PROVISION OF STRENGTHENING ADAPTATION PLANNING PROCESSES AND CAPACITY FOR IMPLEMENTATION OF ADAPTATION ACTIONS IN AGRICULTURAL AND WATER SECTORS IN THE SUDAN (NAP READINESS)

CONSTRUCTING CLIMATE CHANGE VULNERABILITY HOTSPOT MAPS

(SPECIFIED IN LOA)

FLOOD RISK & HOTSPOT

FINAL REPORT

PREPARED FOR FAO- SUDAN

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1. Background

Flooding is one of the most common natural disasters, often with disastrous consequences, it is a natural part of the hydrological cycle, and it has the potential to cause death, displacement, and environmental damage. Floods are among the most shocking natural disasters and can cause irreversible damage. Flooding can occur in a number of different ways. River/stream overflow, heavy rain, breaches in flood protection systems, and rapid melting of ice in the mountains are among the most prominent.

Flood hazard mapping and analysis, which identifies the most vulnerable regions based on physical characteristics that indicate the propensity for flooding, is one of the most important parts of early warning systems or methods for the prevention and mitigation of future flood situations. Flood hazard mapping is a critical component of flood-prone Land use planning and mitigation strategies. Flood hazard mapping provides easy-to-read charts and maps, allowing planners to identify risk areas and prioritize mitigation activities.

The objective of this work is to determine the spatial distribution of flood risk and assess potential damage in agricultural and postural lands that can be caused by flooding, and hence identifies the hotspot area. The product from this work can be used for protecting the community from economic loss, displacement and ensure food security.

1.1. Floods and flash floods hotspot mapping

The factors or parameters which are used in the weighing of the flood prone areas are FIGUSED method which was initiated by Kazakis et al. (2015). These parameters can be described as follows:

Flow Accumulation: Flow accumulation is the total of water which is flowing to a lower area. The accumulation is converted into cell form as output from raster data. High values for accumulated flow indicate areas where concentrations of water flow and have consequences as flood areas. The value of flow accumulation varies from 0 - 50,250 with the highest value found in the outflow area and the lowest value is in the river with a low order.

Distance from Drainage Network: Apart from the concentrating area of surface water, river overflow is crucial at the beginning of the flood event. Often the flooding comes from the river and spreads around it. The role of the river for flooding decreases with increasing distance from the river. Class division on this criterion is based on recordings in the study area. Areas less than 200 m from the river are high flood areas and the effect will decrease with increasing distance more than 2000 m.

Elevation and Slope: Water flows from high elevations to low elevations and for that; slope affects the runoff and infiltration. In flat areas at low elevation, the flood is faster than in areas with high elevations and steep slopes. Naturally, low slopes and elevations are placed at high weights as potentially flooded areas.

Land use affects the level of infiltration: This is related to surface water and groundwater. Forests and dense vegetation support infiltration, while urban and grassland settlements support surface runoff. However, Santoso (2012) and Abdhika (2016) provided separate classifications in land use. Settlements and buildings have the highest weight values. The vegetation is divided into rainfed crop fields, gardens, fields and crop fields. Santoso (2012) and Abdhika (2016) place forests, grasses, shrubs and fresh water as the parameters with the lowest weights.

Table (1): Classification and Rating of Land use

Land use Classification	Rating
Settlement	5
Rainfed crop fields and crop fields land	4
Plantation	3
Field	2
Rocky, forest, grass	1

Source:Based on Santoso (2012) and Abdhika (2016)

Rainfall Intensity: Based on research which was conducted by Kazakis, et al (2015), the intensity of rainfall is expressed using MFI (modified Fournier index). MFI is the average monthly amount of rainfall intensity per rain station. The spatial distribution of rainfall intensity is considered based on station allocation in the study area. Based on the number of distribution stations, Kazakis et al. (2015) use spline interpolation compared to ordinary kriging or co-krigging.

Geology: Based on Kazakis, et.al (2015) research, the geological condition of an area is an important factor in the identification of flood disaster areas, because it has an impact on strengthening or weakening the strength (magnitude) of floods. Permeable rock formations support water percolation and groundwater infiltration. In contrast, crystalline rocks which are impermeable rocks support surface flow. Karst significantly influences the formation of flash floods (Bonacci, et al., 2006). For this reason, karst and sediment lacustrin (clay, marble and silt) are given for a high value (8). The low level is given to alluvial and continental deposits due to their level of infiltration.

The spatial variability in flood risk was determined usually based on six factors: slope (S), elevation (E), flow accumulation (F), geology (G), land use (L), and rainfall intensity (R), which have direct important impacts on flood risk (Kourgialas and Karatzas 2011, 2016; Kazakis et al. 2015). These factors are prepared as six thematic maps, which were then combined into one final flood risk map using linear algebraic function and their weights in the GIS environment. Factors F and G are qualitative, whereas factors S, E, and R are considered quantitative. The factors were classified into five flood risk zones (FRZ): very low, low, moderate, high, and very high. Jenk's natural breaks method applied to classify quantitative (numerical) factors, whereas qualitative factors classified based on their effect in flood recharging. For example, for factor L (land use), forest will be classified as very low flood risk, but residential area as of very high flood risk. For each classified factor's flood risk rating, a numerical value was allocated (very low (1), low (2), moderate (5), high (8), and very high (10)) (Kourgialas and Karatzas 2016). Since all factors do not have the same effect on flooding condition, two types of effects were considered: minor effect, where a change in one factor has an indirect effect on another factor (allocated 0.5 points), and major effect, where a change in one factor has a direct effect on another factor (allocated 1 point). This method is adopted and applied in Algadarief State and some deliverables are obtained and presented in the workshop held on 19/1/2023.

1.2. GIS Overlay Technique

Overlay is an important procedure in GIS analysis. Overlay is the ability to place one map graphics on another map graphic and display the results on a computer screen or on a plot. In short, overlays overlap a digital map on another digital map along with its attributes and produce a combined map of the two that have attribute information from both maps. Overlay is a process of integrating data from different layers. In simple terms, overlays are referred to as visual operations that require more than one layer to be combined physically (Guntara, I., 2013).

Weighing and Scoring Weighing is giving weight to the digital map of each parameter that influences flooding, based on consideration of the effect of each parameter on flooding that will be used in GIS analysis (Suhardiman, 2012). This is based on the influence of the class on events (Anas Sudijono, 2007). The greater the effect on events, the higher the score to get a total score/value, it is necessary to give a value and weight so that the balance between the two can produce a total value which is usually called a score. Giving values for each parameter is the same, namely 1-5, while weighting depends on the influence of each parameter which has the greatest factor in the level of flood vulnerability.

The geographic weighed regression (GWR) will be used to assess relationships between agricultural land uses (crop and wheat) and flood risk areas at subwatershed scale. This model can explore the spatial relationship between dependent and independent variables considering no-stationarity properties of targeted phenomena (Stewart Fotheringham et al. 1996). The GWR equation is from (Fotheringham et al. 1998)

2. Materials and methods

In this work all preparation procedures, such as downloading, extracting, geo-referencing, formatting, and resampling digital data of the factors, were completed prior to analysis. To identify flood-causing variables, literature was used. As a result, slope, drainage density, rainfall, soil texture and land use were prioritized in terms of flood hazard relevance.

Weighting and Scoring Weighting is giving weight to the digital map of each parameter that influences flooding, based on consideration of the effect of each parameter on flooding. Weighting is intended as giving weight to each thematic map (parameter). Determining the weight for each thematic map is based on consideration, how much the possibility of flooding is affected by each geographical parameter that will be used in GIS analysis.

Scoring is giving scores to each class in each parameter. Scoring was based on the influence of the class on events. The greater the effect on events, the higher the score. Giving values for each parameter is the same, namely 1-5, while weighting depends on the influence of each parameter which has the greatest factor in the level of flood vulnerability.

The spatial variability in flood risk was determined based on five factors: slope, drainage density, rainfall, soil texture and land use, which have direct important impacts on flood risk. These factors were prepared as thematic maps, which were then combined into one final flood risk map with their influenced weights in the GIS environment. Natural breaks method was applied to classify quantitative (numerical) factors, whereas qualitative factors were classified based on their effect in flood recharging. For example, for factor land use of forest was classified as very low flood risk, but residential area as very high flood risk. For each classified factor's flood risk rating, a numerical value was allocated (very low, low, moderate, high, and very high).

In this work Sudan's states were treated individually and the vulnerable flood risk maps were constructed. There after the agricultural and pasture land areas were extracted and overlaid on the vulnerable flood risk maps to generate the hotspots due to flooding risks.

2.1 Data and Methods of Mapping of Flood Risk

The basic flood-producing factors in this project were derived from: (Rainfall, Soil texture, Slopes, Drainage-density, Land use/ Land cover), and it have been collected from different sources. It can be described as follow:

The Rainfall factor:

Rainfall is a significant factor in creating a flood risk map, the greater the amount of rainfall, the greater the flood-producing runoff, and vice versa (Adiat et al. 2012; Blistanova et al. 2016; Gazi et al. 2019) Annual mean rainfall data for 30 years was classified into five categories based on its impact on flood risk.

The Slope factor:

Slope is an important factor in determining the rate and duration of water flow. (Wondim 2016; Gigoviç et al. 2017; Rimba et al. 2017; Rincón, et al. 2018; Desalegn and Mulu 2020; Singh et al. 2020a). It has a significant impact on flood risk assessment because it affects the quantity surface runoff generated by precipitation.

The Drainage density factor

The drainage density layers were created with the help of the GIS environment and the DEM. The drainage density was categorized into a continuous scale in accordance with the flood hazard rating.

The Soils factor:

The type of soil has a significant impact on the rate of infiltration and the water-holding capacity of the area. As a result, it may be considered one of the factors in defining flood-prone areas. Sandy soils have higher saturated hydraulic conductivities than finer grained soils due to the greater pore space between the soil particles.

The Land use/Land cover factor (LULC):

The LULC play an important role in flood water movement by impeding, delaying or accelerating surface flow. It influences infiltration rates, the interaction of surface and groundwater, and debris flow. Built-up areas are classified as extremely high, Forestland, on the other hand, has a very low capacity to generate floods and is classified as extremely low.

2.2 Analytic Hierarchy Process (AHP) Model

In AHP, weights and thematic layers for each level (criteria classes) are assigned and their relative importance is determined using (1–5) scale. The relevance or preference of each thematic layer relative to the other thematic layers on flood prone area delineation selection was conveyed by assigning weights. This was accomplished by utilizing relevant reviewed literatures, field observation, and expert judgment. The opinions of experts were gathered to determine the weight of the factors in the analytic hierarchy process. The collected data were processed using GIS. Figure (1) represent a flow chart for the analytic hierarchy method to produce a flood risk map.

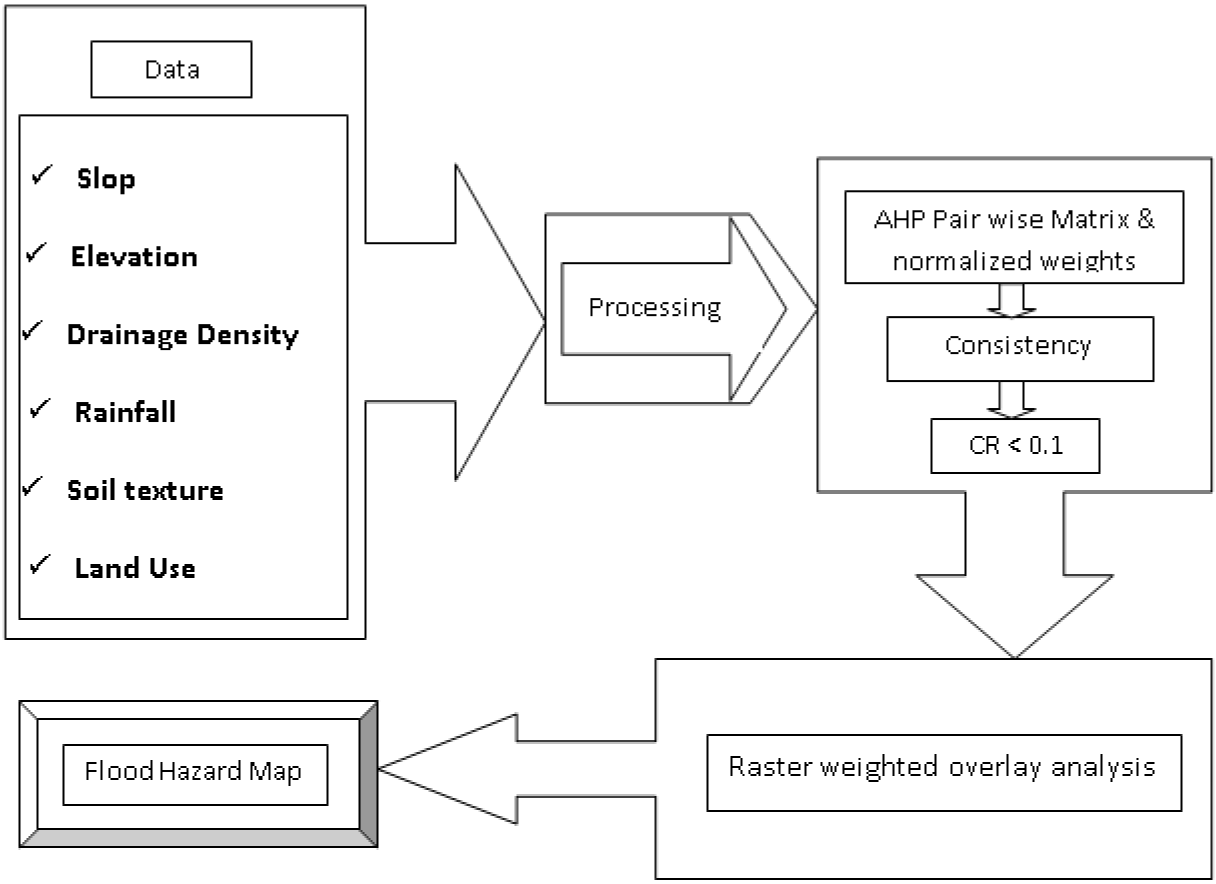


Fig. (1) Methodology flow chart for producing a flood risk maps

3. Mapping of vulnerable areas under flood risk:

Following the above-mentioned procedure, the vulnerable areas under flood risk map were identified and the possible affected areas were determined for each state.

4. Flood Risk and Hotspot Analysis

Samples were taken from the previously developed Flood Risk map, different flood hazard levels were sampled such as very high, high, medium, low and very low flood hazard areas. The severity of flood hazard was coded by giving each location coordinates and an ID. To identify hot spots, areas had to be weighted according to their flood hazard severity. The Getis-Ord Gi* Statistic function was used to plot a cluster map and identify statistically significant points such as a high value location among points of the same value, and create flood hazard areas categories with a Z score and P value associated with each category. To identify areas with high or low values that tend to cluster in a given area, the following equations were used:

$$G_j^*(d)=\frac{\sum_j^n=1\ wij\ (d)xj}{\sum_j^n=1\ x_j} \qquad \text{(1) (Manepalli, U. R, 2011)}$$

$$\mathrm{Z}(G_j^*) = \frac{G_i^* - E\ (G_i^*)}{\sqrt{VAR\ (G_i^*)}} \qquad \text{(2) (Mitra, S, 2009)}$$

Where:

- d = distance threshold
- w ij = weight of target neighbour pair
- x j = severity index at location j

All floods' locations were categorized in four categories based on their Z scores which signifies their statistical significance level. The breaks were provided at Z scores of 1.65, 1.96 and 2.58, which shows statistical significance level of 0.10,0.05 and 0.01 or confidence level of 90%, 95% and 99% respectively.

Flood risk maps were used in all states of Sudan to identify areas vulnerable to flood risk and its degree for each state separately. Based on this data, maps were developed for areas most vulnerable to flood risk and areas least vulnerable based on the Getis-Ord Gi* Statistic function, where flood hotspots were identified for each state to support decision makers to intervene to protect lives and livelihoods in hotspot areas.

4.1 Flood Risk & Hotspot in Northern State:

Figure (2a) shows the areas of flood risk in the Northern State, where it is noted that the areas at very high risk of flooding are concentrated in the southern parts of the state, especially in the El Golid and El Daba localities, while the degree of flood risk decreases towards the North and West away from the River Nile, where the susceptibility of lands to flooding risk gradually increases from the southeast to the northwest, i.e. from very high susceptibility to flooding to high, medium and low, respectively. However, the distinctive feature of the state is that most of its areas is susceptible to flooding to a medium or high degree.

The hotspot approach was used to identify and map areas with lower or higher flood risk index values in the Northern State. Hotspots in Figure (2b) represent a small area or area with greater sensitivity to flood risk compared to cold spots, which represent areas or areas with less sensitivity to flood risk. Al-Daba, Al-Gold and Merowe represent hotspots while Al-Barqiq represents a cold spot. Floods in the Northern State caused extensive damage, displacing thousands of peoples and creating critical needs in the health, water, sanitation and shelter sectors. According to (Sudan Floods Dashboard, 2024).

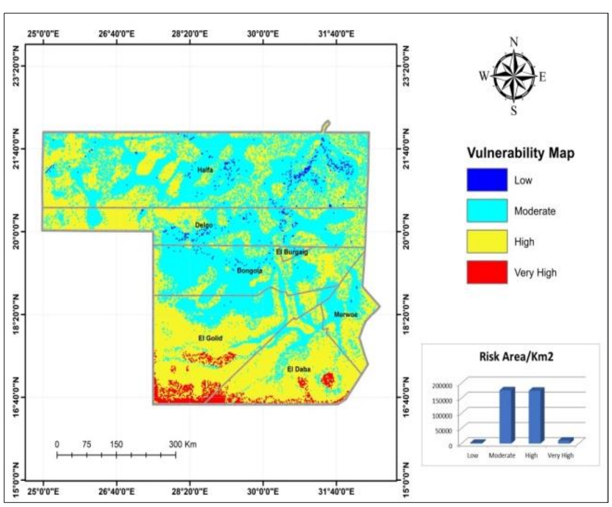


Fig 2a: Flood Risk in Northern State

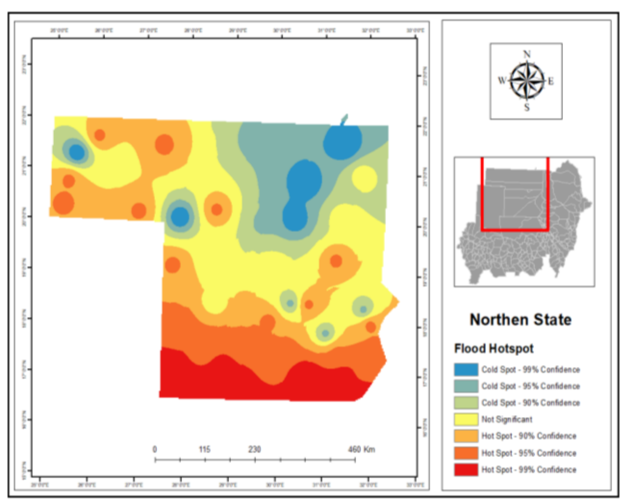


Fig 2b: Flood Hotspot in Northern State

4.2 Flood Risk & Hotspot in River Nile State

The degree of land exposure to floods in River Nile State varies between very low and very high, as most of the lands exposed to the risk of very high floods risk are concentrated in the central and southwestern parts of the state, especially in the areas adjacent to the Nile and Atbara rivers in Ad Damer locality, in addition to the center of Shendi locality, while the lands exposed to the risk of moderate floods risk are concentrated in most of the Northern localities of the state, especially Atbara, Berber, Buhaira and Abu Hamad Locality, the latter of which includes large areas of lands exposed to the high floods risk and these areas are concentrated on both sides of the River Nile. As for the areas less exposed to the floods risk with very low and medium degrees, they represent less than 3% of the total area of the state.

Figure (3b) indicates the hot and cold spots of floods in River Nile State, where three hot spots appear in red in the southern parts of the state with a statistical significance of 99% and are confined to Shendi, Ad Damer and Al-Mutamma. While the hot spots are concentrated in Abu Hamad locality. As for the cold spots of floods, they are concentrated in the middle of the state and its far North, specifically Abu Hamad and Al-Buhaira localities. The yellow color indicates that there is no statistical significance for the probability of flood susceptibility or non-flood susceptibility in the areas it covers.

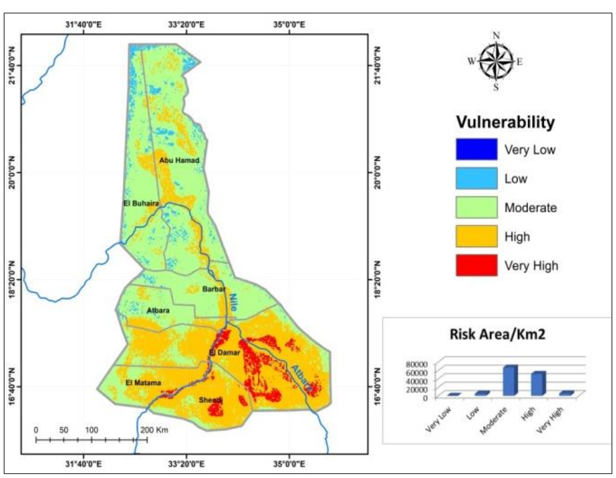


Fig 3a: Flood Risk in River Nile State

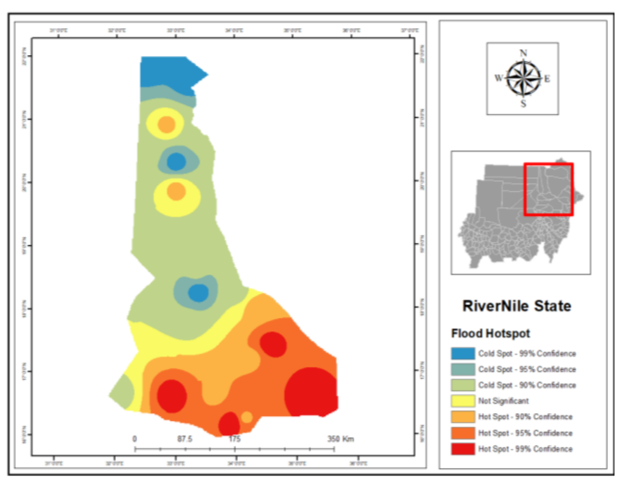


Fig 3b: Flood Hotspot in River Nile State

4.3 Flood Risk & Hotspot in Khartoum State

The East Nile locality is considered one of the most vulnerable localities to flood risk in Khartoum State, as it is noted that more than 90% of the area vulnerable to flood risk at a very high level is concentrated in the Eastern and Southern parts of the locality, where the area is covered by seasonal Wadies network and has a high population density, due to the availability of agriculture land as well as natural pastures. As for the areas vulnerable to flood risk at a low or very low level, they are concentrated in the Northern, Western and Northwestern parts of Khartoum State, particularly in Khartoum Bahri, Karari and Ombada localities. While the lands vulnerable to flood risk at a high level are concentrated in the center of the state, Figure (4a). Figure (4b) shows a hot spot with a significance of 99% and a warm spot with a significance of 95% in East Nile locality. This locality ranks first in terms of the frequency of floods, followed by El-Khartum Bahri and parts of Karari locality, where the least warm spots appear. While the cold spots cover a large area of Karari and Ombada localities, large parts of Omdurman locality appear in yellow, indicating that there is no statistical significance whether the conditions form hot or cold spots. Most of the agricultural lands that produce crops and livestock are concentrated in East Nile locality, in addition to the presence of agricultural villages in high density

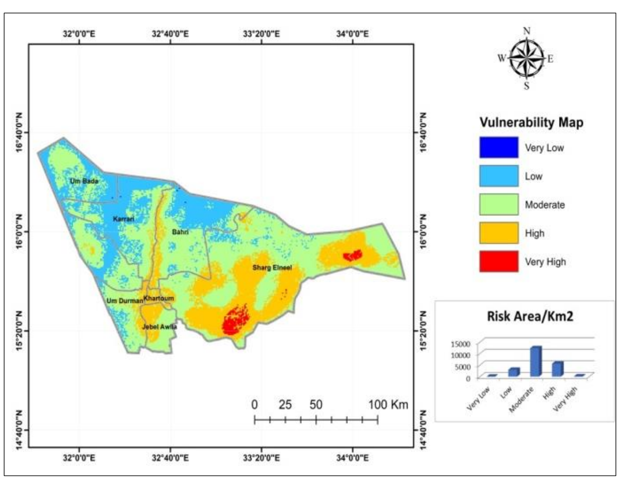


Fig 4a: Flood Risk in Khartoum State

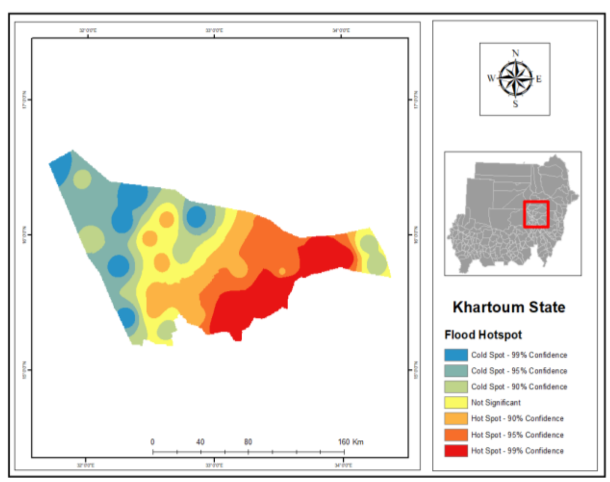


Fig 4b: Flood Hotspot in Khartoum State

4.4 Flood Risk & Hotspot in Al Gazira State

Figure (5a) shows that the areas at high risk of flooding are concentrated in the center of Umm Elqura locality and south of Al Managil locality. However, it is noted that most of the state's lands are at medium, high and low risk of flooding, respectively. The areas at very low risk of flooding do not exceed 2% of the state's total area. It is worth noting that the Northern parts of the state are at risk of Nile flooding, while the Southern parts are more vulnerable to floods resulting from increased rainfall rates.

Figure (5b) shows the hot and cold spots of flood-sensitive areas in Gazira State. The dark red color indicates the area's most vulnerable to flood risk at 99%, which are hot spots and are concentrated in Umm Al-Qura, Damdani and Al-Managil, followed by the light red color at 95%, which is concentrated in the East and South of Al-Jazeera and indicates warm areas, then the light red color at 90%, which is concentrated in parts of Al-Managil, Damdani, Umm Al-Qura, South and East of Gazira. As for the cold spots at their three percentages (99%, 95% and 90%), they indicate the areas least vulnerable to flood risk, respectively, and the cold spots are concentrated in the north of Gazira, Al-Hasahisa and Al-Kamlin. Gazira State is considered one of the states most at risk of flooding, due to the coverage of the White and Blue Niles over large parts of the state.

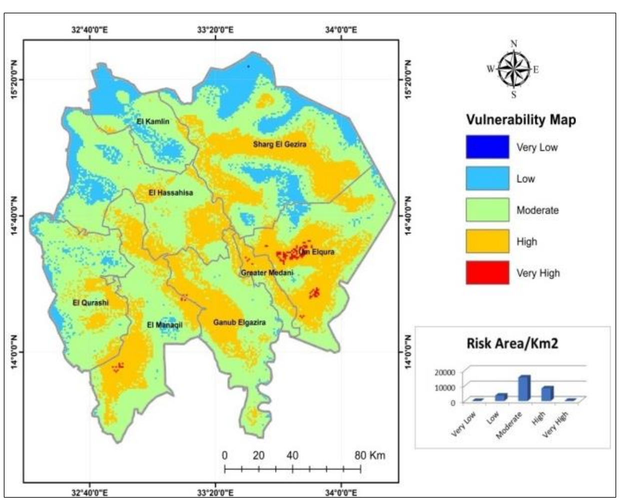


Fig 5a: Flood Risk in Gazira State

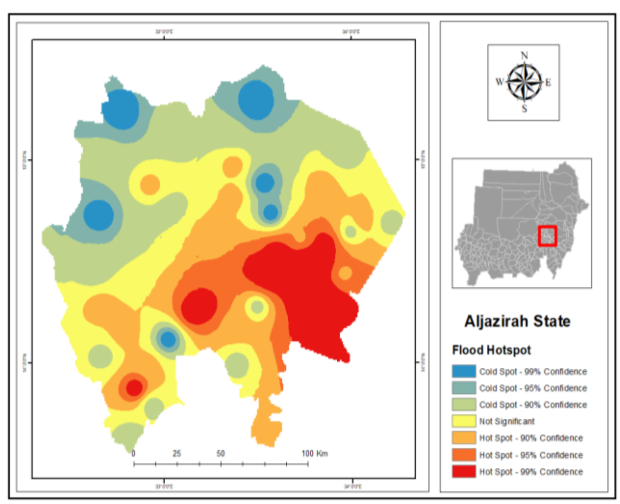


Fig 5b: Flood Hotspot in Gazira State

4.5 Flood Risk & Hotspot in White Nile State

Figure (6a) shows the susceptibility of lands to flood risk in White Nile State, which receives very high rainfall rates compared to the rest of the Sudanese states located to the North, in addition to the millions of cubic meters of water that cross the state annually via the White Nile. The state is also characterized by a high percentage of silt in its soil, which limits the infiltration of water into the groundwater basins. Therefore, White Nile is considered the most vulnerable state in Sudan to flood risk. The degree of vulnerability to flood risk in White Nile State varies greatly depending on the distance or proximity to the Nile, as the degree of vulnerability to flood risk increases in areas close to the Nile compared to areas far from it. This is a distinctive feature of all the lands of the state except for the Southern regions, which are characterized by their high and very high vulnerability to flood risk.

Figure (6b) shows the hot and cold spots of the flood areas in White Nile State, where the red gradient indicates the statistically significant hot spots, the blue gradient indicates the statistically significant cold spots, and the yellow gradient indicates the absence of statistical significance. The hot spots are concentrated in the southeastern parts of the state in Al-Jebeliya locality and the Eastern parts of Al-Salam locality. The cold spots are concentrated in the Southern parts of Al-Salam locality and to a lesser extent in both Al-Qatina and Amramta localities.

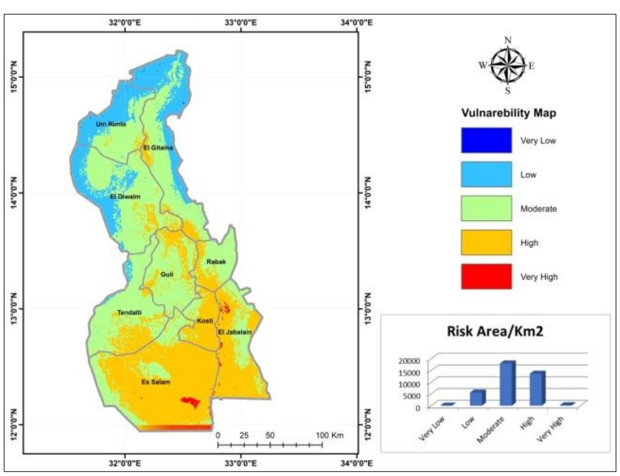


Fig 6a: Flood Risk in White Nile State

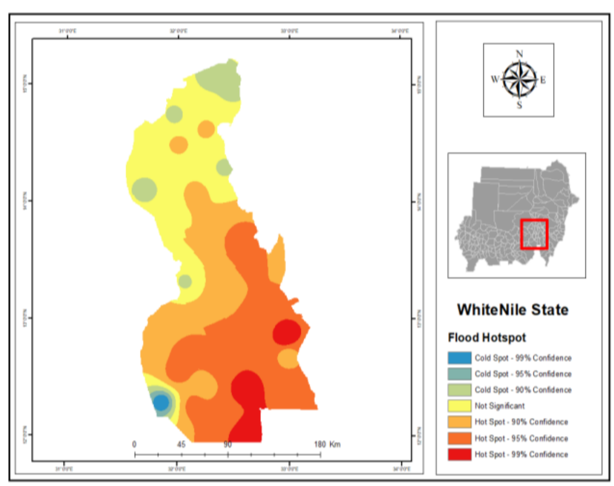


Fig 6b: Flood Hotspot in White Nile State

4.6 Flood Risk & Hotspot in Kassala State

Figure (7a) shows that more than 90% of the area of the rural Wad Al-Hilu locality is at high risk of flooding, and the locality alone is characterized by the presence of an area at very high risk of flooding. The areas at medium risk of flooding represent about 50% of the total area of the state, with areas at low or very low risk of flooding in the eastern parts of the state, representing no more than 5% of the state’s area.

Figure (7b) shows the hot and cold spots of the flood-prone areas in Kassala State, eastern Sudan. The hot spots appear in red and indicate the dangerous areas, while the cold spots appear in blue and indicate the non-dangerous areas. In the far South of the state, a red spot appears, representing the most dangerous areas sensitive to flood risk. This spot is located in the rural areas of Wad Al-Hilo. While cold spots appear in both the rural areas of Hamshkoreib and northern Delta. In general, flood concentration increases towards the south, due to high rainfall rates, high population density, and farmers' preference to live in areas with heavy rainfall and fertile soil. Some people tend to settle near rainwater drainage basins and seasonal valleys to practice irrigated agriculture on the edges of the valleys and benefit from the surface water stored in the excavations, which exposes themselves to the risk of flooding, especially during the rainy season.

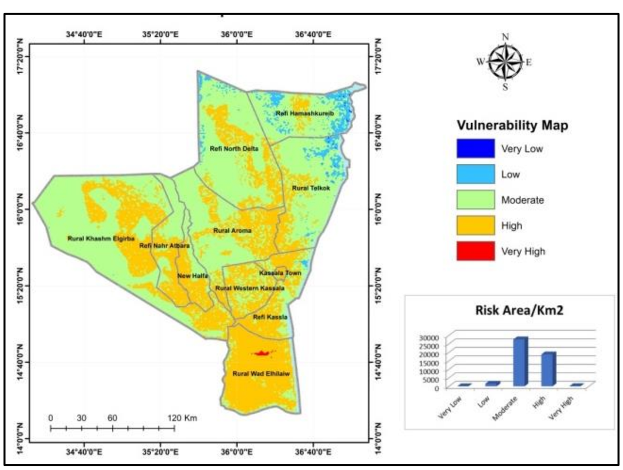


Fig 7a: Flood Risk in Kassala State

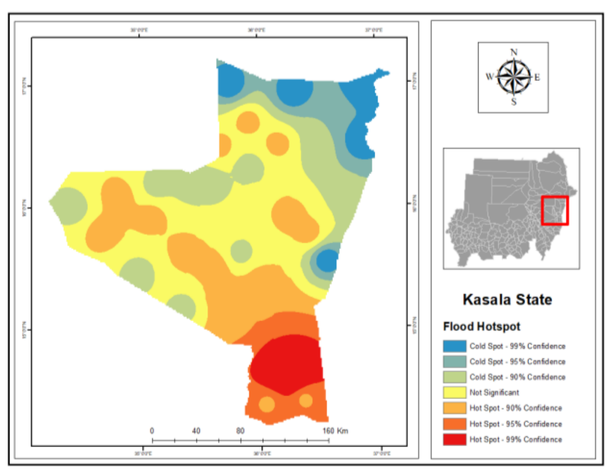


Fig 7b: Flood Hotspot in Kassala State

4.7 Flood Risk & Hotspot in Gadarif State

Areas at high risk of flooding are concentrated in the southern localities of the state, especially Qalaa Al-Nahl and East Gadarif, which together represent about 4% of the state's area, while areas at low risk of flooding are concentrated in the Northern parts of the state, especially Al-Butana. However, it is noted that 40% of the state's area is at medium risk of flooding. It is worth noting that most of the areas at high risk of flooding are located within the scope of rain-fed agricultural lands.

Figure (8b) indicates the hot and cold spots of the lands exposed to the risk of flooding in Gadarif State, where it is noted that the hot and warm spots in red are concentrated in the southern localities of the state, while the cold spots are concentrated in the northern part of it, specifically in the locality of Butana. East Gadarif, Rahad and Qalaa Al-Nahl are considered areas exposed to the risk of flooding and represent hot spots for several reasons, the most important of which are: high rainfall rates in the southern parts compared to the northern parts, in addition to the concentration of the seasonal valley network in the region, including the semi-seasonal Rahad River. Therefore, the region obtains an estimated percentage of rainwater and surface runoff, and these quantities may exceed the drainage capacity of the valleys and creeks, reaching the flood stage, especially during the rainy season.

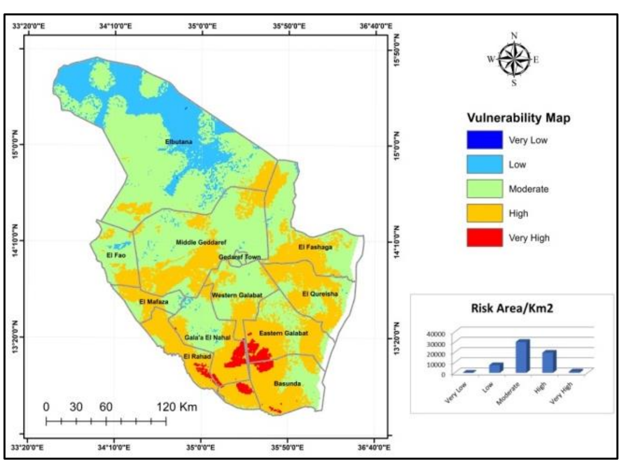


Fig 8a: Flood Risk in Gadarif State

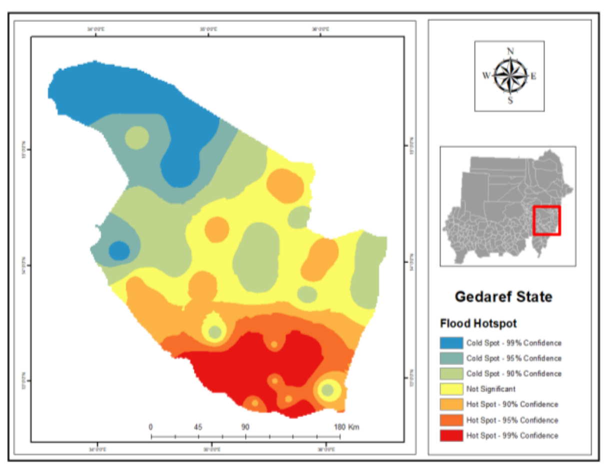


Fig 8b: Flood Hotspot in Gadarif State

4.8 Flood Risk & Hotspot in Red Sea State

Figure (9a) shows that there are two areas with very high flood risk, one in the Tokar Delta and the other in Haya. The rest of the Red Sea State has either high or medium flood risk, except for the Northern parts of Halaya locality and some scattered pockets in the different localities, which have low or very low flood risk. Some areas are at high risk of flooding but are not clearly shown on the map. An example of this is the flooding of Khor Arbaat due to the collapse of the dam.

The Red Sea State is characterized by high elevations and sloping creeks, in addition to the steep slope towards the Red Sea. This has contributed to the recurrence of torrents and floods, especially in agricultural and residential areas near the valleys, in Aqeeq and Tokar, in addition to floods resulting from the collapse of dams, as was the case with the collapse of Arbaat Dam in 2024 AD . Figure (9b) shows the hot and cold spots of floods in the Red Sea State. Due to the difference in terrain and the direction of the slope of valleys from the high areas east and west, the hot and cold spots are distributed throughout the state without a specific pattern, as we find hot and cold areas in the north, south and east, while the hot, warm and less warm spots are confined to the western parts of the state.

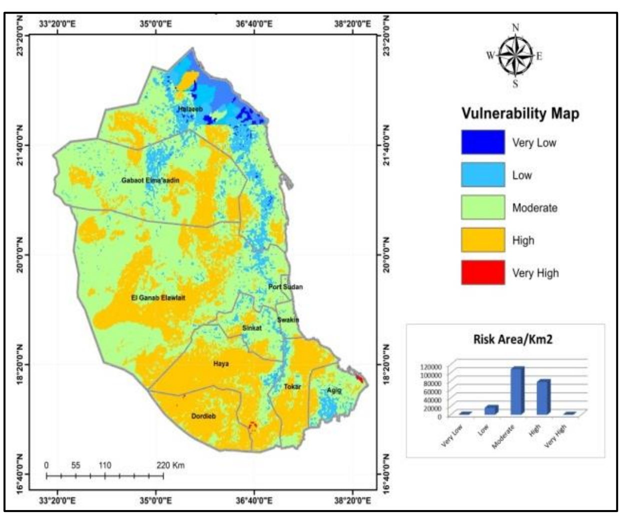


Fig 9a: Flood Risk in Red Sea State

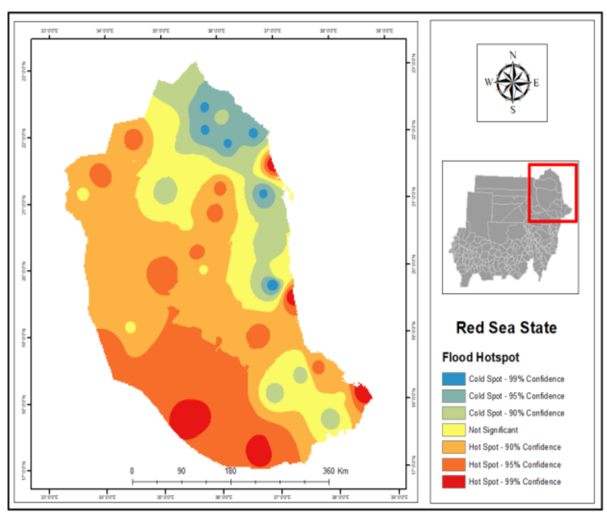


Fig 9b: Flood Hotspot in Red Sea State

4.9 Flood Risk & Flood Hotspot in North Darfur State

Figure (10a) shows that the areas at high risk of flooding represent more than 30% of the total area of the locality and are concentrated in the southern parts of the state, where there are fertile agricultural lands and a network of seasonal valleys descending from the heights of Jebel Marra, in addition to the relatively high population concentration in those areas, which contributed to the high percentage of lands at high risk of flooding in the region, while the areas at high risk of flooding cover 60% of the area of the state, and yet they do not pose a threat to the lives of the population and their livelihoods, due to the presence of sandy soil that is characterized by high porosity, in addition to the region being characterized by an ideal slope that contributes to good water drainage.

Figure (10b) shows the hot and cold spots of flooding in North Darfur State, where the cold spots cover the northern parts of the state except for the oasis area in the heart of the desert, and this is attributed to the nature of rainfall in the desert lands. As for the southern parts, they fall within the range of hot spots. It is noted that the camps for internally displaced persons are among the most important areas exposed to the risk of flooding. This is due to the fact that most of them are built on agricultural lands interspersed with seasonal valleys, which has contributed to exposing people's lives to danger and destroying the infrastructure of the displaced.

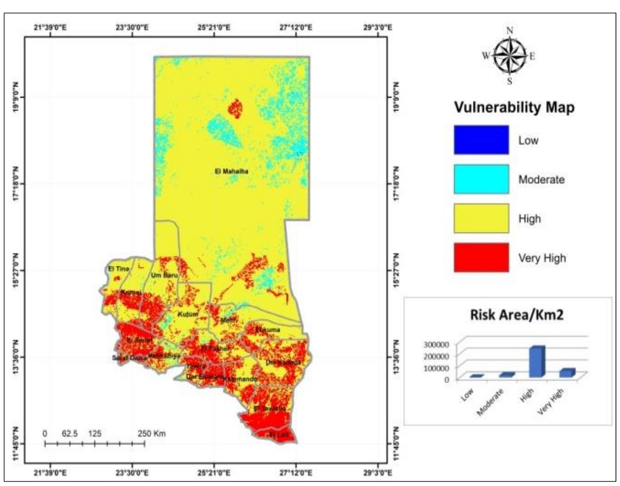


Fig 10a: Flood Risk in North Darfur State

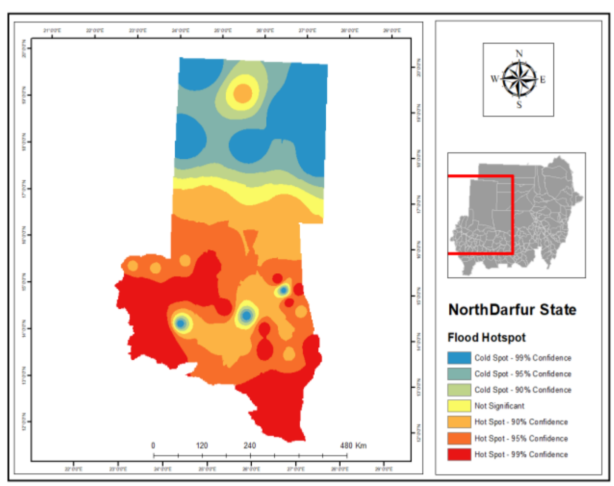


Fig 10b: Flood Hotspot in North Darfur State

4.10 Flood Risk & Flood Hotspot in South Darfur State

Figure (11a) shows the vulnerability of lands to floods in South Darfur State, the degree of risk and the most important areas of its concentration. It is noted that 87% of the state's lands are highly susceptible to flood risk and 9% of them are very highly susceptible. This is attributed to the type of soil and the degree of surface slope. It is also noted that most of the areas susceptible to flood risk are concentrated in the southern parts of South Darfur State, while the areas exposed to low and very low flood risk are concentrated in the North part.

From the figure (11b) which shows the hot and cold spots of flooding in South Darfur State, it is noted that the hot spots are concentrated in areas with a dense network of dry valleys in addition to a high population density, while the cold spots are concentrated in barren lands. Consequently, agricultural and residential lands are affected by the risk of flooding, and livelihoods are also affected, especially for groups that practice agriculture and settle near fertile agricultural lands and dry valleys, as they are the main source of drinking water and irrigation of agricultural crops, especially in the winter season. As for floods in pastoral lands, they are considered not to affect humans and animals and do not harm nomads' dwellings, but rather contribute to providing drinking water for animals.

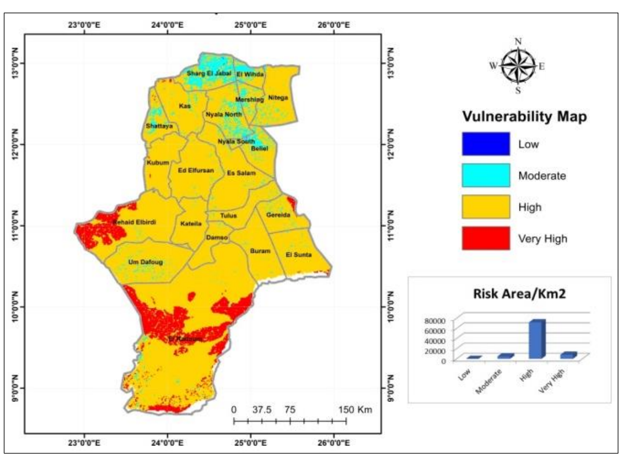


Fig 11a: Flood Risk in South Darfur State

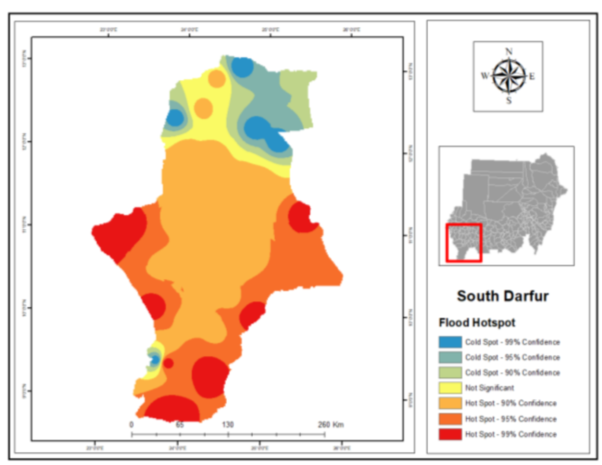
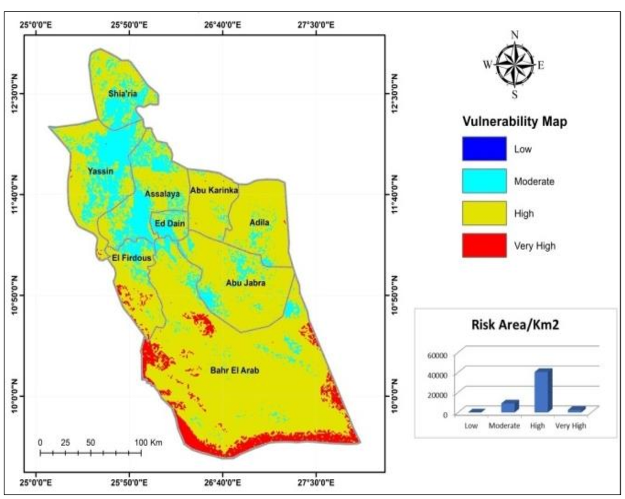


Fig 11b: Flood Hotspot in South Darfur State

4.11 Flood Risk & Flood Hotspot in Eastern Darfur State

Figure (12a) shows the hot and cold spots of floods in East Darfur State, which is an agricultural production area, both plant and animal. According to the susceptibility to flood risk, the lands of East Darfur State range from very high, high and medium flood risk areas from south to north respectively, where the lands with very high flood risk are concentrated in the southern parts of the state, while the lands with medium flood risk are concentrated towards the North. As for the lands with low flood risk, they are concentrated in relatively small foci, as their area does not exceed 10% of the total area of the state.

Figure (12b): shows the hot and cold spots of floods in East Darfur State, which is a state characterized by its agricultural wealth and rain-fed agriculture. The hot spots are concentrated in the southern parts, especially in the alluvial fans or the areas where the valleys meet the Arabian Sea, as well as the agricultural lands around the seasonal valley courses, where the villages of farmers are concentrated. As for the cold spots, they are concentrated in the agricultural and pastoral lands located to the north, with a hot spot in Adila locality, which is located in the far Northeast of the state and is an area where agriculture and animal husbandry are practiced.



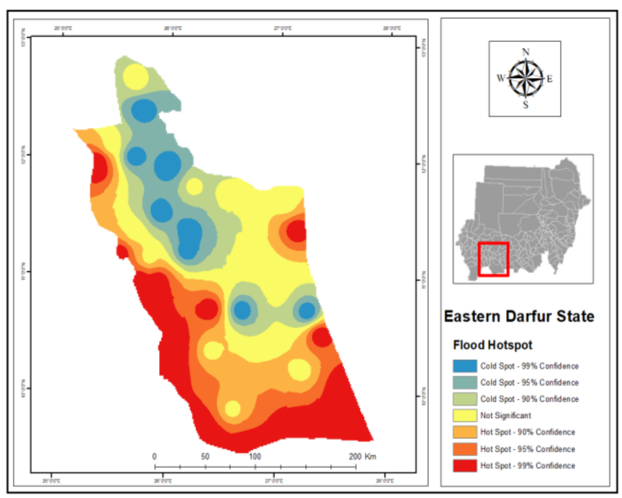


Fig 12a: Flood Risk in Eastern Darfur State

Fig 12b: Flood Hotspot in South Darfur State

4.12 Flood Risk & Flood Hotspot in West Darfur State

Figure (13a) shows that low and very low flood risk areas are concentrated in the northern parts of West Darfur State, while high flood risk areas are concentrated in the southern half of the state. Very high flood risk areas are concentrated in Habila and Kerinek localities.

Dry valleys in Sudan in general and West Darfur in particular are the most important source of flood waters, which threaten the lives of residents, destroy property and affect livelihoods in the traditional agricultural and pastoral sectors. Al-Geneina city is one of the cities affected by the floods of Kaja Valley during the wet seasons, especially in years when rainfall rates are above average. Figure (13b) shows the hot and cold flood spots in West Darfur State. Due to the multiplicity of valleys and their coverage of most of the central region, floods do not follow a specific pattern. We notice the overlap of hot spots with cold spots in one administrative unit. For example, Al-Geneina locality has warm and cold spots. A group of indicators work to distribute floods in the region, the most important of which are: terrain, soil type, density of vegetation cover, in addition to the amount of rainfall and the network of dry valleys.

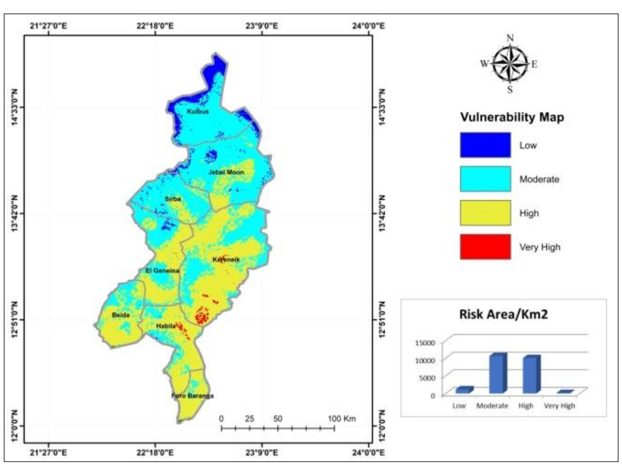


Fig 13a: Flood Risk in West Darfur State

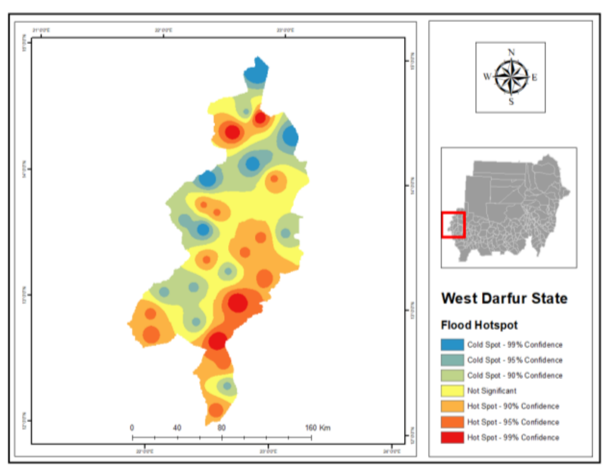
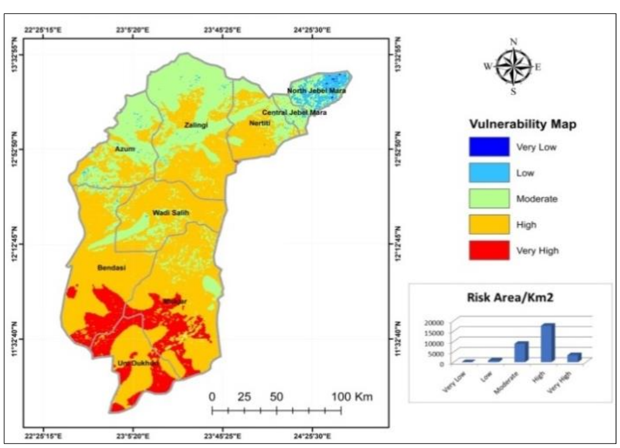


Fig 13b: Flood Hotspot in West Darfur State

4.13 Flood Risk & Flood Hotspot in Central Darfur State

The susceptibility of lands to flood risk in Central Darfur State ranges from North to South, as in other Darfur states. Lands with a high degree of flood risk are concentrated in the south, while lands with a very low degree of flood risk are concentrated in the far north of the state. Lands with a high degree of flood risk represent about 50% of the state’s total lands. (Figure14a). Central Darfur is characterized by rugged terrain, where the highest mountain peak in Sudan is located, Jebel Marra, where a large number of perennial valleys and waterfalls descend, in addition to its distinctive length and abundance of the rainy season. The light blue color indicates less cold spots compared to cold spots, while the light red color indicates less warm spots compared to hot and warm spots (Figure14b). Because a large percentage of the state's lands are covered by a network of seasonal valleys, the state is considered a fertile land for frequent floods and torrents, especially during the rainy season, as more than 90% of the state's lands are covered by hot spots. Despite the recurrence of floods and torrents in the region, most of this water is disposed of through the valley network outside the state due to the high elevation above sea level, and the waters of the Jebel Marra valleys supply all Darfur states with water, as well as the neighboring country of Chad.



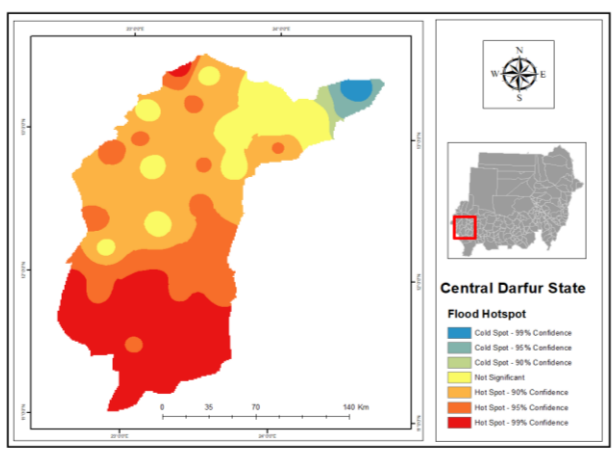


Fig 14a: Flood Risk in Central Darfur State

Fig 14b: Flood Hotspot in Central Darfur State

4.14 Flood Risk & Hotspot in North Kordofan State

Figure (15a) shows the vulnerability of lands to flood risks in North Kordofan State, where the risk level ranges from very low to very high. Areas at very high flood risk are concentrated in Rahad, Amruaba, Amdam Haj Ahmed and Shikan Locality, while areas at low and very low flood risk are concentrated in the Northern parts of the state, including Jabrat Al-Sheikh and Sudari Localities. In general, we note that 50% of the state's land area is at medium flood risk and 34% of the state's area is at high risk.

Figure (15b) shows the distribution of hot and cold flood spots in North Kordofan State, one of the agricultural and animal production areas in Sudan. Previous economic activities are exposed to floods, as soil is washed away in agricultural lands and animals die due to recurring floods, especially in the southern parts of the state where there is heavy rain and sandy clay loam soil. In the Northern parts bordering the desert, hot wells are transferred and cold flood spots increase. Cities and human settlements are also affected, especially those built near dry valleys or in low-lying areas where water collects during the rainy season and damages the superstructure of cities.

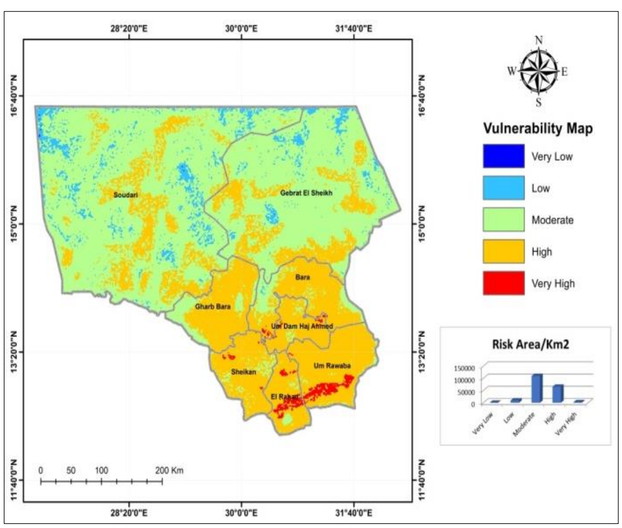


Fig 15a: Flood Risk in North Kordofan state

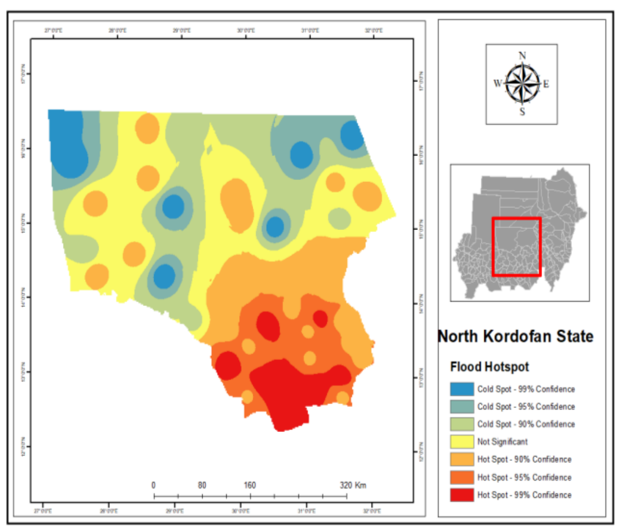
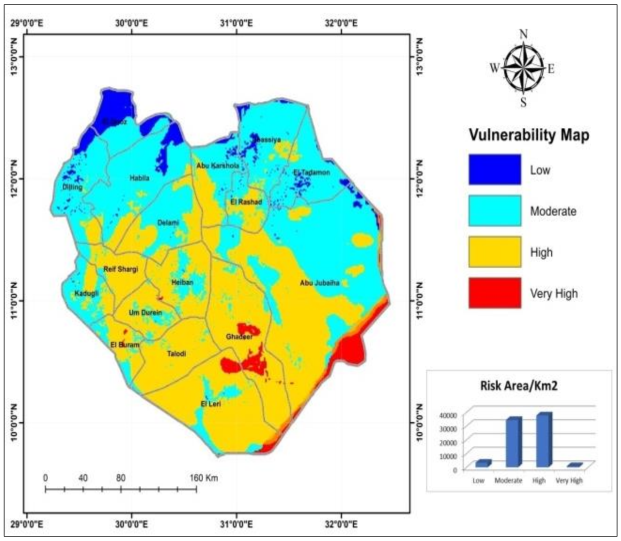


Fig 15b: Flood Hotspot in North Kordofan state

4.15 Flood Risk & Hotspot in South Kordofan State

The vulnerability of the lands of South Kordofan State to flooding ranges from low in the far north to medium and then high in the south, with very high spots in the center and southeast. The distinctive feature of the lands of the state is that 50% of them are highly vulnerable to flooding and 40% are moderate. Abu Jibeiha and Al-Liri localities include most of the lands vulnerable to very high flooding. Figure (16a) shows areas at risk of flooding in South Kordofan State.

South Kordofan State is considered one of the border states that lies within the rich savannah range, where there is heavy rainfall and tall grasses, and thus it is characterized by abundant agricultural and animal production, as it produces most of the crops of wheat, grains and legumes in addition to raising animals, especially cows. These traditional activities are usually affected by recurrent floods and the planted crops fail due to the inundation of agricultural lands with flood waters. The superstructure, infrastructure and human settlements are also affected by floods during the wet season. Figure (16b) shows the areas of flood concentration in South Darfur State, where hot and warm spots are concentrated in the south while cold spots are concentrated in the north.



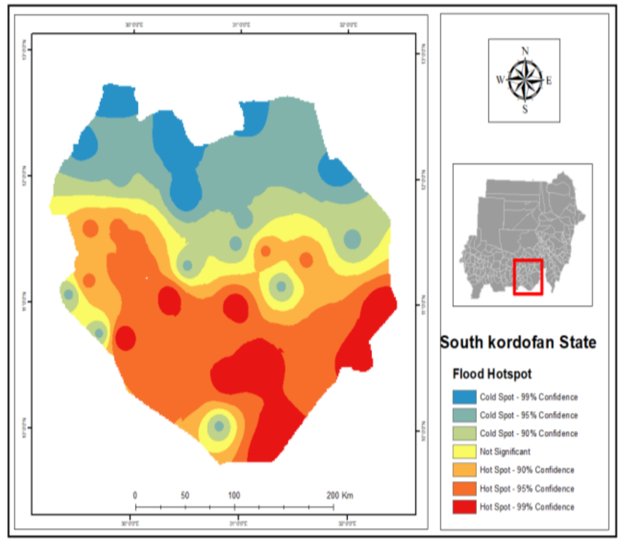


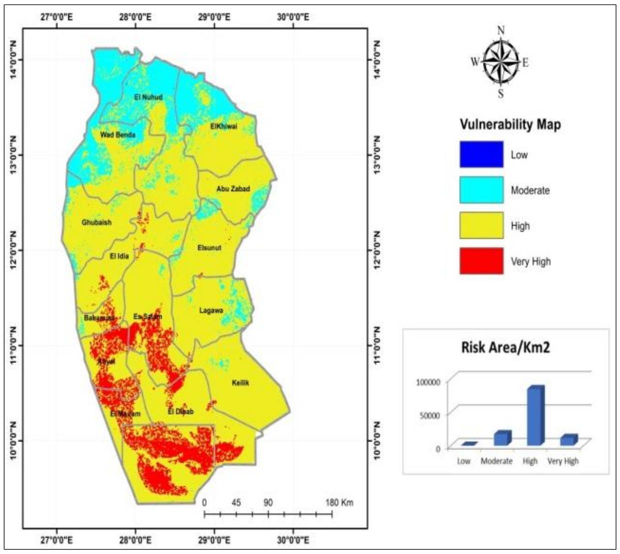
Fig 16a: Flood Risk in South Kordofan state

Fig 16b: Flood Hotspot in South Kordofan state

4.16 Flood Risk & Flood Hotspot in West Kordofan State

Figure (17a) shows the gradient of the state's flood risk from North to South, with the Southern parts of the state shown in red, indicating a very high risk, and the northern parts of the state shown in blue, indicating a medium risk. Yellow covers more than 60% of the state, indicating a high risk. The lands exposed to a very low flood risk represent only 0.5% of the local area.

West Kordofan State is considered one of the most important agricultural and livestock production areas in western Sudan. The state, like other states in Sudan, is affected by floods. Floods often result from the sudden flow of dry valleys during the rainy season. According to Figure (17b), the hot and warm flood spots are concentrated in the southwestern parts of the state, which receive large amounts of rainfall compared to the semi-desert northern parts. However, the northern parts are more affected by floods than the southern parts due to the extreme climate in the north. However, most of the cold flood spots are concentrated in the north and east of the state. Floods often affect the infrastructure and superstructure of the state's main cities, destroy agricultural lands, and wash away soil and crops. Livelihoods in the region are constantly affected by floods, in addition to environmental degradation and its associated effects on human and animal health.



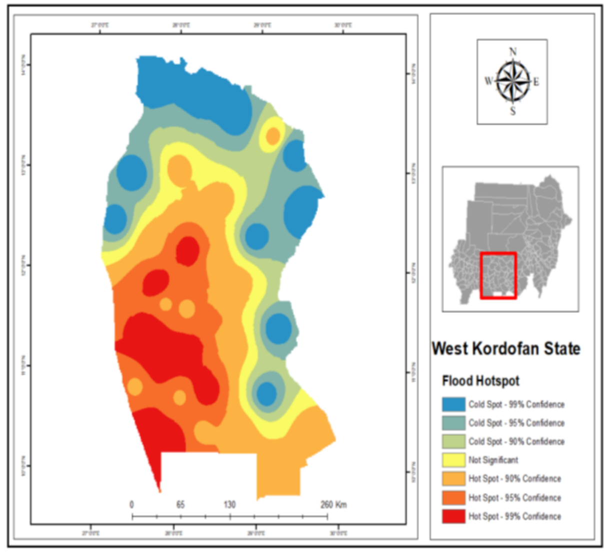


Fig 17a: Flood Risk in West Kordofan State

Fig 17b: Flood Hotspot in West Kordofan state

4.17 Flood Risk & Flood Hotspot in Sennar State

Figure (18a) shows the classification of Sennar State lands in terms of their susceptibility to flood risk into lands with very low, low, medium, high and very high flood risk. Most of the lands located in the southwestern corner are highly susceptible to flood risk, with relatively small spots in the same part of the state being highly susceptible to flood risk, while lands with medium flood risk represent about two-thirds of the state's area, which is the dominant feature of the state's lands.

From the figure (18b): We notice that the hot and cold spots of floods in Kassala State, where the hot spots are concentrated in one locality, which is the Dinder locality, due to the recurrence of the flooding of the Dinder River, which is a seasonal river, and the warm spots are concentrated in the localities of Abu Hajar and Sennar, in addition to large parts of the Dinder locality. As for the cold spots, they are concentrated in the northern parts of the locality, especially north of Sennar and south of Al-Dali in the southwestern corner of Sennar State. The Blue

Nile is one of the most important factors in the recurrence of floods in the state, in addition to the dry rivers and valleys that are tributaries of the Blue Nile.

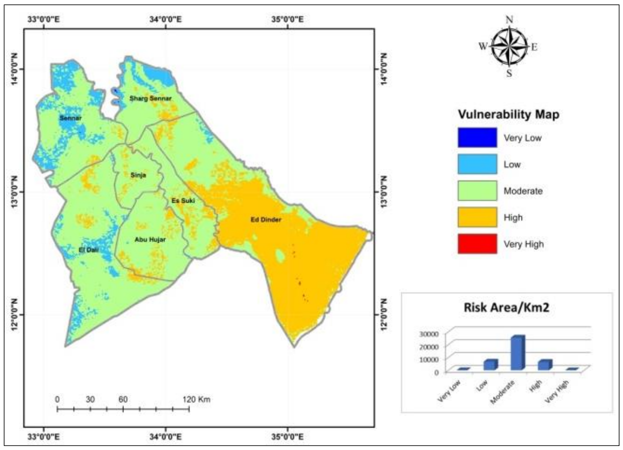


Fig 18a: Flood Risk in Sennar State

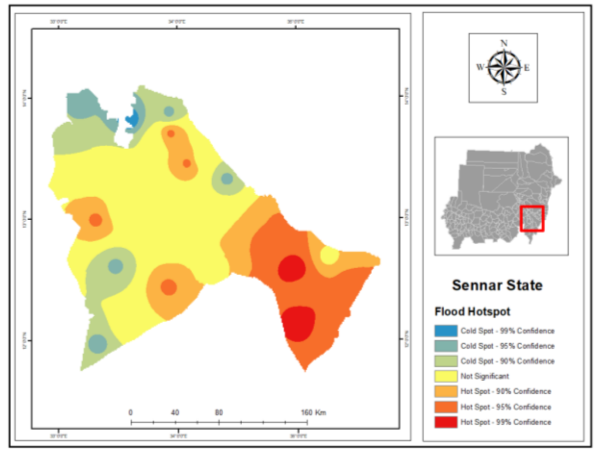


Fig 18b: Flood Hotspot in Sennar State

4.18 Flood Risk & Flood Hotspot in Blue Nile State

Figure (19a) shows the vulnerability of Blue Nile State lands to flood risk and the classification of the risk level into very low, low, medium, high and very high. The lands vulnerable to flood risk are very high around the Blue Nile River, while the areas vulnerable to flood risk are concentrated in the southern and eastern parts of the state, while the areas vulnerable to flood risk are concentrated in the southern and eastern parts of the state.

Figure (19b) shows the flood hotspots in Blue Nile State, where hotspots are concentrated on both banks of the Nile, especially in the main cities such as AL-Damazin and Al-Roseires, while cold spots are concentrated in the southeastern part of the state away from the Blue Nile. In general, hotspots are concentrated near the Nile Basin and the dry valley basins sloping towards it. Floods destroy infrastructure, and thus the fragility and sensitivity of the region to floods will negatively affect the wheel of agricultural and animal production and negatively affect the livelihoods of farmers and herders, as well as the infrastructure of education, health and the transportation network. This requires the installation of special devices for early warning of floods and the development of the necessary plans to deal with crises.

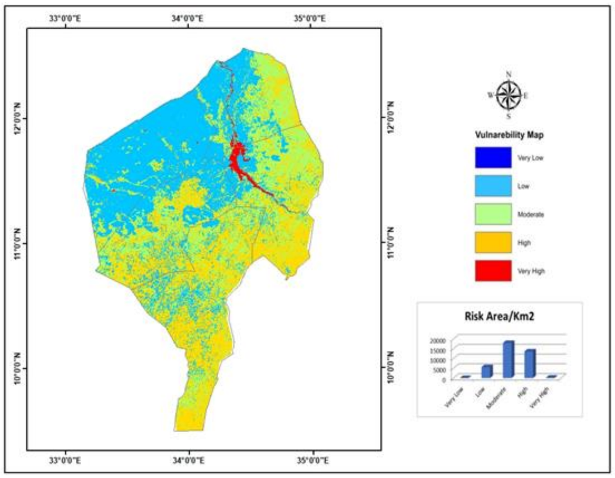


Fig 19a: Flood Risk in Blue Nile State

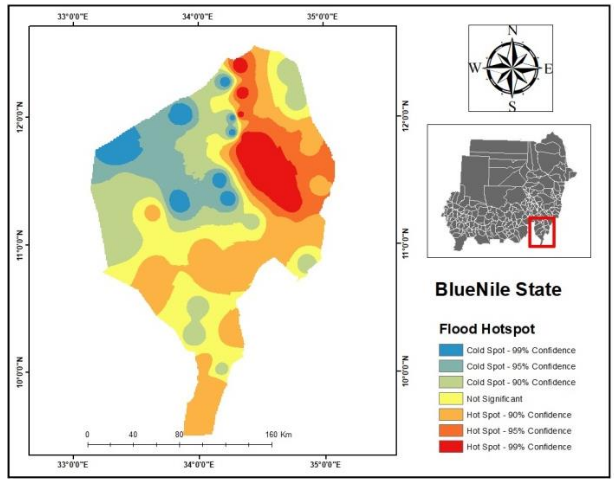


Fig 19b: Flood Hotspot in Blue Nile State

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