International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Remote Sensing Techniques Monitoring Climate Change: A Case Study of Flash Floods in Abu Hamad Area, Northern Sudan

Mohamed Salah Osman Ibrahim, Bashier Ahmed Abdalla Ahmed Kanan
Survey Engineering / Sudan University of science and technology

Abstract: Earth observation has become an important field in recent years due to the increasing frequency of climate-related disasters and advances in modern technologies and studies, including remote sensing sciences. Remote sensing has proven to be of great value and utility due to its enormous capabilities in early warning systems for potential hazards associated with climate change, such as flash floods and other climate-related disasters. By integrating it with geographic information systems (GIS) and other information, these technologies provide powerful tools for conducting comprehensive studies and analyses. The insights from these analyses enable decision-makers to make informed choices immediately, which may help mitigate the effects of disasters by predicting potential risks, identifying vulnerable areas, and developing effective response strategies. This paper presents a case study of the catastrophic flash floods that struck some northern regions of Sudan during the fall of 2024. These floods resulted in significant loss of life, extensive property damage, and environmental pollution from the discharge of harmful substances such as mercury and chemicals used in mining operations. The study included the geographical boundaries of the area under study and satellite images of the area with varying temporal resolution to illustrate the areas affected by floods.

1.1.1 Keywords: Earth Observation (EO), Climate change, Earth Observing System (EOS), Machine Learning (ML), National Aeronautics and Space Administration (NASA), Flash Flood Guidance System (FFGS), sediment transport index (STI), Stream Power Index (SPI) and Topographic Wetness Index (TWI), Intergovernmental Panel on Climate Change IPCC

2 INTRODUCTION

Earth Observation (EO) is the comprehensive process of collecting data about the Earth's surface, bodies of water, and atmospheric conditions. This is accomplished through various remote sensing platforms, including ground-based instruments, aircraft equipped with specialized sensors, and satellites orbiting the planet. By utilizing these technologies, scientists and researchers can gather vital information that enhances understanding of environmental changes, natural resources, and climate dynamics. This includes monitoring and assessing the natural and human-made environments and their changes. [1, 2].

Current EO instruments:

- Floating buoys for monitoring ocean currents, temperature, and salinity.
- Land stations that record air quality and rainwater trends.
- Sonar and radar systems for estimating fish and bird populations.
- Seismic stations and Global Positioning System (GPS) stations and Satellites that scan the Earth from space [2].

2.1 Climate change

Long-term changes in weather patterns and temperatures are referred to as climate change. These changes may occur naturally due to significant volcanic eruptions or sun activity variations. However, Human activity has been the primary cause of climate change since the 19th century, primarily the combustion of fossil fuels like coal, oil, and gas. [3]. Space data has a variety of uses for a variety of purposes. Satellite monitoring is one of the best and most modern methods that provide high and large coverage of vast areas of the earth. In addition to the improvements made to these satellites, it has become possible to make the most of all available technologies, in addition to the entry of artificial intelligence, which provides good options and results that can be relied upon in many applications. [4].

In recent years, Earth observation (EO) satellites have produced vast amounts of freely available geospatial data. This challenges traditional spatial data infrastructures (SDIs) in storing, processing, and analyzing these datasets. To tackle these issues, new technologies like cloud computing and array database systems have been developed for the effective management of large Earth observation data.[5] .

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

2.2 Remote Sensing

The term remote sensing has many definitions, but the United States Geological Survey (USGS) defines it as the “process of detecting and monitoring an area’s physical characteristics by measuring its reflected and emitted radiation from a distance." typically using satellites or aircraft. Special cameras capture these images, helping researchers understand the Earth better. [6].

Getting information about the surface and interior of the Earth has become a priority for a lot of researchers.

Remote sensing and Geographic Information Systems (GIS) evolved from previous technologies such as surveying, photogrammetry, mapping, mathematics, and statistics. [7]. Remote Sensing Satellites have emerged as key tools for observing and surveying the Earth on various scales. These observations enable rapid atmospheric, surface, and ocean mixed layer monitoring while safely assessing hazardous environments. Continuous satellite data complements limited field measurements, offering valuable modelling and data analysis information.

In the early development of observational satellites, sensors were designed for specific purposes. In the 1970s, instruments like Landsat and the Advanced Very High-Resolution Radiometer (AVHRR) monitored land surfaces and clouds, while the Total Ozone Mapping Spectrometer (TOMS) focused on total column ozone, and the High-resolution Infrared Radiation Sounder (HIRS) aided in weather forecasting and climate monitoring. These missions provided valuable data and received acclaim from their respective scientific communities. Over time, many missions were extended and improved based on the experience gained. [8].

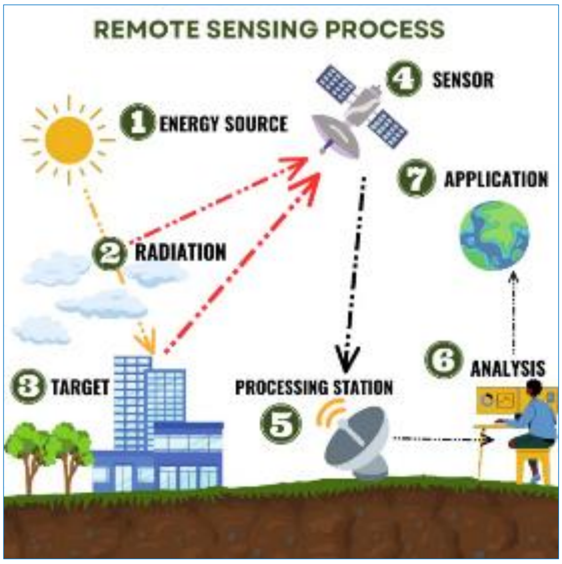


Figure 2-1 Remote Sensing Process[9]

The two main types of remote sensors are active and passive. Both entail measuring the energy that is reflected or emitted across particular electromagnetic spectrum regions as shown below.

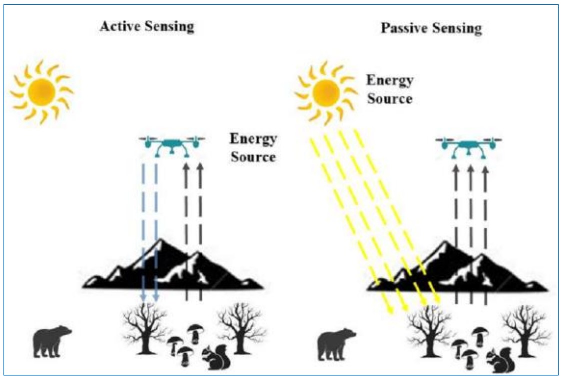


Figure 2-2 Remote Sensing types[10]

2.2.1 Satellite missions in monitoring climate change

Satellite missions in monitoring climate change can be:

- Monitoring gases
- Monitoring changes
- Monitoring vegetation
- Monitoring oceans
- Monitoring sea levels

2.3 The management of disasters

The management of disasters is an important tool for mitigating the impact of risks[11] ; Disaster management presents some of the biggest challenges due to the inability to predict future events, as well as the sheer magnitude of the risk that prevents the development of a comprehensive solution due to the four main stages of disaster management: prevention, preparedness, response, and recovery, The data sensed can provide valuable information in each of these stages, enabling scientists and authorities to better understand spatial phenomena as well as providing them with objective data sources for decision-making [12].

After a disaster, whether natural or man-made, disaster management requires large amounts of spatial and temporal data. Satellite remote sensing is the ideal tool for this, providing information across wide ranges and at specific time intervals. Although theoretically, remote sensing techniques can be applied in various stages of disaster management, such as:

- Prevention (Mitigation)
- Preparedness.
- Response And Reconstruction

The number of natural disasters has increased fivefold over the last 50 years. Whether it’s a storm, fire, flood, tornado, earthquake, or hurricane, people are at greater risk of being affected by a climate-related event now than ever before[13].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Figure 2-3 Disaster Management Cycle[13]

in practice, have so far been mostly used for warning and monitoring only[14].

Remote sensing can be used to assist in risk reduction initiatives by identifying natural hazard zones associated with floodplains, coastal inundation, and active faults.

Remote sensing techniques can also be used to provide an indicator of the recovery rate in a post-disaster area based on indicators such as vegetation regrowth, debris removal, and reconstruction. [12].

2.4 *Earth observation satellites*

Satellites are used for Earth observation to monitor various phenomena from space. It uses different sensors to observe natural events, monitor disasters, and assess human impact on Earth. Satellites are positioned all over the globe.
The results of these observations are provided as satellite images or data, which can be analyzed to yield valuable information about the Earth.
This allows for effective monitoring of global environmental changes and helps clarify the processes involved through research.
The data generated by satellites can vary significantly based on the type of sensor used.
Sensors are typically classified into two categories: Optical and Microwave.

- Visible and near-infrared sensors identify object types and quantities by capturing sunlight reflected from their surfaces. However, they cannot operate under clouds or at night. They provide insights into vegetation distribution, urban areas, and ocean colours.
- Thermal infrared sensors detect heat waves from objects warmed by sunlight, allowing them to measure land and sea temperatures, volcanic activity, and wildfires, even at night when clouds permit.
- Lidar measures distances to objects using visible to near-infrared light, assessing features like tree heights, ice thickness, and wind speed.
- Synthetic Aperture Radar (SAR) emits microwaves to analyze Earth's surface, functioning in all weather and lighting conditions. It is used to monitor topographical changes, deforestation, flooding, and ship movements.
- Microwave radiometers measure geophysical conditions related to water and energy cycles day and night, assessing sea surface temperature, water vapour, rainfall, sea ice distribution, and snow cover thickness [15].

2.4.1 *NASA's Earth Observing System*

NASA's Earth Observing System All of NASA's Earth-observing satellite missions (many of which are joint with other countries and/or agencies) as well as other aspects of NASA's Earth Science programme are covered on this website, in addition to the initial Earth Observing System (EOS) missions. NASA's Science Mission Directorate's Earth Science Division provides funding for the EOSPSO.

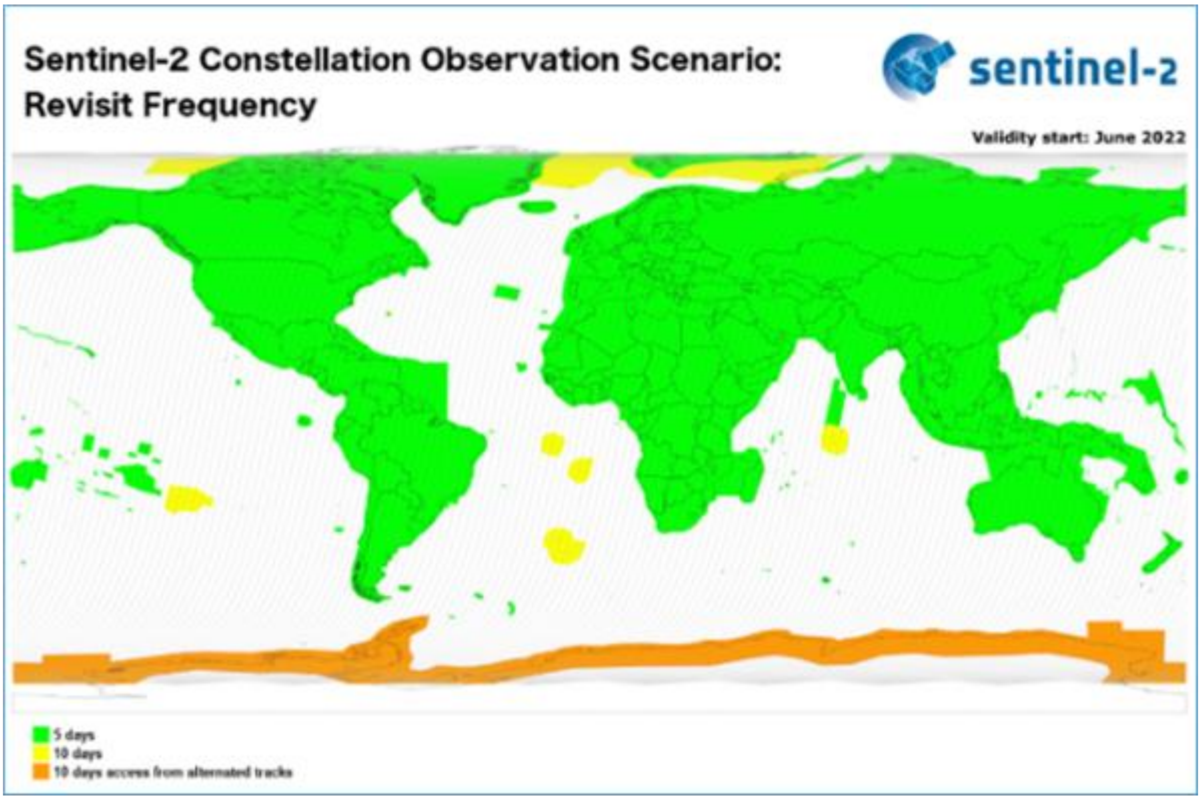
Figure 2-4 NASA Earth Science Division Missions

2.4.2 *Orbits of Earth Observation Satellites*

An orbit is the path satellites, such as those for Earth observation, take around our planet. The choice of orbit depends on the specific goals of each satellite.

Earth observation satellites mainly operate in a synchronous sub-recurrent orbit, a specialized type of polar orbit that traverses the planet's polar regions. This orbit is particularly advantageous for gathering consistent data over time. A synchronous sub-recurrent orbit is a sophisticated combination of two key concepts: it incorporates the characteristics of a sun-synchronous orbit, where the angle between the orbiting satellite's plane and the Sun remains constant from the Earth's viewpoint, allowing the satellite to consistently observe the same area at the same local solar time. Additionally, it integrates the notion of a sub-recurrent orbit, ensuring that the satellite revisits the same geographic location at the same time each day, albeit after a set interval. This unique combination enables Earth observation satellites to efficiently gather and analyze crucial environmental data, making them invaluable for monitoring the planet's changes. [15].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026



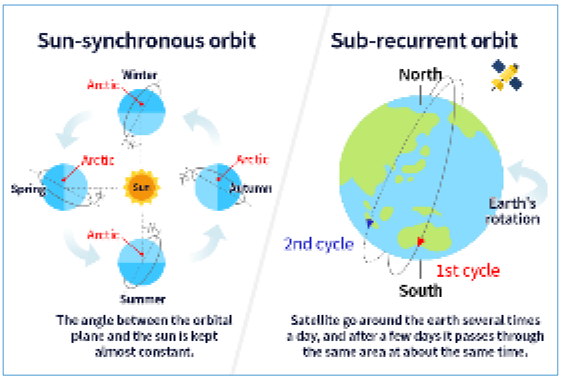


Figure 2-5 Orbits of Earth observation satellites[15]

Earth observation satellites fall into two main categories: those operated by government agencies (public domain) and those built and maintained by private companies (private domain).
In this study, the light focuses on the sentinel-2 satellite.
The Sentinels are a group of satellites designed to provide essential data and imagery for Copernicus, the Earth observation programme of the European Union.

2.4.3 Sentinel - 2

Sentinel-2 is a constellation of optical imaging satellites within the European Union's Copernicus Earth observation program.
It currently includes three identical satellites: Sentinel-2A (launched in 2015), Sentinel-2B (2017), and Sentinel-2C (scheduled for 2024). Their orbits are coordinated to optimize coverage and revisit times [16].
This polar-orbiting, multispectral imaging mission is designed for land monitoring, providing imagery of vegetation, soil, water cover, and coastal areas. [17].
The Sentinel 2 mission supports Disaster Monitoring: Quickly responding to major

disasters, identifying priority areas for aid, and providing critical geographical information for remote regions lacking accurate data after events like floods or earthquakes. [18].

Figure 2-6 Revisit time for Sentinel-2. [19]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Table 2-1 Highlights the key band combinations used in Earth observations and other applications.[19]

Application	**Layers Band combination**									**Product Type**	
	True Color B4, B3, B2	False color B8, B4, B3	NDVI	False colour (urban) B12, B11, B4	Moisture index	SWIR	NDWI	NDSI	Scene classification (L2A only)	L1C	L2A
Geophysical			✓	✓	✓	✓	✓		✓	✓	✓
Land Monitoring	✓	✓	✓	✓					✓	✓	✓
Maritime Monitoring	✓			✓	✓		✓			✓	✓
Emergency Management	✓	✓	✓	✓	✓	✓		✓		✓	✓
Security	✓			✓	✓		✓	✓		✓	✓

Satellites, lightning monitoring systems, radar, and rain gauges are the primary instruments used to identify severe rainfall linked to flash floods, compared to gauges or radar, satellite data estimates are less precise and direct, but they offer the advantage of high resolution and comprehensive coverage over oceans, hilly regions, and sparsely populated areas where other rainfall data sources are unavailable. Satellite-derived rainfall can be an essential tool for recognizing threats from smaller-scale rainfall and flood events, as flash flood events frequently begin with significant rainfall in places with little instrumentation that may go unnoticed.[20].

2.5 Flash floods

There is a flash flood when rain falls too quickly on the ground so that it cannot drain away quickly enough.

Among the deadliest natural disasters in the world, flash floods claim about 5,000 lives every year, and their effects on the environment, economy, and society are profound. Flash floods, which make up over 85% of all flooding incidents, also have the greatest fatality rate of all the flooding classes, including coastal and riverine flooding, Forecasting flash floods presents a distinct problem from large-river floods because of their short time durations and tiny spatial scales. Flash floods can range in duration from a few minutes to many hours, depending on the land surface and local hydrometeorological and geomorphological features. They can happen anywhere in the world. However, there is no official procedure or capability for creating flash flood alerts for most of these places.[21].

2.6 Climate Change in Sudan

There is a complex relationship between water resources and climate change in the Blue Nile Basin, as demonstrated by the Grand Ethiopian Renaissance Dam. While the dam has the potential to provide benefits, it also presents challenges, particularly for Sudan. Sudan faces difficulties in coordinating and sharing data with Ethiopia, which hampers its preparedness for potential crises. Heavy rainfall could lead to significant water releases from the dam, resulting in structural failures and flooding in Sudan. This situation underscores the urgent need for a comprehensive risk assessment, improved data sharing, and regarding the implications of the dam. [22].

Climate change and environmental degradation are profoundly affecting Sudanese society, with dire consequences across various sectors. In 2021 and 2022, Sudan suffered catastrophic flooding that claimed the lives of over 146 individuals, injured 122 others, caused extensive damage to infrastructure, and displaced hundreds of thousands. The most vulnerable, particularly rural communities, are bearing the brunt of these disasters. Drought and unpredictable rainfall have devastated farmers and pastoralists, leading to the destruction of vital ecosystems, restricted access to essential grazing lands, and significant livestock losses. Moreover, these challenges disproportionately impact economic opportunities as disruptions to traditional agricultural and pastoral activities escalate. [23].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Figure 2-7 Floods in Khartoum[24]

Figure 2-7 Shows the negative effects of the floods that occurred in Sudan in 2020.

2.7 Previous Study

2.7.1 A Review of Earth observation-based Drought Studies in Southeast Asia

Drought is a common natural event that can significantly harm people's health, the economy, and the environment. With climate change, extreme droughts are likely to become more frequent and impactful. Observing droughts from space is essential for providing timely information to manage and respond to drought, particularly in areas with limited local data.

This paper reviewed drought studies using Earth observation (EO) products in Southeast Asia from 2000 to 2021. The number of publications is increasing, with 70% from Vietnam, Thailand, Malaysia, and Indonesia, which together account for nearly 97% of the economic losses due to drought.

Researchers primarily use vegetation indices from remote sensing sensors for drought monitoring. However, around 21% of the studies lack accuracy assessments, and most rely on rainfall data for validation.

It is founded on a connection between the area studied and the data resolution, with 81% of articles focusing on local and national levels. Despite growing interest in drought research, challenges remain in measuring drought over large areas and long periods, integrating different remote sensing data, and using machine learning for prediction. [25].

2.7.2 Earth Observation Data Supporting Non-Communicable Disease Research: A Review

A non-communicable disease does not transfer between individuals and includes conditions like cancer, diabetes, stroke, and mental illnesses. These diseases share two main features: environmental impact and chronicity, often leading to reduced quality of life, higher premature death rates, and economic burdens due to healthcare costs and lost workforce productivity. They also weaken the immune system, making individuals more susceptible to communicable diseases. Addressing non-communicable diseases is a critical issue for modern healthcare and governments.

The occurrence of these diseases is linked to environmental factors (the exposome) alongside genetic predispositions. Stressors such as poor air quality, noise, and extreme temperatures can increase vulnerability to such diseases. This paper reviews the use of Earth observation data and public health data in researching non-communicable diseases, analyzing 146 peer-reviewed articles. Our findings indicate that this area of study is relatively new, largely emerging in the past five years, with potential for further development. We advocate for greater integration of advanced remote sensing products to improve the mapping of exposomes and assess population vulnerability and resilience regarding non-communicable diseases. [26].

2.7.3 Machine learning information fusion in Earth observation: A comprehensive review of methods, applications and data sources

This paper reviews significant data-driven information fusion algorithms based on machine learning (ML) techniques for Earth observation. It modelled the Earth using a diverse range of observations from various sensors that measure states and processes at high spatial and temporal resolutions. Earth observation comprises remote sensing systems on satellites and airborne platforms, as well as in-situ observations, numerical models, and social media data.

ML techniques are crucial for extracting meaningful insights from vast amounts of data. This paper highlights key advancements in information fusion, focusing on impactful Earth observation applications where ML has yielded significant results. We also summarize commonly used datasets, models, and sources, explaining their importance and accessibility. Finally, we illustrate ML data fusion through selected case studies and discuss the future of the field. [27].

2.8 Study Problem

One of the climate change affections is that floods represent devastating natural disasters that can lead to loss of life and severe economic repercussions, underscoring the urgent need for effective protection of individuals and properties.

The most frequent natural disasters that can damage infrastructure and result in economic losses, environmental damage, and fatalities are flash floods. Numerous variables, including the increasing habitation of floodplains, increased runoff from hard surfaces, insufficient management policies, and silted-up drainage, exacerbate the increased storm frequency and intensity associated with climate change.

With the ongoing impacts of climate change and increasing urbanization, the likelihood of flooding is projected to rise significantly. This study is dedicated to comparing and developing a flood hazard map for a specific area in River

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Nile State, which will incorporate a thorough risk management assessment and provide detailed flood hazard susceptibility mapping. This proactive approach is essential for safeguarding communities and minimizing future risks.

Figure 2-8 Heavy rains damage more than 500 houses in the country's north. [28]

Sudan's Northern State experienced heavy rains that damaged at least 464 houses. In Merowe city, located about 330 kilometres (210 miles) from Khartoum, at least 300 houses were affected, according to the state-run SUNA news agency. And described this region along the Egypt-Libya border as a desert that rarely received rain in the past but has faced severe rainfall over the last five years. [28, 29].

The floods have also caused significant damage, destroying over 26,000 homes and partially damaging another 33,000.

The International Organization for Migration (IOM) estimates that more than 172,000 people have been displaced in 15 of Sudan's 18 states. Many citizens have indicated that this year's floods and rains were a surprise to them and had never happened before. This is due to the effect of climate change that led to this disaster. [29, 30]. Climate change and environmental degradation are profoundly affecting Sudanese society, with dire consequences across various sectors. In 2021 and 2022, Sudan suffered catastrophic flooding that claimed the lives of over 146 individuals, injured 122 others, caused extensive damage to infrastructure, and displaced hundreds of thousands. The most vulnerable, particularly rural communities, are bearing the brunt of these disasters. Drought and unpredictable rainfall have devastated farmers and pastoralists, leading to the destruction of vital ecosystems, restricted access to essential grazing lands, and significant livestock losses. Moreover, these challenges disproportionately hinder women's economic opportunities as disruptions to traditional agricultural and pastoral activities escalate.

These floods cause many ongoing cholera outbreaks that have tragically led to an additional 185 fatalities, as reported by the Health Ministry, one of them is cholera.

Figure 2-9 Sudan's flood, and cholera crises worsen as death hits 390 [30]

3 DATA & METHOD

1.1 Data

The initial source of data is satellite images with multi-temporal resolution obtained from the Copernicus and USGS websites during the same season in different years.

Several types of geospatial data have been used in this study; the data was a combination of satellite images Sentinel-2 for multitemporal data and vector data, (Table *3-1*, Table *3-2***)** showing the imagery data obtained from the Copernicus, USGS website All data are in a metric unit's system's Universal Transverse Mercator (UTM) zone 36N projection [31].

Table 3-1 Raster Data Used in the Study

Name	Date
S2A_MSIL2A_N0400_R078_T36QWG	01-07-2022
S2A_MSIL2A_N0400_R078_T36QWG	31-07-2022
S2A_MSIL2A_N0400_R078_T36QWG	30-08-2022
S2B_MSIL2A_N0509_R078_T36QWG	01-07-2023
S2B_MSIL2A_N0509_R078_T36QWG	30-08-2023
S2A_MSIL2A_N0510_R078_T36QWG	10-07-2024
S2A_MSIL2A_N0510_R078_T36QWG	20-07-2024
S2B_MSIL2A_N0511_R078_T36QWG	04-08-2024
S2A_MSIL2A_N0509_R078_T36QWG	19-08-2024
S2A_MSIL2A_N0511_R078_T36QWG	08-09-2024
S2B_MSIL2A_N0511_R078_T36QWG	13-09-2024
SRTM (Digital Elevation Model) USGS	-

Table 3-2 Vector Data of Study Area

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Name of layers	Type Of Data
Residential in Study Areas	Vector Data
Streams in the study area	Vector Data
States Boundary	Vector Data
River Nile	Vector Data
Roads	Vector Data

1.2 *Study Area*

The study was conducted in Abu Hamad city, in Abu Hamad locality in River Nile State, 128224.742 square kilometres. The study area covered approximately 6558.28 square kilometres and was situated in the Nile state, The (Figure 3-1) shown study area, The geographical coordinates of the study area range from latitudes 19°52'54.06" N to 19°12'2.96" and longitudes 33° 4'8.98" E to 33°53'56.9E, usually based either on the Sudan reference system or WGS84. [32].

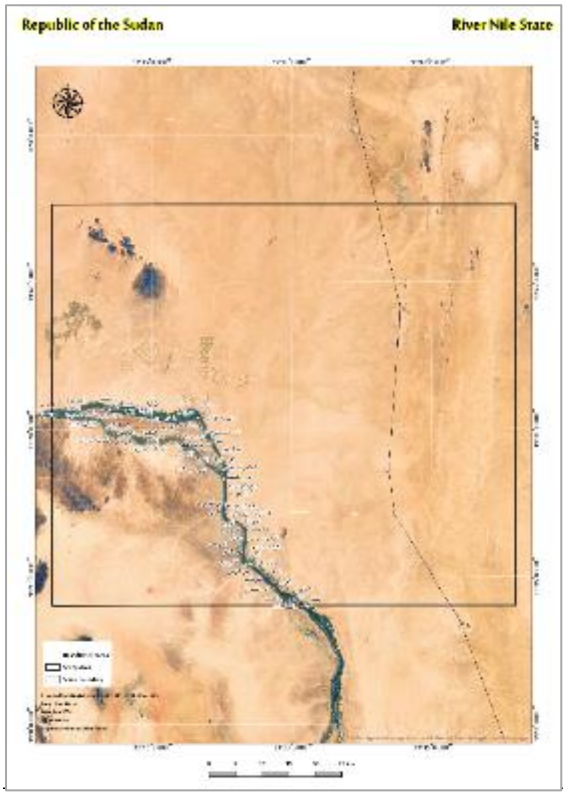


Figure 3-1: Study Area

1.3 *Method*

The study uses comparative and analytical approaches to compare the different images of the study area and the analysis of the flash flood that happened in the fall of 2024. and the objective of this study is the integration of topographic attributes (elevation, slope, curvature, and streams), topographic profiles, and hydrologic indices Steam Transportation Index (STI), Stream Power Index (SPI) and Topographic Wetness Index (TWI) derived from a digital elevation model (DEM) in a geographic information system (GIS) environment to detect areas associated with flash flood caused by rainfall storm and sediment transport and accumulation.

4 RESULTS AND DISCUSSION

The impact of topography flow directions and stream valleys is considered one of the important factors affecting the flash floods that occurred in the study area. Therefore, some influential factors were taken into consideration, such as the Elevation, Stream Power Index (SPI), Sediment Transport Index (STI), and Topographic Witness Index (TWI).

4.1 *Digital Elevation Model (DEM)*

Elevation is an important factor in identifying areas at risk of flooding, as it influences the spread, direction, and depth of floodwaters.

Due to the water's tendency to flow and accumulate in response to gradients in gravitational potential energy, a DEM can be used to model flood impact on erosion, degradation, and sediment accumulation.

The Shuttle Radar Topography Mission (SRTM) data was used to create a digital elevation model with a spatial resolution of 30x30 meters over the study area. Flooding is most likely to occur in areas with low elevations on the elevation map.

On February 11–22, 2000, the space shuttle Endeavour flew the Shuttle Radar Topography Mission (SRTM). The National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) collaborated on an international project to collect radar data, which was used to create the first near-global set of land elevations. [33].

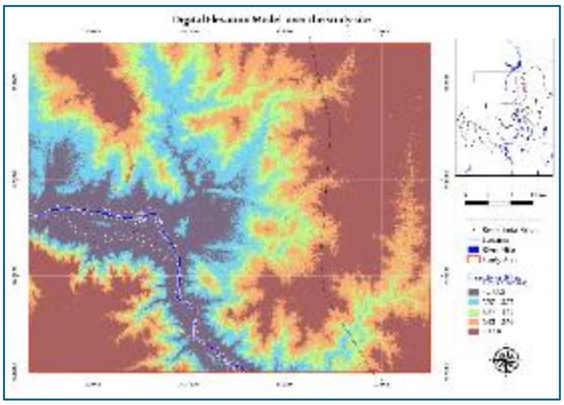


Figure 4-1 DEM over the study Area

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

4.2 Slope

The slope is an important component in estimating flood risk because it affects water flow velocity and surface runoff infiltration. [34]. In streams and rivers, steeper slopes generally result in faster runoff and higher flow velocities than gentler slopes. As a result, runoff from steep places tends to pool in low-slope areas, increasing the likelihood of floods. [35].

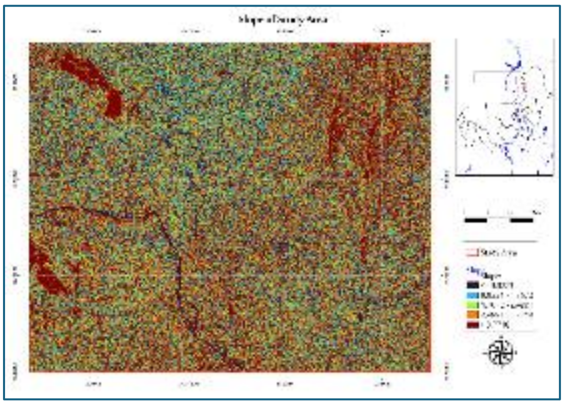


Figure 4-2 Slope of Study Area

4.3 Hydrologic Indices

4.3.1 Sediment Transport Index

Due to the water's tendency to flow and accumulate in response to gradients in gravitational potential energy, a DEM can be used to model flood impact on erosion, degradation, and sediment accumulation. [36] .

Additionally, it is crucial to the spatial variation of hydrological conditions such as soil moisture content, groundwater flow, and slope stability. Soil elevations have been described spatially using topographic attributes based on slope and orientation. [37].

Sediment transport can be estimated using many relationships found in the literature. The relationship STI, based on unit stream power theory, is best suited for integration with GIS. [38], It is a non-linear function of specific discharge and slope, and it is derived by considering the transport capacity-limiting sediment flux and catchment evolution erosion theories [39, 40]This index is important because the floods carried a lot of sediment through the valleys, including hazardous waste, such as mining waste, that local citizens spoke about. This can cause many health disasters.

The Equation 4-1 [40] Below is the STI

Equation 4-1 Sediment Transport Index

$$\boldsymbol{STI = Power(Flow\ Accumulation\ /22.13, 0.6) * Power("\ sin\ ("slope")\ /0.896, 1.3)} ----- (1)$$

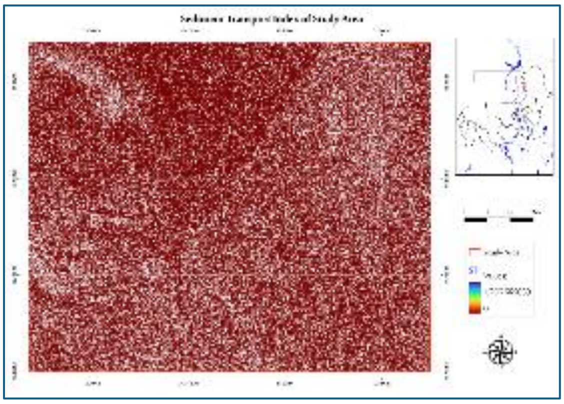


Figure 4-3 Sediment Transport Index

Figure 4-3 Shows the STI-derived map with values varying between 0 and 1766.66, It illustrates the spatial distribution of the sediment transport capacity and accumulation The highest values are related to the steep slopes, these areas are associated with a significant degree of sediment transportation and, consequently, significant soil erosion and degradation.

4.3.2 Topographic Wetness Index

The topographic wetness index (TWI) is a fundamental concept in the field of hydrology and geomorphology, used to assess and model the spatial distribution of water accumulation and potential wetness within the landscape. It is a valuable tool for understanding the flow of water through different terrains, aiding in environmental management, land use planning, and natural resource conservation.

The Topographic Wetness Index (TWI) integrates the water supply from the upslope catchment area and downslope water drainage for each cell in a DEM. [41]

Species distributions and environmental processes are governed by soil moisture, yet measuring and extrapolating soil moisture across space is challenging. For this reason, the Topographic Wetness Index (TWI), which is based on a digital elevation model, is frequently employed as a stand-in for soil wetness. However, TWI can be computed using a variety of techniques, which may have an impact on how TWI relates to species assemblages and soil moisture. [41].

The topographic wetness index (Equation 2)is defined as:

$$TWI = ln\left(\frac{a}{tan\beta}\right) ----- (2)$$

Equation 2 TWI

where (a) is the local upslope area draining through a certain point per unit contour length, and (tan β) is the local slope in radians. The TWI has been used to study the effects of spatial scale on hydrological processes.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

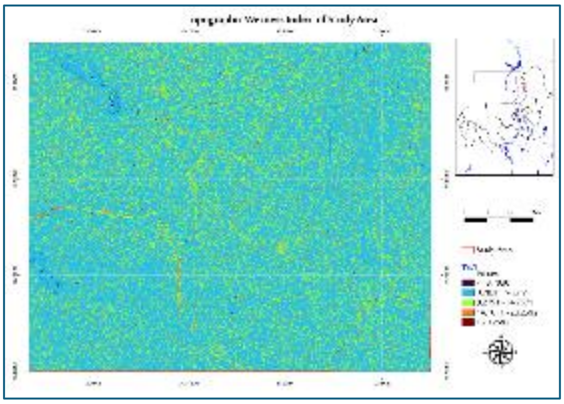


Figure 4-4 Topographic Wetness Index

4.3.3 Stream *Power Index (SPI)*

The Stream Power Index (SPI) measures how much erosion streams contribute to flowing water power. The calculation of SPI is based on Slope and contributing area. SPI approximates locations where gullies might be more likely to form on the landscape [42, 43].

SPI is calculated using the following equation:

$$SPI = Ln(([Flow\ Accumulation\ ] + 0.001) * ((Slope/100) + 0.001 - - - - - (3)$$

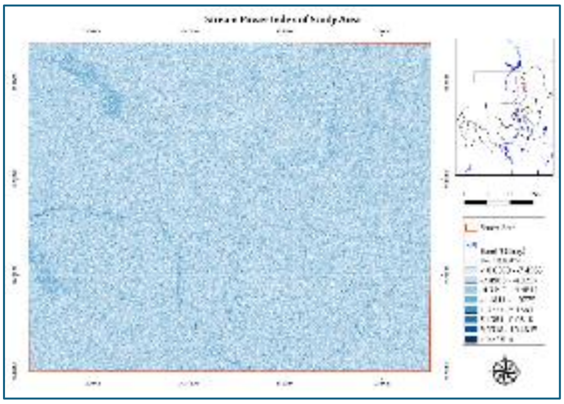


Figure 4-5 Stream Power Index

According to these indices-derived maps, after a Flash flood, the runoff water power delivers vulnerable topsoil and contributes strongly to the erosion and land degradation process, and then transports soil material and sediment to the plain through the natural action, i.e., water power and gravity. A colour gradient is commonly used to show SPI on ArcMap maps, with the colour varying according to the index value that is being displayed. The following are some facts regarding typical colour gradients:

Areas with low SPI values, or those with low flow energy and minimal erosion, are usually represented by dark hues like dark blue or dark green, Light to bright colours represent areas with high SPI values, indicating high flow energy and higher erosion. These areas are more susceptible to erosion and sediment transport.

By monitoring the changes in satellite images for the study area, it appeared that during the years 2022 and 2023 there were no floods and some new agricultural projects appeared in 2023, but during the fall of 2024 floods appeared figures below represent the changes.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Figure 4-6 Sentinel 2 satellite image taken on July 1, 2022

The satellite image does not show any water accumulation in the study area.

Figure 4-7 Sentinel 2 satellite image taken on July 31, 2022

The satellite image does not show any water accumulation in the study area, but some clouds appear.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

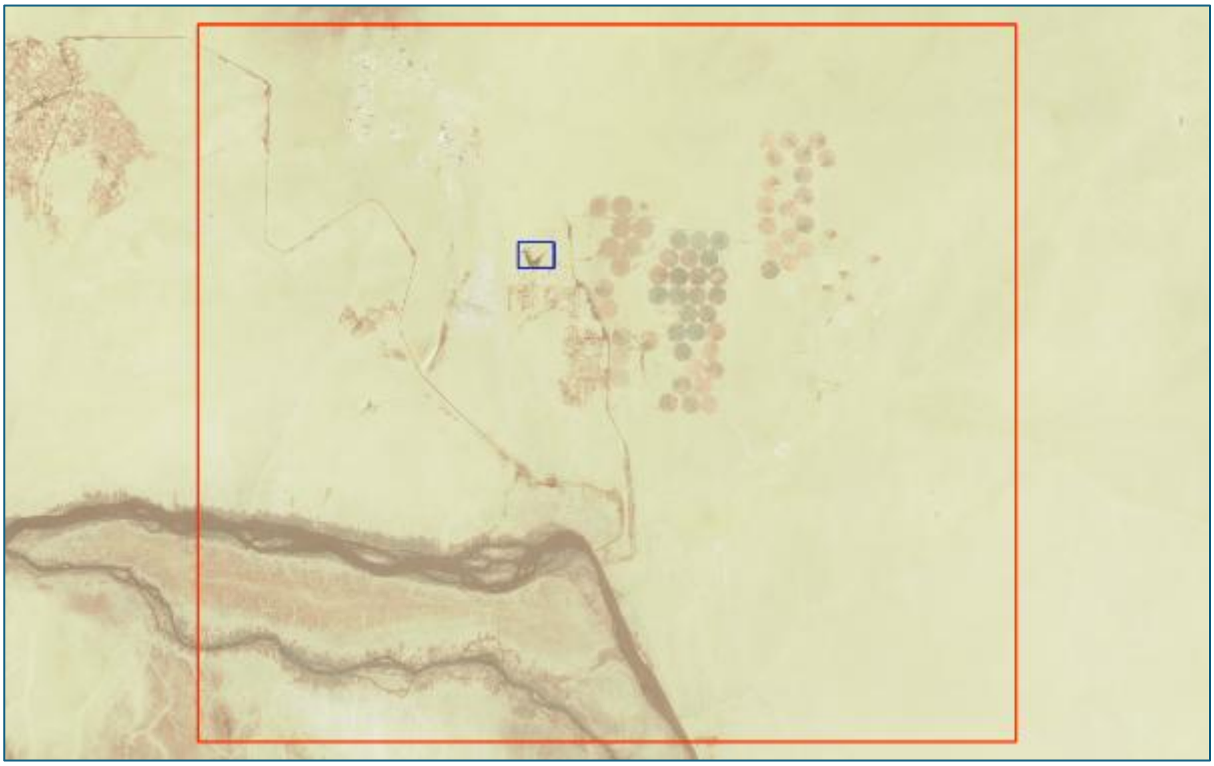


Figure 4-8 Sentinel 2 satellite image taken on August 30, 2022

The satellite image shows some water accumulation in the study area.

Figure 4-9 Sentinel 2 satellite image taken on August 10, 2023

The satellite image does not show any water accumulation in the study area., but some new agriculture projects appear.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Figure 4-10 Sentinel 2 satellite image taken on August 30, 2023

The satellite image does not show any water accumulation in the study area.

Figure 4-11 Sentinel 2 satellite image taken on July 10, 2024

The satellite image does not show any water accumulation in the study area, but extra new agriculture projects appear.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

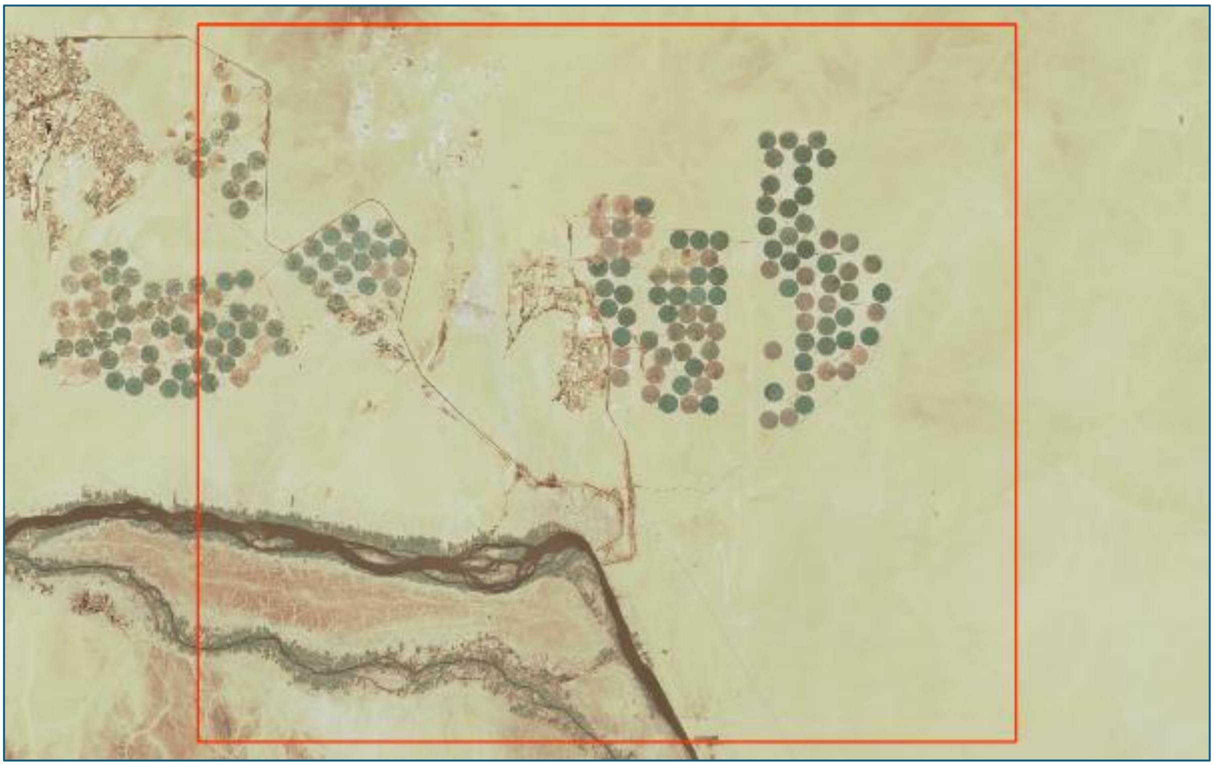


Figure 4-12 Sentinel 2 satellite image taken on July 20, 2024

The satellite image does not show any water accumulation in the study area.

Figure 4-13 Sentinel 2 satellite image taken on August 4, 2024

The satellite image shows water accumulation in the study area, but some clouds appear.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

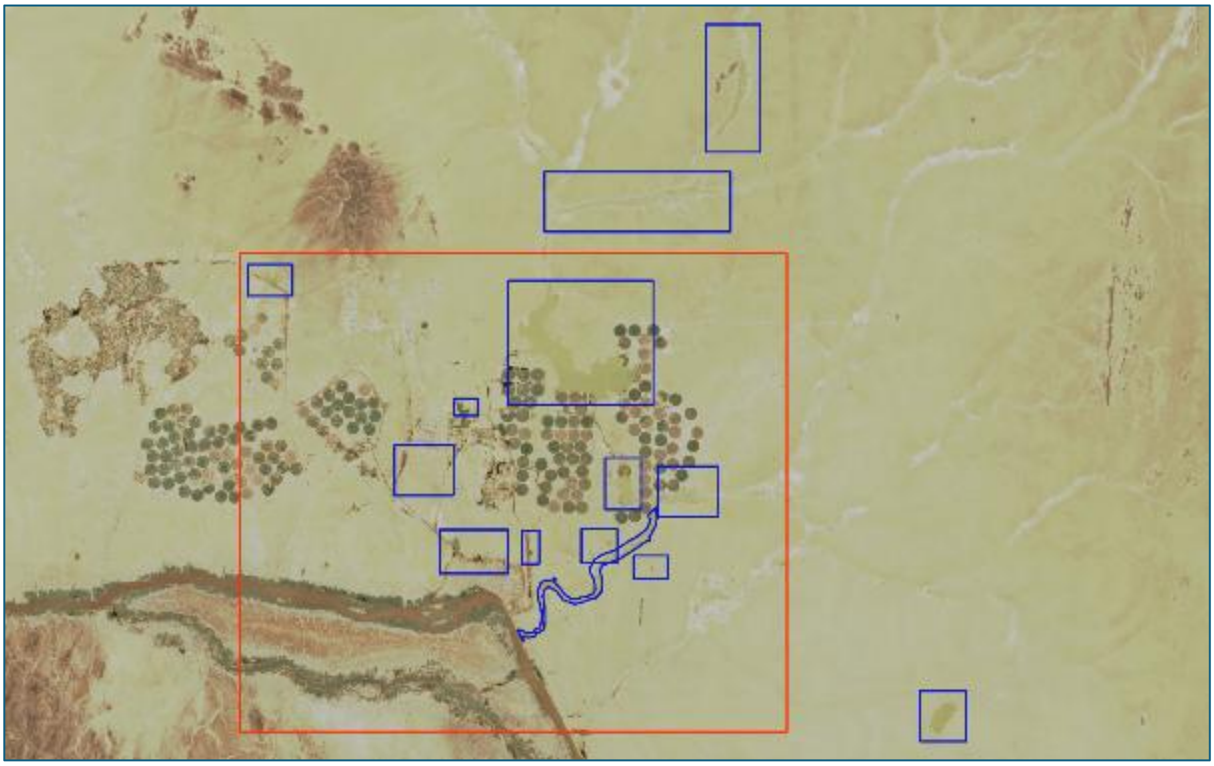


Figure 4-14 Sentinel 2 satellite image taken on August 19, 2024

The satellite image shows water accumulation in the study area and the water comes from the Northeast Direction of the study area through streams and valleys.

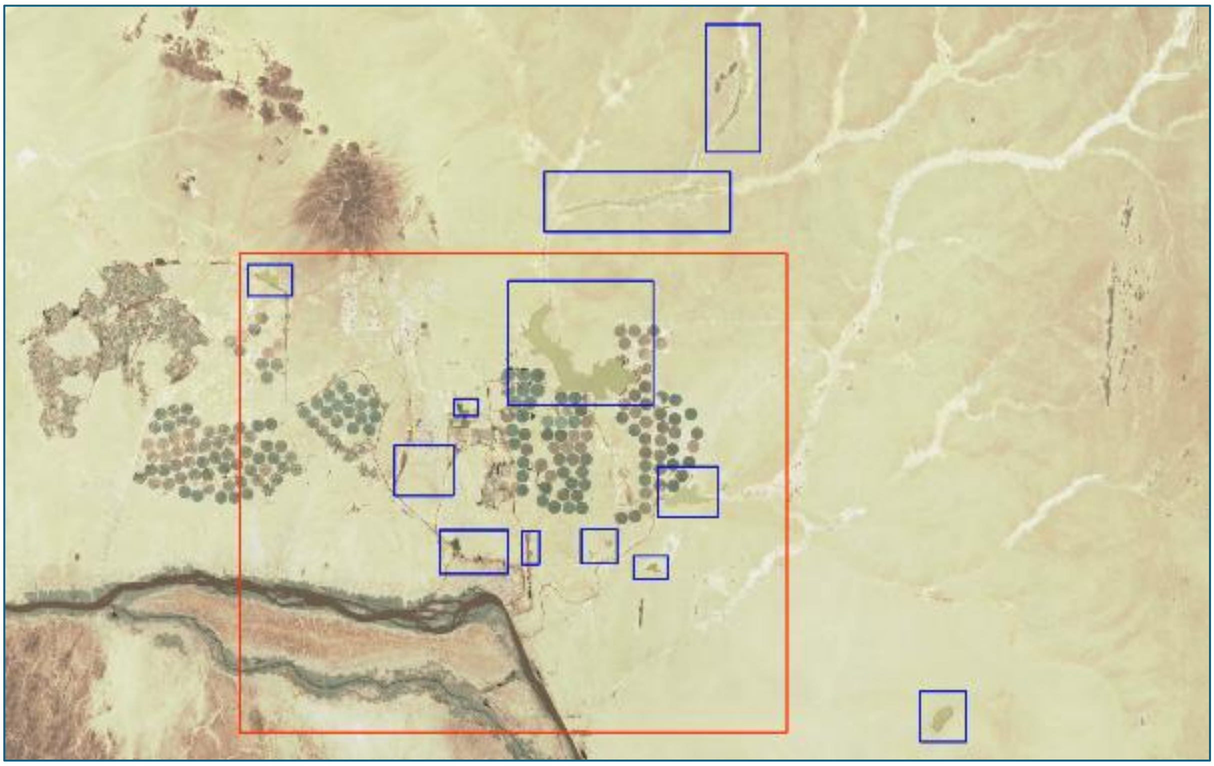


Figure 4-15 Sentinel 2 satellite image taken on September 8, 2024

The satellite image shows water accumulation in the study area and the decrease of the water comes from the Northeast Direction of the study area through streams and valleys.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

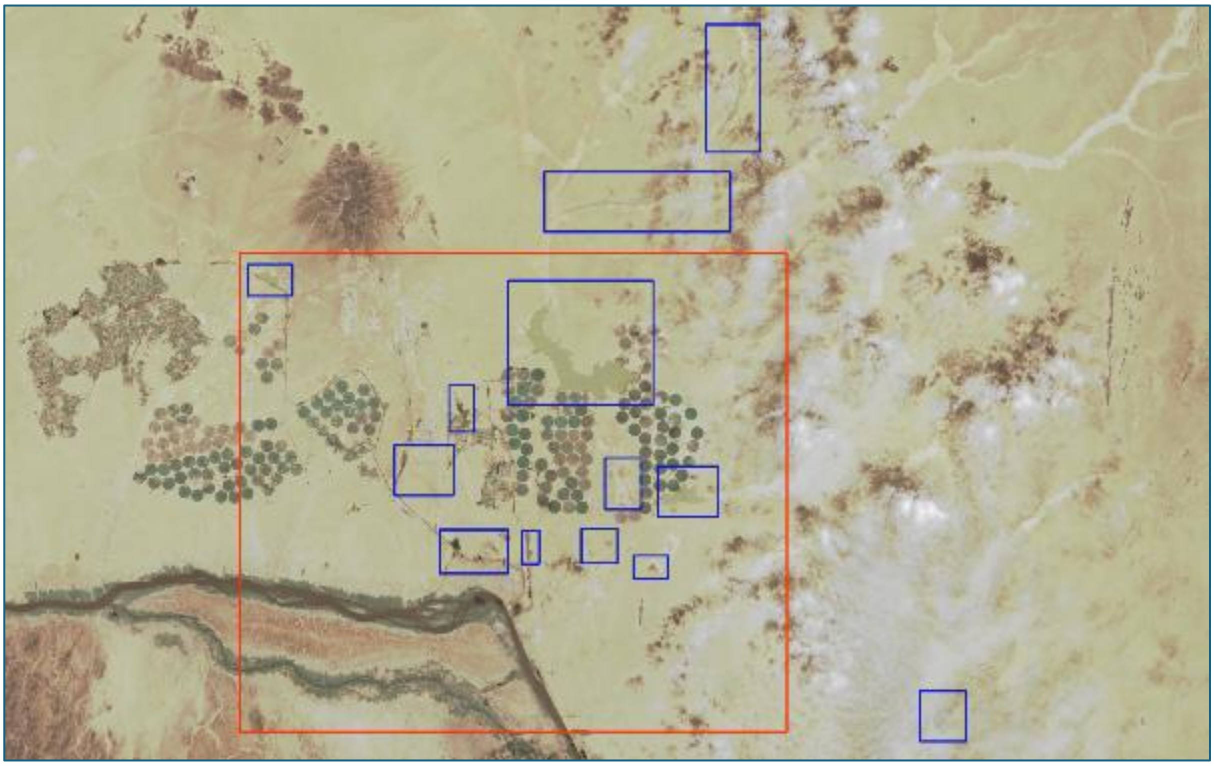


Figure 4-16 Sentinel 2 satellite image taken on September 13, 2024

The satellite image shows water accumulation in the study area and the decrease of the water comes from the Northeast Direction of the study area through streams and valleys.

Due to these reasons, it is crucial to identify the factors that can affect the likelihood of a flash flood occurring on a given terrain. Topographical characteristics (steeply sloping terrains, mountain valleys, ravines, and blind drainage) can indicate terrains that are susceptible to this phenomenon.

Climate, topography, drainage networks, and past patterns of flash flooding can all be taken into consideration when assessing the risk of flash floods in a given area.

The ability to access meteorological, hydrological, and geological data is also essential for estimating hazards.

Past flood information (especially from residents) is also needed.

There has been an increase in climate-related hazards (droughts, floods) throughout Europe and a close connection with geographical location, according to the IPCC report.

4.4 Flash flood guidance system

To assist hydrologic and meteorological forecasters worldwide, the Hydrologic Research Centre, a non-profit public-benefit corporation based in San Diego, California, USA, conceived and developed the flash flood guidance system (FFGS). The FFGS's main goal is to give disaster management organizations and operational forecasters up-to-date information on the risk of small-scale flash flooding in a given area.[44, 45].

More than three billion people have benefitted from the Flash Flood Guidance System (FFGS), which has helped save lives and lessen damage from flash floods in 72 nations. Flash floods still pose a serious threat to property, lives, and livelihoods, nevertheless, particularly in light of uncontrolled expansion in flood-prone areas and the additional difficulties posed by climate change. To address this worldwide issue, coordinated efforts are needed at the national, regional, and international levels to improve current systems and expand coverage to additional nations. This is in line with the Early Warnings for All initiative, which aims to guarantee that early warning systems safeguard all people on Earth within the next five years.[46].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

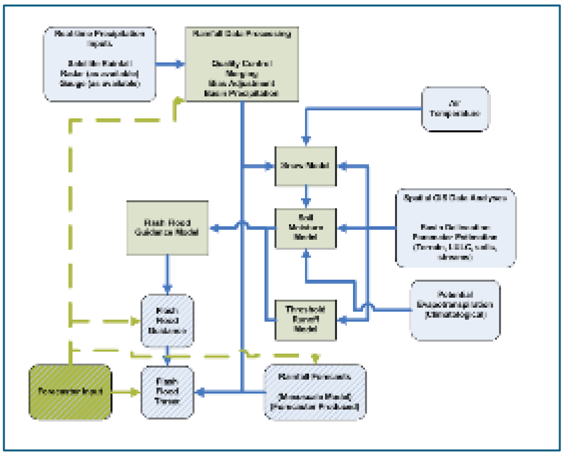


Figure 4-17 The key technical components of the FFG system are shown in the following schematic.[47]

Figure 4-18 Flash flood guidance interface[47]

4.4.1 *Flash flood the protocol*

Flash floods happen quickly and typically within a few hours following intense rain. As they tear across neighbourhoods, streets, valleys, etc., flash floods turn into roaring water torrents that sweep away whatever is in their path. Levee or dam failure can also result in flash floods. A warning sign of impending severe flood conditions should be heavy rain[48].

4.4.1.1 *Flood WATCH*

released when flash flooding conditions are ideal. In most cases, a WATCH covers multiple counties. If the water starts to rise, now is the time to start planning your course of action and where you will go[48].

4.4.1.2 *Flash Flood WARNING*

Provided in the event of imminent or dangerous flash floods. Typically, a WARNING is a more focused, narrower region. This may be issued as a result of a dam or levee failure or excessively heavy rain. You and your family are in immediate danger from flash floods; therefore, you need to take immediate action. Moving to higher ground might just take a few seconds[48].

4.4.1.3 *Flash Flood EMERGENCY*

issued under EXCELLENTLY rare circumstances where a flash flood is occurring or is about to occur and exceptionally heavy rain is posing a serious risk to human life. Emergency personnel usually report LIFE-THREATENING water rises that necessitate evacuations or water rescues[48].

4.4.1.4 *Safety Guidelines for River Floods and Flash Floods*

The National Weather Service is an agency of the United States federal government these guidelines must flow for safety[48]:

- Avoid places like culverts, drainage ditches, and stream beds that are prone to flooding during times of intense precipitation.
- If flooding is an issue in your area, get to higher ground.
- Keep an eye out during times of heavy rain if you live or work in an area that is prone to flooding.
- Because flood hazards are more difficult to see at night, use extra caution.
- Turn around; do not drown! The majority of flash flood fatalities happen when individuals drive their cars into flood waters; therefore, never drive your car into unknown depths.
- If your car stalls, get out of it right away and go for higher ground. Cover the car and sweep it aside because flood water might rise quickly.

5 CONCLUSION AND RECOMMENDATION

The obtained results show that hydrologic indices demonstrated that rainfall and Topographic morphology is the major contributing factors for flash flooding and catastrophic inundation in the study area. The runoff water power delivers vulnerable topsoil and contributes strongly to the erosion and land degradation processes, and then transports soil material and sediment to the plain areas through natural action, i.e., water power and gravity. The valleys are zones of flow accumulation Receiving the contribution of a large upslope drainage areas, thus allowing high rates of erosion. Conversely, low runoff aggressiveness is connected with areas of low slopes. Likewise, the role of the Lithology associated with the terrain Morphology is decisive in flash floods and land degradation in this region.

The flood risk analysis must cover the flood risk assessment, risk management, and risk communication. The solutions to climate change are various.

such as decreasing the number of gases,

reducing the consumption of fuel, using renewable energy, and using modern

technologies like remote sensing.

REFERENCES

1. (EUSPA), E.U.A.f.t.S.P. *What is Earth Observation?* 12/11/2024-5:00AM; Available from: https://www.euspa.europa.eu/eu-space-programme/copernicus/what-earth-

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

observation#:~:text=Earth%20Observation%20(%20EO%20)%20is%20the,that%20benefits%20all%20European%20citizens.
2. digitalearthafrica. *Earth observation*. 12/11/2024 5:10 AM; Available from: https://www.digitalearthafrica.org/about-earth-observation#:~:text=Earth%20observation%20(EO)%20is%20the,further%20advance%20its%20core%20capabilities.
3. Nations, U. *What Is Climate Change?* 17_11_2024 9:30 PM; Available from: https://www.un.org/ar/climatechange/what-is-climate-change.
4. Mohamed Salah Osman, K.A.A.S., Abubaker Hassan A. kheiri, *Artificial Intelligence Network Approaches for Image Classification in Sudan.* International Journal of Scientific Engineering and Science, 7_7_2024. **Volume 8, pp. 120-132, 2024.**(Issue 6): p. pp. 120-132, 2024.
5. Gomes, V.C., G.R. Queiroz, and K.R. Ferreira, *An overview of platforms for big earth observation data management and analysis.* Remote Sensing, 2020. **12**(8): p. 1253.
6. Campbell, J.B. and R.H. Wynne, *Introduction to remote sensing*. 2011: Guilford Press.
7. Elachi, C. and J.J. Van Zyl, *Introduction to the physics and techniques of remote sensing*. 2021: John Wiley & Sons.
8. Dubovik, O., et al., *Grand challenges in satellite remote sensing*. 2021, Frontiers Media SA. p. 619818.
9. Kain, D.T. *Basics of Remote Sensing and GIS*. Feb 27, 2023 15/11/2024 9:00 PM; Available from: https://sigmaearth.com/basics-of-remote-sensing-and-gis/.
10. Analytik. *What is Remote Sensing?* 15/11/2024 9:00 PM; Available from: https://analytik.co.uk/what-is-remote-sensing/.
11. Hoque, M.A.-A., et al., *Tropical cyclone disaster management using remote sensing and spatial analysis: A review.* International journal of disaster risk reduction, 2017. **22**: p. 345-354.
12. Joyce, K.E., et al., *Remote sensing and the disaster management cycle.* Advances in geoscience and remote sensing, 2009. **48**(7): p. 317-346.
13. AkitaBox, *4 Phases of Disaster Management Explained (the Easy Way)* June 21, 2023.
14. Van Westen, C., *Remote sensing for natural disaster management.* International archives of photogrammetry and remote sensing, 2000. **33**(B7/4; PART 7): p. 1609-1617.
15. Earth-graphy. *Types of Earth observation satellites*. 12/11/2024 6:30AM; Available from: https://earth.jaxa.jp/en/eo-knowledge/eosatellite-type/index.html#:~:text=Earth%20observation%20satellites%20are%20the,and%20%E2%91%A3%E2%91%A4%20are%20microwave%20sensors.).
16. eoPortal. *Copernicus: Sentinel-2*. Last updated: Sep 24, 2024, 12/11/2024 7:50AM; Available from: https://www.eoportal.org/satellite-missions/copernicus-sentinel-2#overview.
17. ESA. *Introducing Sentinel-2*. 12/11/2024 7:55 AM; Available from: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2/Introducing_Sentinel-2#:~:text=As%20well%20as%20monitoring%20plant,assumes%20ownership%20of%20the%20satellites.
18. Copernicus. *Copernicus Sentinel 2 overview*. 12/11/2024 12:22PM; Available from: https://www.copernicus.eu/en/copernicus-documents-library/copernicus-sentinel-2-overview.
19. Copernicus. *S2 Mission*. 13/11/2024 7:00PM; Available from: https://sentiwiki.copernicus.eu/web/s2-mission#:~:text=S2%20Mission-,Overview%20of%20Sentinel%2D2%20Mission,swath%20width%20is%20290%20km.&text=The%20Sentinel%2D2%20twin%20satellites,risk%20mapping%2C%20and%20security%20concerns.&text=Each%20of%20the%20satellites%20in,:%20the%20Multi%2DSpectral%20Instrument%20.
20. Laboratory, N.N.S.S. *Flood Detection*. 15/11/2024 4:00PM; Available from: https://www.nssl.noaa.gov/education/svrwx101/floods/detection/#:~:text=The%20main%20tools%20used%20to,%2C%20radar%2C%20and%20rain%20gauges.
21. Organization, W.M. *Flash Flood Guidance System with Global Coverage (FFGS)*. 15/11/2024 2:00PM; Available from: https://wmo.int/projects/ffgs.
22. Ahmed El-Affendi, I. *Impact of Grand Renaissance Dam (GERD) on Agriculture in the Sudanese Blue Nile Basin*. December 16, 2022 13/11/2024 8:30 PM; Available from: https://infonile.org/en/2022/12/impact-of-grand-renaissance-dam-gerd-on-agriculture-in-the-sudanese-blue-nile-basin/.
23. OCHA, S., *Sudan: 2022 Flood Response Update 03 (As of 30 November 2022)*. 30 November 2022 13/11/2024 8:00 PM.
24. Asefa, D.T., *For the Sudan, the Grand Ethiopian Renaissance Dam is a matter of life or death*. October 4, 2020 13/11/2024 9:00 PM.
25. Ha, T.V., et al., *A review of earth observation-based drought studies in Southeast Asia.* Remote sensing, 2022. **14**(15): p. 3763.
26. Sogno, P., C. Traidl-Hoffmann, and C. Kuenzer, *Earth observation data supporting non-communicable disease research: A review.* Remote Sensing, 2020. **12**(16): p. 2541.
27. Salcedo-Sanz, S., et al., *Machine learning information fusion in Earth observation: A comprehensive review of methods, applications and data sources.* Information Fusion, 2020. **63**: p. 256-272.
28. aljazeera. *War-torn Sudan battered by torrential rains*. 12/11/2024 8:30 PM; Available from: https://www.aljazeera.com/gallery/2023/8/8/hundreds-of-homes-damaged-as-torrential-rains-batter-sudans-north.
29. (IOM), I.O.f.M., *DTM Sudan Flash Alert: Heavy Rains and Flooding in Abu Hamad locality, River Nile, Update 002 (6 August 2024)*. 6 Aug 2024.
30. Times, T.S. *Sudan's flood, cholera crises worsen as death hits 390*. September 8, 2024 12/11/2024 9:00 PM; Available from: https://thesudantimes.com/sudan/sudans-flood-cholera-crises-worsen-as-death-hits-390/.
31. Sami, K., *Implementation Status of UNGGIM National Geospatial Information Management. Sudan Country Report* Thirteenth session of the UN Committee of Experts, New York, 2-4 August 2023.
32. Sami, K., *Sudan Geodetic and Geospatial Reference System.* International Journal of Trend in Scientific Research and Development, 2023. **7, of IJTSRD.2023.**
33. Center, E.R.O.a.S.E. *USGS EROS Archive - Digital Elevation - Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global*. July 30, 2018 14/11/2024; Available from: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1.
34. Rahmati, O., H.R. Pourghasemi, and A.M. Melesse, *Application of GIS-based data driven random forest and maximum entropy models for groundwater potential mapping: a case study at Mehran Region, Iran.* Catena, 2016. **137**: p. 360-372.
35. Bui, D.T., et al., *A novel deep learning neural network approach for predicting flash flood susceptibility: A case study at a high frequency tropical storm area.* Science of The Total Environment, 2020. **701**: p. 134413.
36. Bannari, A., et al. *Detection of areas associated with flash floods and erosion caused by rainfall storm using topographic attributes, hydrologic indices, and GIS*. in *Global changes and natural disaster management: Geo-information technologies*. 2017. Springer.
37. Moore, I.D., et al., *Soil attribute prediction using terrain analysis.* Soil science society of america journal, 1993. **57**(2): p. 443-452.
38. Kothyari, U.C., M.K. Jain, and K.G. Ranga Raju, *Estimation of temporal variation of sediment yield using GIS/Estimation de la variation temporelle de l'exportation sédimentaire grâce à un SIG.* Hydrological Sciences Journal, 2002. **47**(5): p. 693-706.
39. Moore, I.D. and J.P. Wilson, *Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation.* Journal of soil and water conservation, 1992. **47**(5): p. 423-428.
40. Abderrazak, B., et al., *Detection of Areas Associated with Flash Floods and Erosion Caused by Rainfall Storm Using Topographic Attributes, Hydrologic Indices, and GIS*. 2017. p. 155-174.
41. Kopecký, M., M. Macek, and J. Wild, *Topographic Wetness Index calculation guidelines based on measured soil moisture and plant species composition.* Science of the Total Environment, 2021. **757**: p. 143785.
42. Louloudis, G., et al., *Remote Sensing Data and Indices to Support Water Management: A Holistic Post-mining Approach for Lignite Mining in Greece.* Mine Water and the Environment, 2023. **42**(4): p. 618-638.
43. Khademalrasoul, A. and H. Amerikhah, *Investigation of Geomorphometric Parameters to Simplify Water Erosion Modelling (a Case Study: Emamzadeh Watershed, Iran).* Polish Journal of Soil Science, 2022. **55**(1): p. 1-18.
44. Stewart, B., *Implementation of a flash flood guidance system with global coverage, A joint proposal by WMO Commission for Hydrology and WMO Commission for Basic Systems. 2007*. 2007.
45. Georgakakos, K.P. *Modern operational flash flood warning systems based on flash flood guidance theory: Performance evaluation*. in

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Proceedings of the International Conference on Innovation Advances and Implementation of Flood Forecasting Technology, Bergen-Tromsø, Norway. 2005.

46. Organization, W.M. *WMO Strengthens Global Cooperation to Protect All Lives from Flash Floods*. 15/11/2024 3:30 PM; Available from: https://wmo.int/media/news/wmo-strengthens-global-cooperation-protect-all-lives-from-flash-floods#:~:text=News,within%20the%20next%20five%20years.
47. wikipedia. *Flash flood guidance system*. 15/11/2024 3:00PM; Available from: https://en.wikipedia.org/wiki/Flash_flood_guidance_system#cite_note-Georgakakos2005-2.
48. government, T.N.W.S.i.a.a.o.t.U.S.f. *Weather Forecast Office Severe Weather Awareness - Flood Safety*. 15/11/2024 5:00PM; Available from: https://www.weather.gov/mob/severe_flood#:~:text=River%20Flood%20and%20Flash%20Flood%20Safety%20Rules%3A&text=Move%20to%20higher%20ground%20if,into%20water%20of%20unknown%20depth.