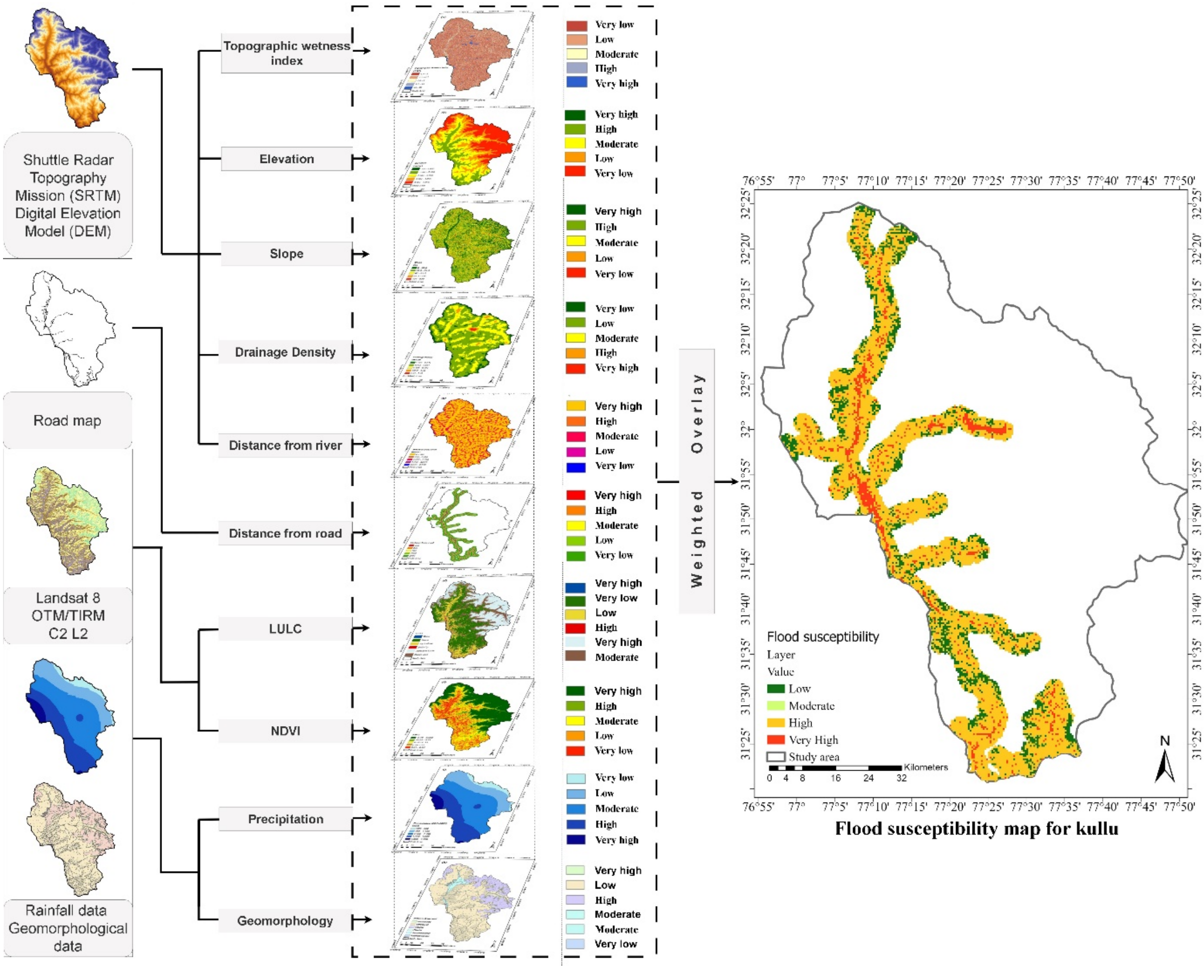

Figure 6. Weighted overlay for developing flood susceptibility map

4.3 Geodesign Based Modeling

It includes the use of 3D visualization in GIS to support conversations that are interactive between the general public, decision-makers, and relevant stakeholders. This helped in gaining a greater understanding of the environmental conditions and difficulties present in the study area that need to be evaluated for flood-resilient planning. 3D visualization facilitates faster comprehension of the issues on many scales (Luo et al., 2017; Liu et al., 2012; Smelik

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et al., 2011). The most susceptible area as shown in Figure 7 was considered for flood-resilient modeling.

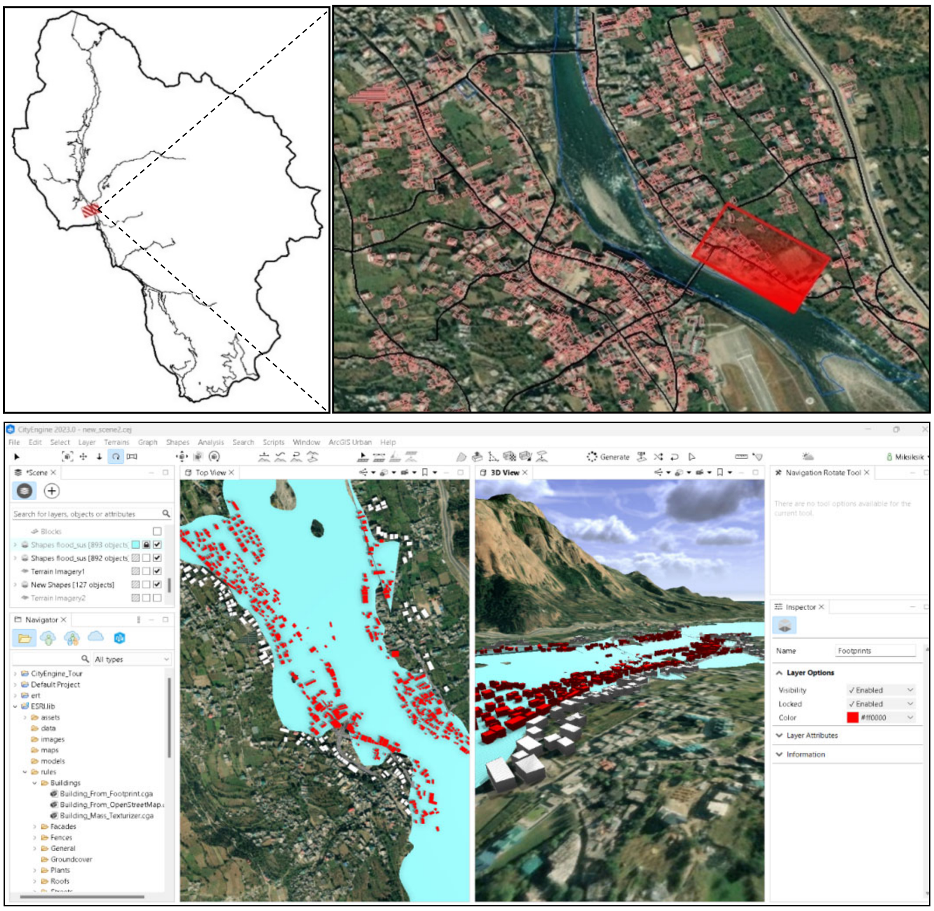

Figure 7. CityEngine utilized to demonstrate the research site using GIS-based data analysis to identify an area which is mostly affected by flood

CityEngine was utilized to develop the 3D model of the selected area, which made it possible to integrate GIS data, pictures, water systems, buildings, and route networks to develop surroundings. CityEngine quickly simulated the 3D scene of the area using the procedural modeling method by writing relevant class, numerical, and material parameters to rules files (Grêt-Regamey et al., 2013). This model was designed with the adaptation measures in view, which included expanding the capacity of flood retaining facilities, utilizing permeable pathways, and adding more green belts, gardens, and recreational spaces. The CityEngine parameters were modified based on the rankings of the flood-influencing factors. This made it possible to simulate 3D city models quickly. The 3D model was made available as a CityEngine Web Viewer interface, which acted as a forum for experts, decision-makers, and stakeholders to engage in conversations and collaborations about design. The stakeholders discussed and utilized the CityEngine modeling techniques to investigate the possible flood-resilient measures as shown in Figure 8. The developed model can also help policymakers to frame policies that are adaptive and responsive to reduce the impacts of floods on human lives and property.

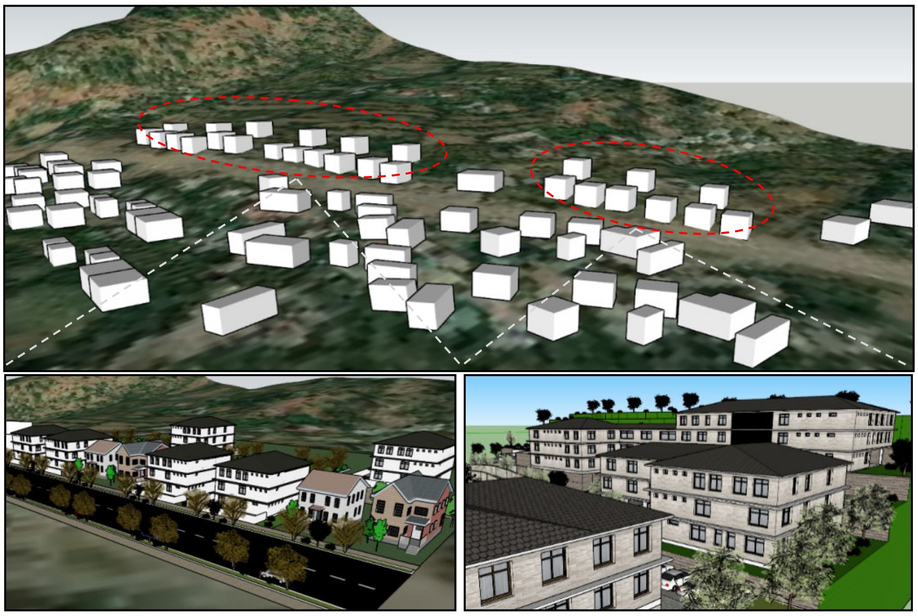

Figure 8. Proposed town model with open spaces, parks, and fields to make the area more resilient to floods

The outcome helped in determining the present and future development of the area under consideration. To make accurate predictions, decision-makers must consider a variety of possibilities during the process (Wu & Chiang, 2018). Additionally, they may base their ideas on the data that is currently accessible to forecast expected events both in the present and future. A review of several research publications reveals that very few of them are exclusively based on GIS; this suggests that the use of GIS alone is no longer capable of fulfilling current demand. These days, identifying problems is no longer the only issue; fixing them has also become crucial. In the future, a major trend will be the use of GIS data collection and analytics as design enhancement to help ease environmental and human concerns.

5. CONCLUSIONS

Hill areas are becoming more vulnerable to floods due to climate change and excessive rainfall, which poses a challenge to sustainable development. This study focused on developing a flood-resilient town through a geodesign-based framework that may reduce the impact of floods in hill areas. The geodesign-based framework makes it possible for individuals to comprehend and handle the intricate processes of data gathering, data analysis, and modeling for flood-resilient planning. The integration of remote sensing data, geospatial analysis, expert survey, statistical approach for its analysis, and city engine for the development of flood resilient scenario has been used in the present research. This unique and robust integration gives a very strong theoretical contribution to using the existing geodesign framework for modeling flood-resilient scenarios in highly vulnerable zones.

Geodesign can help in flood resilience by assessing flood hazard zones, exposure analysis, and risk quantification. It enables optimal flood risk management through geospatial data utilization in planning.

The three-stage framework was put into practice to determine if flood-influencing factors had been appropriately considered for design and planning, as well as to evaluate the planning gap related to flood resilience on its own. Local governments can identify high-risk regions and put early warning systems in operation to lessen the effects of flash floods by utilizing modern technologies like GIS mapping and real-time monitoring systems. Reducing susceptibility requires significant infrastructure enhancements, such as the development of reinforced embankments, elevated buildings, and resilient drainage networks. Furthermore, improving natural water absorption and lowering surface runoff can be achieved by implementing green infrastructure, including vegetated waterways and wetlands. It has been found that the geodesign-based framework allows planning and design for hilly regions to be created with sufficient precision. However, geodesign is still in the early stages of development; therefore, not many organizations or researchers have examined it, although practitioners in the field can very efficiently employ it in flood-resilient urban planning. To preserve the natural buffer zones offered by forests and riverbanks, which are essential for mitigating floods, policies must place a high priority on ecosystem conservation. To create and carry out comprehensive flood control strategies, cooperation between local communities, non-governmental groups, and government agencies is crucial. Thus, the regeneration of urban areas and the consideration of flood resilience are necessary to encourage public government engagement in planning by making use of such a platform for active participation and idea sharing. The approach used in the present study can serve as a model for other flood-prone areas located in hills.

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