

Evaluate and analyse the flood risk and potential flood zones in the Blue Nile State utilizing multicriteria decision analysis (MCDA) and the analytical hierarchy process (AHP)

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Abstract

Floods are natural disasters that can cause loss of life and significant economic damage, highlighting the need for effective protection of people and property. With climate change and urbanization, flooding is expected to become more frequent. This study aims to create a flood hazard map for Blue Nile State through risk management assessment and susceptibility mapping. Using the analytical hierarchy process (AHP) within a Geographic Information System (GIS), we integrated key factors such as average annual rainfall, slope, elevation, topographic wetness index, proximity to rivers, land use, land cover, normalized difference vegetation index, and distance from roads. The study used a variety of geospatial data, including remote sensing and supplementary data. Satellite imagery provided essential information, while thematic layers from different sources were used for mapping. Secondary data were generated through multicriteria analysis. Using ArcGIS and QGIS software, maps were created to show slope, rainfall distribution, rivers, and urban land use, all represented in the UTM zone 36N projection with metric units. The flood risk map indicated that approximately 2.58% of the area is at very low risk, 10.79% at low risk, 21.74% at moderate risk, 31.58% at high risk, and 33.29% at very high risk. Future research should enhance flood risk assessments by including additional factors such as demographics, income, education, water usage, emergency preparedness, and soil type.

Key words-AHP: Analytic hierarchy process, TWI: Topographic wetness index, QGIS, NDVI: Normalized difference vegetation index, LuLc: Land use & Landcover, MFI: Modified Fournier index, Multi-criteria evaluation (MCE), CLUP Comprehensive Land Use Plan,

I. INTRODUCTION

Flooding represents a significant area of inquiry within hydrology and poses considerable concerns in agriculture, civil engineering, and public health disciplines. Human activities have frequently exacerbated both the frequency and severity of floods[1]. For example, changes in land use, including deforestation and the degradation of wetlands, modifications to waterways, and flood management strategies such as levees, can have contributed to this phenomenon. Additionally, broader environmental challenges, including climate change and rising sea levels, further amplify these issues. Specifically, climate change, characterized by increased precipitation and extreme weather events, has intensified other factors that lead to flooding, thereby resulting in more severe occurrences and an elevated risk[2]. In recent years, climate change has had both direct and indirect effects on populations globally, and in Sudan, the Grand Ethiopian Dam caused many climate changes. Floods represent one of the most prevalent natural disasters, significantly impacting populations and infrastructure[3][4]. In Sudan, this situation has compelled numerous individuals to relocate and modify their activities[5]. Intense precipitation and increasing water levels of the Nile River have prompted flash floods in various regions of Sudan[6], and due to the Grand Ethiopian dam and climate change that can affect the region in this study, we evaluate the potential impacts of flash floods in the Blue Nile region.

II. STUDY AREA

Blue Nile State is situated in the southeastern region of Sudan, positioned between the latitudes of 10°–12° N and the longitudes of 33°–35° E. It is bordered by Sennar State to the northeast, Ethiopia to the southeast, and South Sudan to the west. The Blue Nile River traverses the state from the south, originating from the Ethiopian highlands as a narrow and rapidly flowing stream, in contrast to the White Nile. The state encompasses an area of 45,844 square kilometers and is estimated to have a population of 1,193,293 residents. According to the 2006 census conducted by the Central Bureau of Statistics, the recorded population was 832,112[7]. The capital of the state is Ad-Damazin, which is notable for housing the Roseires Dam, the principal source of hydroelectric power in Sudan[8]. The specific region selected for this study Figure(1) is located within Blue Nile State, encompassing the areas of El Roseires, El Damazeen, and portions of Qessan Locality, covering an approximate area of 11,156.53 square kilometers.

III. PREVIOUS STUDIES

A. *Multi-criteria decision-making for flood risk management: a survey of the current state of the art*

This paper provides a comprehensive review of the application of multi-criteria decision-making (MCDM) techniques in the domain of flood risk management, analyzing a total of



Fig. 1: Study Area

128 peer-reviewed publications spanning from 1995 to June 2015. The findings indicate a significant increase in studies pertaining to flood-related MCDM methodologies, with over 82% of the analyzed papers being published since 2009. The predominant focus of the research has been on ranking flood mitigation alternatives and evaluating aspects of risk, hazard, and vulnerability. The Analytical Hierarchy Process (AHP) emerged as the most widely utilized method, followed in frequency by TOPSIS and Simple Additive Weighting (SAW). Nonetheless, this paper identifies notable research gaps, particularly in the area of uncertainty analysis, which remains infrequently employed in studies related to flood management. Furthermore, stakeholder participation has often been restricted to particular phases, such as the definition of criteria weights. Future research endeavors should aim to address these uncertainties and enhance stakeholder engagement throughout the decision-making process to improve both the quality of decisions made and the implementation of measures concerning flood risk.[9].

B. A GIS-based flood risk mapping of Assam, India, using the MCDA-AHP approach at the regional and administrative level

This study endeavors to establish a robust methodology for flood risk mapping in Assam, located in Northeastern India, by integrating components of hazard and vulnerability. Utilizing the Analytical Hierarchy Process (AHP) within a Geographic Information System (GIS) framework, the study formulates three indices: the Flood Hazard Index (FHI), the

Flood Vulnerability Index (FVI), and the Flood Risk Index (FRI). Significant indicators, including topography, geology, meteorology, drainage, land use, and demographic factors, were incorporated into the analysis. The findings indicate that over 70% of Assam is classified within the moderate to very high hazard category, 57.37% exhibits moderate to high vulnerability, and more than 50% is categorized as moderate to very high risk[10].

C. Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire)

This study conducts an assessment and mapping of flood risks in Abidjan, a district in Côte d'Ivoire, which is susceptible to flooding due to both natural and anthropogenic factors. By utilizing the Analytic Hierarchy Process (AHP) model within a Geographic Information System (GIS) framework, the research integrates various criteria including slope, drainage density, soil type, rainfall, population density, land use, and sewer system coverage. The resulting flood risk map indicates that 34% of the area is categorized as being at high to very high risk of flooding. Furthermore, the study identifies eight out of the thirteen municipalities within Abidjan as highly vulnerable to flooding, thereby underscoring the necessity for decision-makers to formulate robust strategies for managing flood risks in the region[11].

IV. DATA AND METHODS

A. Method

The methodology comprised two essential phases: risk analysis and risk assessment (evaluation). During the initial phase, an examination was conducted on flood hazards, vulnerabilities Figure(2), and overall flood risk, which served as the foundation for the long-term management of the flood protection system. In the second stage, the factors identified in the initial stage utilizing the Analytic Hierarchy Process (AHP) are evaluated within the framework of Multi-Criteria Decision Analysis (MCDA) to generate a hazard map for the designated area, taking into account risk perception weighing.

1) *AHP hierarchy Process*: The Analytical Hierarchy Process (AHP) constitutes a decision support model developed to address intricate decision-making challenges through the organization of these dilemmas into a multilevel hierarchical structure that encompasses objectives, criteria, sub-criteria, and alternatives. The factors utilized in this methodology were selected based on research exhibiting analogous characteristics see Figure(3). A relative comparison matrix was implemented to assess the factors influencing the probability of flooding within the study area. This matrix facilitates the comparison of each factor against others by juxtaposing rows of components to evaluate their relative significance[12][13].

B. Data

The study employed a comprehensive array of geospatial data, categorized into remote sensing data and supplementary data refer to Table(I). Satellite imagery was utilized to

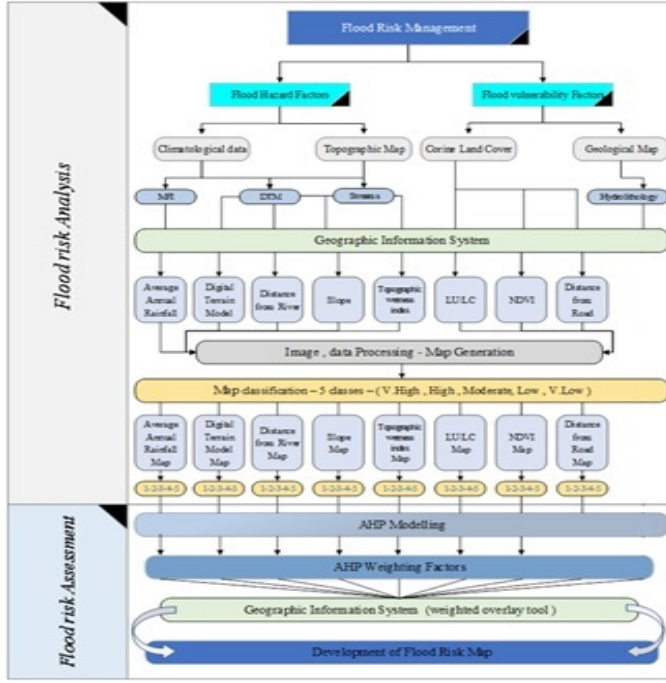


Fig. 2: Methodology



Fig. 3: Analytic hierarchy process (AHP)

acquire essential information, while thematic layers sourced from various origins were employed for mapping purposes. Secondary data were generated through an approach known as multicriteria analysis. Utilizing ArcGIS and QGIS software, a series of maps were produced, depicting characteristics such as slope, rainfall distribution, streams (rivers), and urban land use. All data were represented in the Universal Transverse Mercator (UTM) zone 36N projection, employing metric units.

V. FLOOD HAZARD FACTORS

Effective flood management necessitates a comprehensive evaluation of flood hazards[14]. Consequently, the indicators are elaborated upon in detail below.

A. Elevation

Generally, elevation constitutes a crucial determinant in identifying areas susceptible to flooding, as it profoundly influences the dispersion of floodwaters, the direction of flow, and the depth of flooding[15]. An elevation map of the Gabs area was developed utilizing a digital elevation model characterized by a spatial resolution of 12.5×12.5 meters, originating from SRTM data supplied by ALOS PALSAR through the Geophysical Institute of the University of Alaska Fairbanks.

TABLE I: Data

GIS & remote sensing data	Date of acquisition	Bands	Resolution	Source
Satellite images	August 2023	B04, B08	10m	Sentinel-2 - European Space Agency
Digital Elevation Model (DEM)	2009	-	12.5 m	Geophysical Institute of the University of Alaska Fairbanks ALOS -PALSAR
Land Use Land Cover	2020	-	10m	ESRI
Average Annual Rainfall	2022	-	-	Current Datasets and Static Climatologist[13]
Auxiliary data	Date	format	scale	Source
Vector data	2016	Shapefile	-	Sudan Survey Authority. Open street maps.

Within the study area, the elevation map is classified into five categories, with the lowest elevations exhibiting the highest vulnerability to flooding.

B. Slope

The gradient is a critical element in evaluating flood risks, as it affects water flow velocity and the infiltration of surface runoff[16]. The slope was determined from elevation contours and classified into five categories. Steeper slopes generally lead to expedited runoff and elevated flow velocities in streams and rivers in contrast to more gentle slopes. As a result, runoff from steeper areas is prone to accumulate in low-slope regions, thereby heightening the risk of flooding in these areas[17].

C. Topographic wetness index(TWI)

The Topographic Wetness Index (TWI), alternatively referred to as the Compound Topographic Index (CTI), serves as a steady-state wetness index that is frequently utilized to evaluate the influence of topography on hydrological processes[18]. The Topographic Wetness Index (TWI) is determined by the slope and the upstream contributing area per unit width perpendicular to the direction of flow. Initially, this index was devised for hillslope landscapes. However, in flat areas, the accumulation values increase significantly, thereby diminishing the relevance of TWI in such regions. This index demonstrates a strong correlation with various soil characteristics, including horizon depth, silt content, organic matter, and phosphorus levels[19]. Various methodologies for calculating the Topographic Wetness Index (TWI) predominantly differ in the approach utilized to ascertain the upslope contributing area Equation(1) is defined as:

$$TWI = \ln \frac{a}{\tan \beta} \quad (1)$$

The local upslope area that drains through a specific point per unit contour length is represented as (a) , while $(\tan\beta)$ denotes the local slope expressed in radians. The TWI has been utilized to examine the effects of spatial scale on hydrological phenomena processes.

D. Distance from River

The proximity to the river is a critical factor in identifying areas at risk of flooding and evaluating the flood hazard index. Regions in closer proximity to the river network exhibit greater vulnerability to flood hazards, whereas the influence of this variable decreases as the distance from the riverbed increases. In Gabs, the distance from the drainage network is established by the creation of buffer zones surrounding the drainage system data.

E. Average Annual Rainfall (ARR)

A defining characteristic of flash floods is their swift onset, manifesting shortly after periods of intense rainfall within a brief time frame (typically spanning several hours), particularly in steep, mountainous areas with minimal vegetation[20]. Consequently, precipitation constitutes a vital element in flood prediction, and the rate of rainfall has been selected for the assessment of flood risk in this study. The increased precipitation in a specific area correlates with a heightened flood risk. Rainfall intensity is quantified using the Modified Fournier Index (MFI), which embodies the cumulative average monthly rainfall intensities documented at each rain gauge station.

VI. FLOOD VULNERABILITY FACTORS

The vulnerability factor encompasses Land Use and Land Cover, the Normalized Difference Vegetation Index (NDVI), and proximity to roadways. Comprehensive explanations of these indicators are presented below.

A. Land use/land cover

Land use and land cover constitute critical factors in the examination of flood hazards, as they significantly influence essential hydrological processes, including runoff, infiltration, evaporation, and evapotranspiration. This encompasses elements such as soil deposits, the distribution of buildings, streams, vegetation cover, unoccupied land, and roadways[21]. Forests and vegetation enhance infiltration rates and decrease runoff, thereby mitigating flood potential. In contrast, roads, barren land, waterways, and structures, characterized by their impervious surfaces, elevate runoff rates, thereby contributing to an increased flood risk[22].

B. Normalized difference vegetation index (NDVI)

Vegetation indices are predicated upon the characteristics of plants and serve to reflect the quantity of active photosynthetic radiation, chlorophyll content, and the structure of vegetation. In the present study, the Normalized Difference Vegetation Index (NDVI) has been employed to evaluate the status of

vegetation. The calculation of NDVI involves determining the difference between the reflectance of the near-infrared band (ρ_{NIR}) at wavelengths ranging from 841 to 876 nm and the reflectance of the red band (ρ_{RED}) at wavelengths between 620 and 670 nm, which is then divided by the sum of these reflectance values, as illustrated in the subsequent equation Equation(2):

$$NDVI = \frac{NIR - Red}{(NIR + Red)} \quad (2)$$

In this context, Red and Near-Infrared (NIR) signify the spectral reflectance measurements obtained in the visible red and near-infrared regions, respectively. Additionally, the values of the Normalized Difference Vegetation Index (NDVI) range from +1 to -1 map.

C. Distance from Roads

The proximity of roads constitutes a significant factor that influences the flood risk exposure of a given location. Generally, areas situated closer to roads experience a higher flood risk in comparison to those located at a greater distance. Roads can function as conduits for water, directing it towards low-lying regions and thereby increasing the likelihood of flooding. Furthermore, roads have the potential to impede the natural flow of water, resulting in backups and subsequent flooding in adjacent areas.

VII. CLASSIFIED HAZARD AND VULNERABILITY FACTORS

The primary challenge in multi-criteria evaluation (MCE) lies in ascertaining the appropriate methodology for integrating information derived from multiple criteria to generate a comprehensive assessment. To enhance the integration, processing, and functionality of geographic information system (GIS) software, a series of foundational maps and images have been developed. All preparatory procedures, which include downloading, extracting, georeferencing, formatting, and re-sampling digital data pertaining to the influencing factors, were executed prior to analysis in order to identify the variables contributing to flooding.

All hazard-related factors (Elevation, Topographic Wetness Index (TWI), Slope, Distance from River, Average Annual Rainfall) and vulnerability factors (Land Use/Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), Distance from Road) were systematically reclassified into five distinct subgroups, and a rating scale of 1, denoting very low effect, to 5, denoting very high effect, was assigned using standard classification schemes, specifically quantiles. This classification scheme effectively segments the range of attribute values into equal-sized sub-ranges, thereby enabling one to specify the number of intervals, while ArcMap ascertains the corresponding breakpoints. Ultimately, the factors were reclassified into continuous scales by their respective flood assessment ratings

VIII. DEVELOPMENT OF FLOOD RISK MAP

In this study, the evaluation of flood risk is conducted through the integration of two essential criteria: hazard and vulnerability. The results of the flood risk analysis and assessment are depicted on a map to facilitate enhanced comprehension. The final phase of the methodology encompasses the overlay of analytical techniques utilizing ArcGIS. This Geographic Information System (GIS) tool generates two or more distinct thematic maps of the same geographic area, which are subsequently superimposed upon one another through the weighted overlay tool, resulting in the creation of a new composite map. This particular technique establishes a calculation matrix that identifies the primary alterations within the study area.[23]. The results of the weighted overlay analysis were generated utilizing equal intervals, consisting of five levels: very low, low, moderate, high, and very high.

IX. RESULTS AND DISCUSSION

A. Flood Hazard Factors Analysis Maps

The elevation map of the study area was produced utilizing a Digital Terrain Model (DTM). The elevation was categorized into five distinct levels, ranging from 419 meters to 1007 meters, as illustrated in Figure(4). The lowest elevation values significantly affect the rate of water drainage into the catchment, contingent upon the slopes present.

The Topographic Wetness Index (TWI) map illustrated in Figure(5) for the study area was produced utilizing the Digital Terrain Model (DTM), filled Digital Elevation Model (DEM), and slope data. The TWI has been classified into five distinct levels, ranging from 1.466 to 26.890. Lower TWI values signify a minimal impact, whereas higher values denote a more significant effect on elevation and topographic wetness index. The result of the reclassified slope layer was presented and categorized in degrees Figure(6). The amount of Slope is ranging from 0 to 75.43 degrees. Most maps show a higher slope was located water accumulated during excessive rainfall.

The slope and average annual rainfall maps, shown alongside the river proximity map Figure(7) and Figure(7), were derived from river and stream network data. Areas closer to rivers are more vulnerable to flood exposure, and higher risk scores are assigned to locations nearer to the river system Figure(9). The map's average annual rainfall (AAR) of Blue Nile State Figure(7) was generated based on hazard criteria. The average annual rainfall in July varies between 160 millimeters and 251 millimeters, with precipitation exhibiting an increasing trend from the southeastern region to the northern region of the state. The rainfall data has been classified into five distinct levels utilizing ArcMap.

B. Flood vulnerability Factors Analysis

Factors contributing to flood vulnerability were systematically analyzed through the identification of all pertinent elements for the decision support system. These elements encompass Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), and proximity to transportation infrastructure. Subsequently, these factors were reclassified

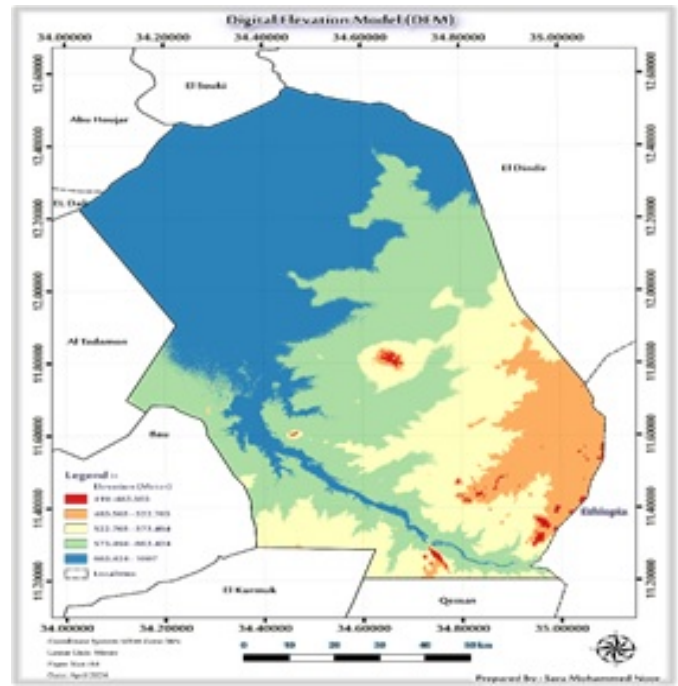


Fig. 4: Digital Elevation Model (Elevations) of Study Area

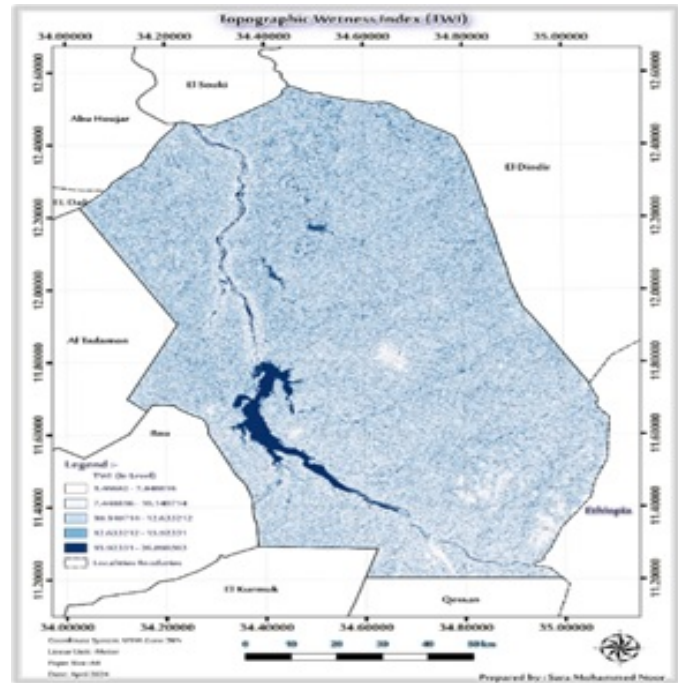


Fig. 5: The Topographic Wetness Index (TWI) of Study Area

and evaluated across five levels according to their impact: very high, high, moderate, low, and very low.

Figure(8) The Normalized Difference Vegetation Index (NDVI), while not a direct cause of flooding, serves as an indispensable instrument in the assessment of flood risk. Through the monitoring of vegetation health via NDVI, researchers can identify regions exhibiting diminished vegetation coverage. Such regions are inherently more vulnerable to soil erosion and increased runoff, thereby heightening the risk of

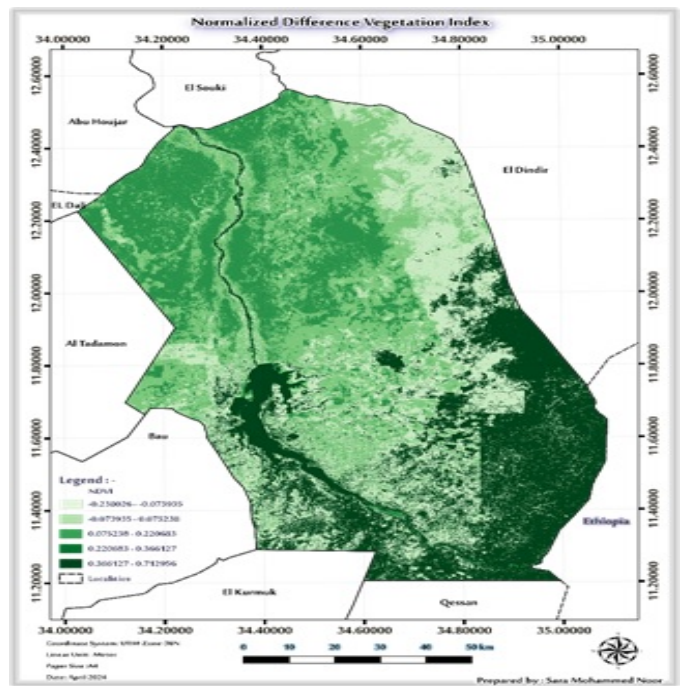


Fig. 8: Normalized Difference Vegetation Index (NDVI) of Study Area

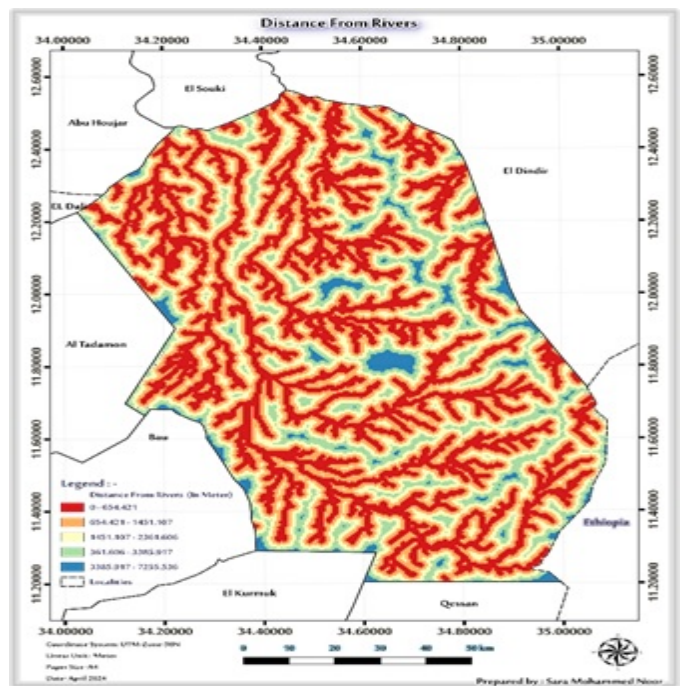


Fig. 9: Distance from the rivers of the Study Area

various land cover types, including urban areas, agricultural lands, and wetlands, to flooding. This information is critical for the formulation of effective flood prevention strategies, which encompass land use management and the conservation of natural flood barriers. The proximity of roads significantly influences flooding dynamics. Roads possess the potential to obstruct the natural flow of water, resulting in water accumulation. Inadequately designed drainage systems associated

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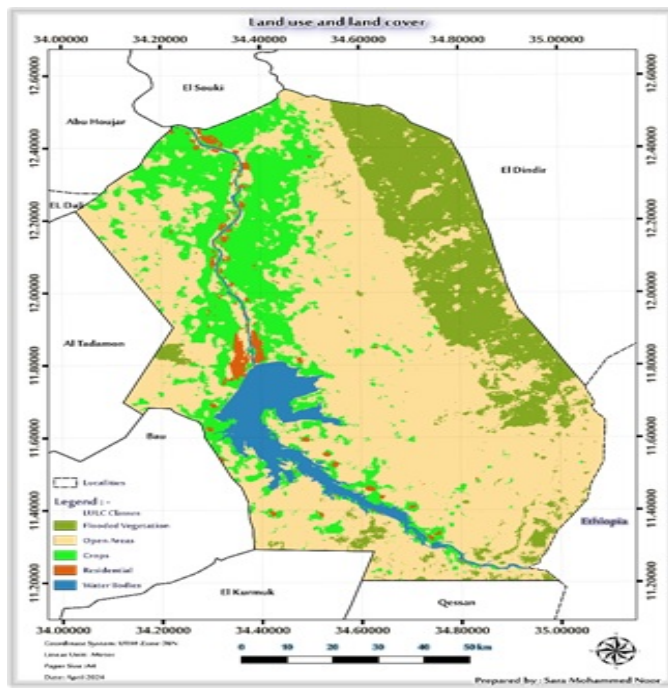


Fig. 10: Land use & Landcover of Study Area

with roads may exacerbate this issue, leading to waterlogging and subsequent flooding in adjacent areas. Furthermore, roads can contribute to soil erosion, thereby diminishing the land's capacity for water absorption and further increasing the risks of flooding Figure(11).

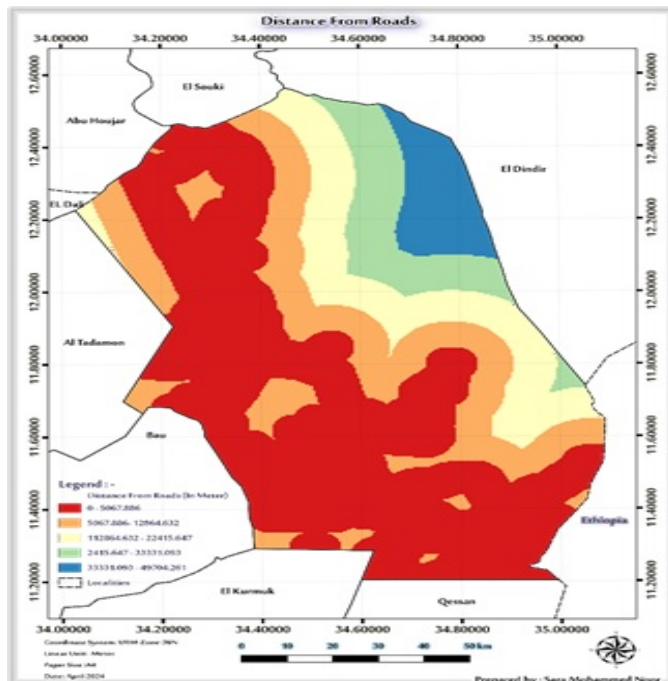


Fig. 11: Distance from roads in the Study Area

Finally, all factors of flood hazard analysis are shown in Table(II).

TABLE II: Flood Vulnerability Factors Analysis

Flood criterion	Classes	Susceptibility Rang and Rating	weight
DEM	419 -483.565	5	18
	483.565 - 522.765	4	
	522.765 - 573.494	3	
	573.494 - 663.424	2	
	663.424 - 1007	1	
TWI	1.46682 - 7.448816	1	17
	7.448816 - 10.140714	2	
	10.140714 - 12.633212	3	
	12.633212 - 15.92331	4	
	15.92331 - 26.890303	5	
Slope	0 - 0.887427	5	13
	0.887427 - 3.253898	4	
	3.253898 - 9.170076	3	
	9.170076 - 20.410813	2	
	20.410813 - 75.431267	1	
Precipitation	160 - 176.773	1	16
	176.773 - 188.906	2	
	188.906 - 201.753	3	
	201.753 - 216.741	4	
	216.741 - 251	5	
LULC	Water bodies	5	7
	flooded vegetation	1	
	crops	3	
	residential	4	
	open areas	2	
NDVI	-0.238026 - -0.073935	5	6
	-0.073935 - 0.075238	4	
	0.075238 - 0.220683	3	
	0.220683 - 0.366127	2	
	0.366127 - 0.712956	1	
Distance From River	0 - 654.421	5	17
	654.421 - 1451.107	4	
	1451.107 - 2361.606	3	
	361.606 - 3385.917	2	
	3385.917 - 7255.536	1	
Distance From Road	0 - 5067.886	5	6
	5067.886- 12864.632	4	
	112864.632 - 22415.647	3	
	2415.647 - 33331.093	2	
	33331.093 - 49704.261	1	

C. FLOOD Risk Assessment

Contributing factors were evaluated and assessed. The decision was segregated into its independent components. It was presented in a hierarchy diagram of at least three levels: goal, criteria, and indicators.

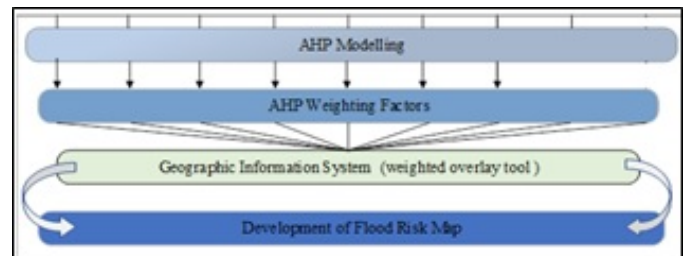


Fig. 12: FLOOD Risk Assessment Stages

Figure(12) depicts the study structure using the Analytic Hierarchy Process (AHP). At the top of the hierarchy is the primary goal: creating a flood risk map. The next level includes the criteria essential for achieving this goal, specifically the flood hazard map and flood vulnerability map. The lowest level comprises the indicators: elevation, slope, Topographic

Wetness Index, average annual rainfall, distance from rivers, land use/land cover, Normalized Difference Vegetation Index (NDVI), and distance from roads.

D. Derivation of the Overall Relative Weights

The designated weight for each parameter was established following the processes of reclassification and normalization. The values ascribed are contingent upon the specific level or category type. Figure(13) Shown the procedures involved in the assignment of feature weights through a pairwise comparison of flood hazard and vulnerability factors.

Name	Weight	Date	Consistency Ratio
Criteria			
more important ?			
A or B (1-9)			
1 2 TWI	Elevation	A	1
1 3	Slope	A	1
1 4	Precipitation	A	1
1 5	LULC	A	3
1 6	NDVI	A	5
1 7	Distance from river	A	1
1 8	Distance from road	A	3
2 3 Elevation	Slope	A	1
2 4	Precipitation	A	1
2 5	LULC	A	3
2 6	NDVI	A	3
2 7	Distance from river	A	1
2 8	Distance from road	A	5
3 4 Slope	Precipitation	A	1
3 5	LULC	A	3
3 6	NDVI	A	1
3 7	Distance from river	B	1
3 8	Distance from road	A	1
4 5 Precipitation	LULC	A	3
4 6	NDVI	A	3
4 7	Distance from river	A	1
4 8	Distance from road	A	3
5 6 LULC	NDVI	A	1
5 7	Distance from river	B	3
5 8	Distance from road	A	3
6 7 NDVI	Distance from river	B	5
6 8	Distance from road	A	1
7 8 Distance from river	Distance from road	A	3

Fig. 13: Pairwise comparison of Flood hazard

The definitive relative weights, derived through the Analytic Hierarchy Process (AHP) based on expert contributions, were established by assessing the Consistency Ratio (CR) between each criterion's relative weight and its corresponding alternative for hazard and vulnerability. These weights are illustrated in Figure(14), Figure(15), and Figure(16). Subsequently, they are incorporated into ArcGIS to generate hazard and vulnerability maps along with the pertinent index values.

Table	Criterion	Comment	Weights	±%
1	TWI		17.5%	4.5%
2	Elevation		17.4%	4.1%
3	Slope		13.4%	5.2%
4	Precipitation		16.1%	1.8%
5	LULC		6.7%	3.8%
6	NDVI		5.9%	2.9%
7	Distance from river		17.5%	4.5%
8	Distance from road		5.6%	3.1%
9			0.0%	0.0%
10			0.0%	0.0%
Result				
Eigenvalue		Lambda	8.474	MRE 39.1%
Consistency Ratio		0.37	GCI 0.17	Pk 3.6% CR 4.8%

Fig. 14: Final relative weights of Flood Hazard and

Matrix	TWI	Elevation	Slope	Precipitation	LULC	NDVI	Distance from river	Distance from road	0	0	normalized principal Eigenvector
TWI	1	1	1	1	3	5	1	3	-	-	17.47%
Elevation	1	1	1	1	3	3	1	5	-	-	17.41%
Slope	1	1	1	1	3	1	1	1	-	-	13.38%
Precipitation	1	1	1	1	3	3	1	3	-	-	16.09%
LULC	1/3	1/3	1/3	1/3	1	1	1/3	1/3	-	-	6.89%
NDVI	1/5	1/3	1	1/3	1	1	1/5	1	-	-	5.87%
Distance from river	1	1	1	1	3	5	1	3	-	-	17.47%
Distance from road	1/3	1/5	1	1/3	1/3	1	1/3	1	-	-	5.62%
0	-	-	-	-	-	-	-	-	1	-	0.00%
0	-	-	-	-	-	-	-	-	-	1	0.00%

Fig. 15: AHP Matrix

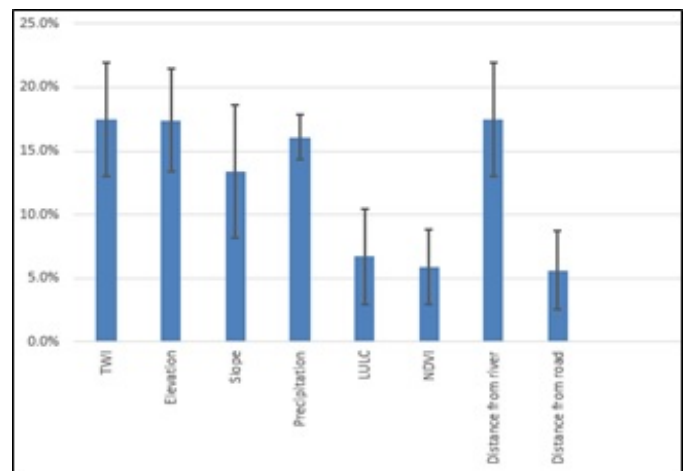


Fig. 16: Final Chart for relative weights of Flood

E. Development of a Flood Risk Map

Upon calculating the criteria weights utilizing the Analytic Hierarchy Process (AHP), these weights were subsequently incorporated into a Geographic Information System (GIS)-based procedure encompassing overlays, raster conversion, and layer clipping. The weighted overlay tools available in ArcGIS were utilized to amalgamate all five flood hazard factors, which were reclassified into five distinct levels. Concurrently, all four flood vulnerability factors were integrated following their reclassification into five levels (Error! Reference source not found.). The findings of the flood risk assessment have been represented in a cartographic format for enhanced understanding. The outcome of the analysis resulted in a composite map that integrates flood hazard, flood vulnerability, and factors maps, utilizing ArcGIS technology. This flood risk map serves as a comprehensive tool for evaluating potential flooding risks Figure(17) Risk levels are categorized using equal intervals and encompass five distinct categories: very low, low, moderate, high, and very high. In total, an area of 288.529 square kilometers is classified as very low risk.

Low-risk regions cover an area of 1203.596 square kilometers, while moderate-risk regions span 2424.604 square kilometers. High-risk regions encompass approximately 3522.213 square kilometers, and very high-risk regions encompass an area of approximately 3,713.042 square kilometers. Figure(18) Shown the percentage distribution of the associated risk levels.

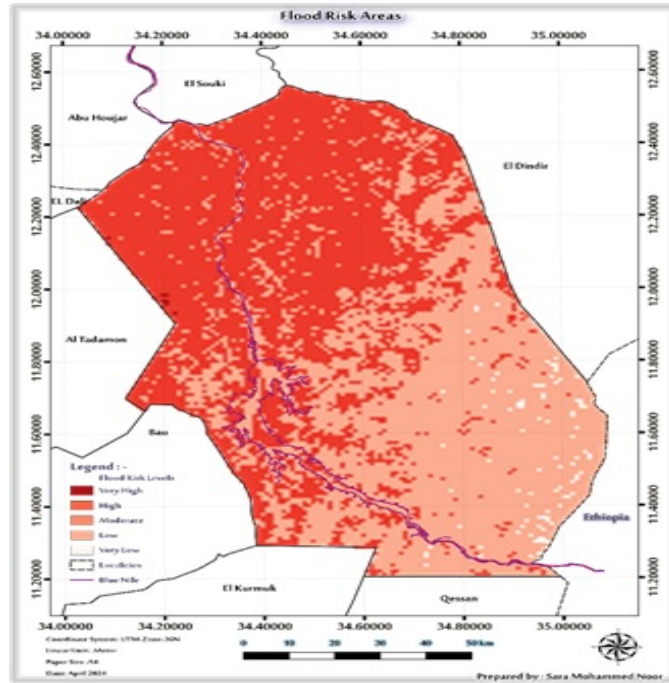


Fig. 17: Flood Risk Map for the Study Area

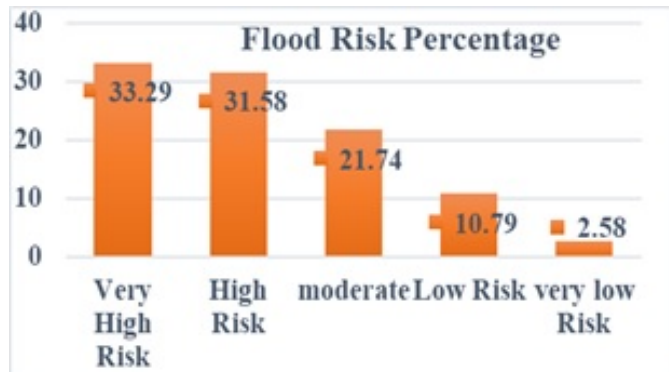


Fig. 18: Flood Risk Percentage for Flood Risk Areas

X. CONCLUSIONS& RECOMMENDATIONS

The paper aims to highlight the negative impacts of flood-prone areas over time. Damage from such events is increasing at an exponential rate, with the impacts of land use, urbanization and climate change being particularly worrisome. This study assessed flood risk areas within part of Blue Nile State by assessing various flood-related factors through multi-criteria decision-making and the Analytical Hierarchy Process (AHP), using GIS-based analysis. ArcGIS was used to map and model primary and secondary data as parameters

contributing to flooding. Parameters considered included elevation, slope, topographic wetness index, mean annual rainfall, proximity to rivers, land use and land cover, normalized mean vegetation index (NDVI), and distance from roads. The methodology relied on hazard analysis and assessment to generate a flood risk map. In the case study, during the analysis phase, a problem tree and a vision tree were created, and strategies for potential solutions were proposed using free Sentinel 2 satellite images captured remotely on August 23. The flood risk map showed that approximately 2.58% of the area is at very low risk, 10.79% at low risk, 21.74% at medium risk, 31.58% at high risk, and 33.29% at very high risk. Future research should enhance flood risk assessments by including additional factors such as demographics, income, education, water use, emergency preparedness, and soil type.

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