

Selecting Suitable Sites for Rainwater Harvesting using GIS & RS Technology in Port Sudan City, Sudan Through Hydrological Modeling

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Abstract

The city of Port Sudan is experiencing a serious scarcity of freshwater resources, which are essential for maintaining basic human living conditions, supporting industrial development, and enabling agricultural growth. Despite a lack of freshwater sources in the region, it frequently encounters flash floods caused by intense rainfall. These floods result in catastrophic events, leading to the loss of human lives and property, disrupting traffic and transportation, and causing partial or complete paralysis of daily life in the area. The study was conducted in Port Sudan City because of its significance as the administrative capital following the Sudan War. Port Sudan became the primary destination for the bulk of the Sudanese population, making it crucial to ensure the provision of fresh water. A hydrological analysis and spatial adjustment were conducted using the Arc GIS 10.8 program to address the issues of flood risk and water scarcity in this city. This program allowed for the selection of optimal locations to construct dams for rainwater harvesting. This program was preferred over traditional and manual methods, as it accounted for specific terrain characteristics that would have otherwise been overlooked. The study revealed a significant abundance of valleys in the area, stemming from the Red Sea mountain range situated west of the city. These valleys converge into seven primary valleys that ultimately drain into the Red Sea, being supplied by a total of 27 main basins. The regions most impacted by floods and the corresponding valleys were also identified, and two solutions were suggested. There are ten locations designated for the construction of dams, with six of them specifically chosen to safeguard the areas that are most subject to flooding.

Key words-*Water Harvest; Human Living Standards; Port Sudan City; Flood Risk; Dams*

I. INTRODUCTION

Since water is essential for life and livelihoods because it maintains ecosystem health, water scarcity has been significantly rising in tandem with

urbanization, population growth, and demand, and is the fundamental element for sustainable development [1]. Finding appropriate and sustainable alternatives to drinking water is one way to solve the water shortage

problem [2]. The extreme water shortage in recent decades proves climate change profoundly impacts earth systems. Groundwater stress was significantly affected by the quick rise in population, industrialization, and irrigation, which raised the water demand. As a result, the issue is given top priority to preserve and manage the current water supplies [3]. Hydrologic approaches must be applied with expertise if water resources are to be developed and managed responsibly. More sophisticated methods for analyzing water problems are needed given the rising demand, the enlarging conflict zones, and the escalating incidence of flood damage [4]. The hydrological response of watersheds is significantly altered by fast-paced urbanization, which, in many cases, spreads into mountainous terrain. Unplanned and disorderly urbanization processes are more common in emerging nations, leading to increased sediment and surface runoff yields and the emergence of dangers such as landslides and flash floods. A decline in downstream water quality is also caused by contaminants washing off the urbanized impermeable upper catchment. Consequently, implementing effective management strategies

that may address the negative effects of urban expansion in an environmentally sound and sustainable way is necessary for urban development in hilly watersheds. These environmentally friendly sustainable management techniques are known as ecological practices (EMPs)[5]. Without question, one of the most common and

damaging natural disasters in the world, especially in Africa, is flooding. It had a detrimental effect on the environment, the economy, and society[6]. Floods are not automatically classified as "disasters" based on their coincidental character, like other disasters. Indeed, they become disasters when they cause injury or adverse effects to people, livelihoods, or property. Among all the natural disasters, floods are perhaps the most common and lethal, happening in most nations[7]. Large volumes of water still overflow into the sea yearly from many areas with limited water supplies. Of course, floods themselves may do a significant lot of damage, but frequently the floodwater is not used to its full potential[8]. The most common definition of a dam is a structure constructed across a river or stream to regulate or impede water flow and increase its level to form a reservoir. This reservoir may be used for a variety of purposes, including general water supply and energy production. Better using new or existing dams which were primarily intended for irrigation or hydropower for the extra goal of mitigating floods might prove to be highly beneficial in the future[9][10]. Dams might be built to provide water for agricultural and home use, so resolving the expected approaching water stress scenario and the water

sector's vulnerability, particularly in Port Sudan. Dams were being used as alternatives to gather, store, and manage water resources effectively to improve the quality of life for residents of rural and certain peri-urban regions[11].

Choosing where to build a dam is one of the trickiest and most contentious issues in water supply management. Therefore, to choose the finest dam sites, thorough research of the interest region must be done, considering all relevant criteria[9]. Therefore, selecting the best sites for future dam building is crucial. Generally speaking, a wide range of players acting at various levels and with various interests are involved in the decisions and procedures leading to the dam siting. Due to political interest or other self-serving concerns of the players who need this to happen rather than the elements that require its success, this typically takes precedence over technical considerations[11][12]. Geographic information systems (GIS) and remote sensing (RS) are widely employed in many natural resource applications, and hydrology is one of the sciences that benefits the most from RS use[5]. As computer technology has developed, GIS and RS have emerged as effective methods for integrating spatial and non-spatial resources for hydrological modeling[13]. In the study region, GIS and RS will be combined in the research to discover viable dam locations. The recommended criteria will be applied considering topographical and morphological variables, and individual weights will be determined. For every situation, a suitability map will be created, and the final dam site appropriateness map will be the result of a multilayered study[9]. A digital elevation model, or DEM, is a quantitative depiction of the surface of the Earth that offers

fundamental details about the relief of the land[14]. DEMs are crucial for applications about topography. There has been a lot of interest in studies on the acquisition of topographical data and the creation of DEMs. Though labor- and time-intensive, traditional techniques like field surveying and photogrammetry can produce very accurate topographical data[15]. It is difficult to obtain high-quality DEM data over a wide region due to the intricate generation process[14].

A. Research problem

The city of Port Sudan suffers from the danger of floods in addition to the great scarcity of freshwater sources, as it depends entirely on Khor Arbaat, which is located 50 km from the city. The study aims to identify the extent of the contribution of the analysis of the hydrological map of the dangers of floods, and thus propose ways to ward off the risks of floods and benefit from their water, helping future and sustainable development.

B. Research Objectives

This study is an integrated document on hydrological analysis and spatial suitability of the city of Port Sudan, which aims to:

- 1) View the hydrology of the area.
- 2) Identify the main valleys and the branches that feed them, identify the water catchment basins, and identify their locations.

- 3) Identify the most affected areas
- 4) Seeking to find the best solutions to avoid the problem of floods in the region by proposing the best places to collect rainwater, to make optimal use of it later, depending on the technology of GIS, and the results of this study can have positive economic and social effects on the population of this region, which may contribute to achieving water security and integrated management of water resources in this region, which suffers from water scarcity.
- 5) Highlighting the importance of the role played by GIS technologies and their great assistance in the decision-making process about preventing the dangers of floods from urban areas, by supporting decision-makers with spatial maps and data related to floods within the study area.

II. LITERATURE REVIEW

A. Water

One natural resource that is necessary for the continuation of life is water as shown in Fig(1)[9]. When it comes to maintaining essential human functions including feeding, breathing, circulation, excretion, and reproduction, water is an essential ingredient. Besides being one of the fundamental elements in the creation of a life habitat, water is also a space for life[16]. Water was once thought to be an infinite natural resource as the seasons replenished it annually. Over time, man has gradually grabbed this resource and utilized it without much constraint. Advances in managing and rerouting surface waters, investigating groundwater, and utilizing

the resources for diverse objectives have been carried out with insufficient attention to maintaining the natural resource's quality, preventing waste and abuse, and conserving it. Water is therefore becoming more and more limited in both dry and drought-prone places as well as in areas with relatively copious rainfall. These days, scarcity is seen in terms of the amount accessible for social and commercial purposes as well as the amount of water needed for natural processes[17].



Fig. 1: The water is the basis for the existence of life on planet Earth

1) Importance of Water: Most of the time, the ability of humans to live depends on the availability of water. Water is a valuable substance by itself because of this, but it also

fluctuates greatly in both time and space[18]. All life depends heavily on water[17]. Since everyone and everything alive depends on water to survive as depicted in Fig(2), including humans, animals, and plants, water is life. Water is essential for maintaining environmental and biodiversity preservation, feeding cattle, enabling industrial output, and ensuring food security. All activities including

drinking, industrial processes, agriculture, and other uses can only be accomplished with fresh water[8]. Enough food supplies and a productive environment are essential for the survival of all living things, and this includes water and its resources. Freshwater demand has been rising quickly worldwide as human populations and the economy have risen[16].



Fig. 2: The importance of water and its impact on life

2) *Water scarcity*: Water has been a plentiful resource for most human societies for thousands of years, almost like a free good. However, this is suddenly changing, and in the world's drier regions, water scarcity is now the biggest threat to food security, human health, and natural ecosystems as shown in Fig(3)[19]. "Water insecurity refers to the state in which a person lacks access to safe and reasonably priced water to meet their basic needs for drinking, washing, and supporting themselves." Thus, a place might be deemed water scarce when a significant portion of its population experiences water insecurity for an extended length of time[8]. One of the most significant and challenging problems of the twenty-first century will be ensuring that freshwater systems continue to maintain ecosystems while also meeting human water demand. Due to rising population and consumption levels in opposition to a finite quantity of renewable freshwater, water scarcity has quickly expanded to many world regions. Water management and usage strategies will need to change to address the threats that water shortage poses to food production, ecosystem health, and political and social stability [20]. Therefore, professionally building dams and carefully choosing suitable dam locations might be a viable solution to the problems associated with water scarcity[9].

B. Floods

The rising and overflowing of a body of water into typically dry ground is known as flooding. There are two ways this might happen:



Fig. 3: lack of water leads to dehydration

- 1) directly when there is so much rainfall that the land surface cannot absorb and redistribute water to avoid a surface buildup
- 2) indirectly, when a river exceeds its banks. Hydro- meteorological conditions are the main cause of river floods. These can come in the form of ice jams or other natural dams, rain, snowmelt runoff that is too much, and rain [21]

A river is more prone to flood if its drainage basin is located in an urban region since urbanization has become a key contributor to urban flooding. Flooding in certain metropolitan areas is mostly caused by inadequate drainage [7].

1) *Types of Flooding*: Prior scholars elucidated many types of floods as follows[22]:

- 1) *Long-Rain Floods*: Low-intensity rainfall that falls over several days or even weeks can saturate the catchment and result in high-flow conditions. Any more rain ultimately exceeds the catchment's storage capacity, resulting in a flood event
- 2) *Short-Rain Floods*: High-intensity, brief rainstorms can saturate certain areas of the watershed. A combination of quick subsurface flow, runoff from saturated areas, and runoff from catchment areas where rainfall intensities exceed infiltration capacity causes flood runoff
- 3) *Flash Floods*: Even in generally dry conditions, floods can be caused by brief, intense rainfalls, primarily of convective origin. Rainfall intensities locally surpass the capacity of infiltration. Due in part to the rainstorm's restricted geographical coverage of the catchment and the fact that the majority of the flow channels are on the surface, the catchment reaction is typically relatively quick
- 4) *Rain-on-Snow Floods*: Rain hits snow that has already accumulated. Numerous factors can lead to massive runoff depths from moderate rainfall depths. In contrast to dry spells, considerable long-wave radiation and latent heat inputs during the rains increase snowmelt. When rain begins, antecedent snowmelt may saturate a significant portion of the watershed, encouraging overland flow
- 5) *Snowmelt Floods*: Snowmelt happens during periods of fair weather, which are frequently accompanied by

a sharp rise in air temperature. Global radiation at higher altitudes and turbulent heat exchange at lower altitudes make up the majority of the melt energy. Typically, snowmelt happens gradually over one or two weeks, soaking the soils, increasing flows steadily, and ultimately resulting in flooding. Rainfall is possible but not very significant

C. Dams

Oceanic salt water makes up the great majority of Earth's water. Fresh water comprises about 2.5 percent of Earth's water, and of that, only 0.034 percent is easily accessible to humans[23]. Large volumes of water are stored and safely retained by dams, and subsequently released for several uses, such as inland navigation, electricity, irrigation, recreation, and food preservation[1]. Dams are among the greatest ways to retain water, use it wisely, and enhance both rural and urban residents' quality of life by supplying water for drinking, industry, and irrigation. Dams are made to collect and store water for later use, but their primary purpose is to locate the water properly as shown in Fig(4)[11]. Choosing the best site for a dam is one of the trickiest and most contentious choices in water supply management. Therefore, it is important to undertake a thorough investigation of the

interest region while considering the aspects that influence the selection of the finest dam sites. However, this procedure is expensive and time-consuming[9].



Fig. 4: Types of dams to retain rainwater

D. GIS

An Earth-spatially referenced system for gathering, storing, analyzing, and managing data and related properties is called GIS, often referred to as a geospatial information system [24]. GIS goes beyond conventional mapping. Although a map provides a depiction of a set of geographical data, it is only one of several components that make up a GIS. GIS encompasses not only the data and their visualization but also all system-wide activities that may be carried out on them[25]. GIS systems are now viewed as decision-making tools more often than they were ten or so years ago. Especially for land appropriateness mapping and modeling, GIS's capacity to facilitate decision-making processes is crucial[26].

1) *GIS and Hydrology*: Water that has seeped through cracks and fissures or flowed over the earth eventually reaches the sea,

where it evaporates once more before the cycle is repeated. The hydrological cycle is the name given to this cyclical activity [5]. One of the most successful methods in hydrology right now is the use of GIS and remote sensing methodology[9]. The identification of a suitable location for water harvesting has been approached with great attention using RS and GIS approaches. The integration of GIS and RS has facilitated the process of obtaining baseline data on a region's hydrological potential [2]. In hydrological modeling, improving accuracy is crucial. RS has not yet developed to the point where it can be used to determine the essential model components directly. It remains an indirect method to this day. RS data will be used to produce several modeling-related metrics. Based on the resolution the researcher chooses for the modeling, for example, the most accurate way to produce maps of land used/cover, digital elevation models as depicted in Fig(5), drainage systems, soil maps, etc [13].

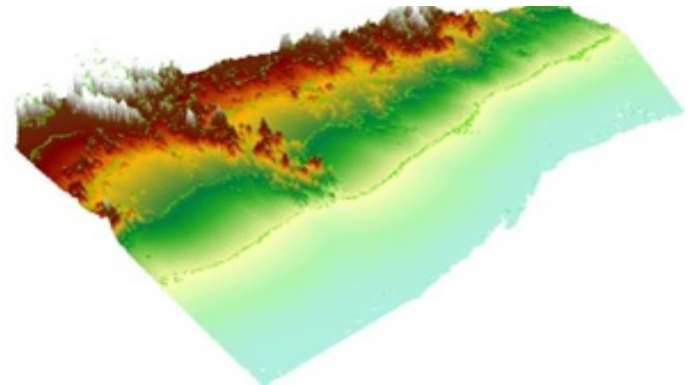


Fig. 5: 3D digital elevation of the Study Area

2) *The Role of GIS in Spatial Suitability* : Finding out if a certain piece of land is suitable for a given purpose is known as land suitability analysis. Stated differently, it refers to the method of assessing the degree of appropriateness and whether a land resource is appropriate for a certain set of purposes. It is important to thoroughly examine the viability of different land uses to steer growth to the most appropriate areas, which will help establish the most desirable route for future development. The process of creating a suitability analysis involves determining the proper appropriateness factors [27]. Notably, GIS plays a significant role in the process of choosing dam locations. Nevertheless, the efficacy and suitability of GIS vary depending on the region [9]. GIS is useful for examining the features of land from various levels at each place to address problems since suitability analysis involves the study of several data sets. It is possible to simplify the depiction of phenomena through the usage of GIS-based models. In GIS, this is accomplished by merging several map layer sets and examining their interrelationships [27]. Decision-makers continue to struggle in the interim with a broad range collection of dam site selection criteria, taking into account the social and environmental aspects of the local ecosystems as well as their inclinations toward feasible growth

at a rapid speed. However, factors like slope and hydrological conditions are crucial considerations for choosing safe dam sites and building dams [9]. In the suitability analysis, GIS offers spatial

overlay capabilities and grid-cell processing methods that enable us to analyze spatial factors[27]. The conventional method of choosing a location is laborious, manual, and doesn't highlight certain aspects of the topography. However, with more geographical capabilities, the GIS can automate and provide a scientific solution to this problem [11].

E. Previous Studies

- 1) (Suitable Site Selection for Rainwater Harvesting and Storage Case Study Using Dohuk Governorate) For the researcher " Gaylan Rasul Fage Ibrahim, Arieann Ali Hamid, Zana Fattah Ali, and others " The results demonstrated that suitable areas for water harvesting, are located in the middle and northern part of the research area, and in intensively cultivated zones. The main soil texture in these suitable sites was loam, while the rainfall rate amounted to 750 to 900 mm. This research shows that 15% and 13% of the area studied can be categorized as having excellent and good suitability for water harvesting, respectively. Furthermore, 21% and 27% of the areas studied were of moderate and poor suitability, while the remaining 24% were not suitable at all.
- 2) (Dam Site Suitability Mapping and Analysis Using an Integrated GIS and Machine Learning Approach) For the researcher " Rami Al-Ruzouq, Abdallah Shanableh, Mohamed Barakat A. Gibril and others" In this research, a hybrid GIS decision-making technique supported by an ML algorithm was developed to identify the most appropriate location to construct a new dam for Sharjah, one of the major cities in the United Arab Emirates. e. The weights of the thematic layers were determined through the analytical hierarchy process supported by several ML techniques, where the best-attempted ML technique was the random forest method, with an accuracy of 76%. Precipitation and drainage stream density were the most influential factors affecting the DSSM. The developed DSSM was validated using existing dams across the study area, where the DSSM provides an accuracy of 83% for dams located in the high and moderate zones. Three major sites were identified as suitable locations for constructing new dams in Sharjah.
- 3) (potential dam sites selection using integrated techniques of remote sensing and GIS in Imo State, Southeastern, Nigeria) for the researcher "Temitope F.Ajibade, Nathaniel A. Nwogwu, Oluwaseun K. Akinmusere and others" In this study, potential sites for construction of dams in Imo State, Nigeria, have been identified by using GIS and RS techniques which were integrated with fuzzy logic to achieve the study objectives. Climatic and geophysical factors such as rainfall, runoff, stream order, soil type, geology type, and land use were considered. These factors assigned fuzzy membership classes according to their contribution to locating suitable dam sites. The fuzzy members for all the factors were combined using the fuzzy overlay technique to produce the suitable dam site selection map. The majority of the selected sites were located in the northwestern part of Imo State which is characterized by high elevation and gentle slope.
- 4) (Suitable dam site identification using GIS-based MCDA: a case study of Chemoga watershed, Ethiopia) for the researcher " Yonas Gebresilasie Hagos, Tesfa Gebrie Andualem, Workineh Tadesse Ayeleand others" The study used six influencing factors to find suitable dam sites, with the model's suitability stream and overall suitability output maps proposed and evaluated as a result. Based on the topography and land use, the results showed that three proposed dam sites in the upper part of the watershed are likely preferable for irrigation, fishery, and clean drinking water supply. The three proposed dam sites in the watershed's lower reaches, however, are better suited to hydropower generation.
- 5) (Geographical Information System (GIS) as a Tool for Determining Suitable Dam Sites in the Upper West Region of Ghana) For the researcher " Prosper Basommi Laari, Reduwan Kassim, and Edward Matthew Osei Jnr" This study used Multi-Criteria Decision Making (MCDM) in a GIS environment in siting dams using five factors namely, slope, rainfall, soil type, protected zones, and settlements. This resulted in a suitability map of the sitting dam showing 4.3% suitable for dam construction, 33% of the area averagely suitable, 53.9% poorly suitable and 8.8% unsuitable for dam construction. The study recommends GIS and MCDM for the effective sitting of dams primarily in semi-arid regions to solve the problem of dams not working efficiently because of the poor location of sites.

III. METHODOLOGY AND DATA USED

A. Study Area

The City of Port Sudan is located in northeastern Sudan on the western coast of the Red Sea in the Red Sea State. It is located between latitudes ($19^{\circ} 18' 0''$ N) and ($19^{\circ} 42' 0''$ N); and longitudes ($37^{\circ} 7' 0''$ E) and ($37^{\circ} 20' 0''$ E) at an altitude of 13 meters above mean sea level, it covers an area of 563.21 Km^2 . As show represented Fig(6)

B. Data Collection

To determine the optimal locations for embankments, this study needed to include both hydrological analysis and spatial appropriateness. Two digital elevation models (DEMs) were downloaded due to the unavailability of a single model covering the entire study area with an accuracy of 12.5m from the site (Alaska Satellite Facility) of the US Space Agency (NASA).

A map of residential areas was obtained from the Sudanese Survey Authority, soil and land use maps from the Presidency of the Dams Implementation Unit, and road and railway maps from the website (Open Street Map), while the map of agricultural areas was extracted from the land use map.



Fig. 6: Study Area

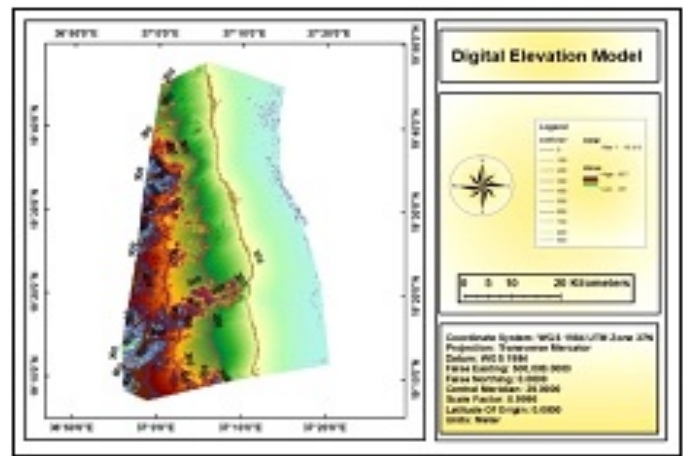


Fig. 8: Digital Elevation

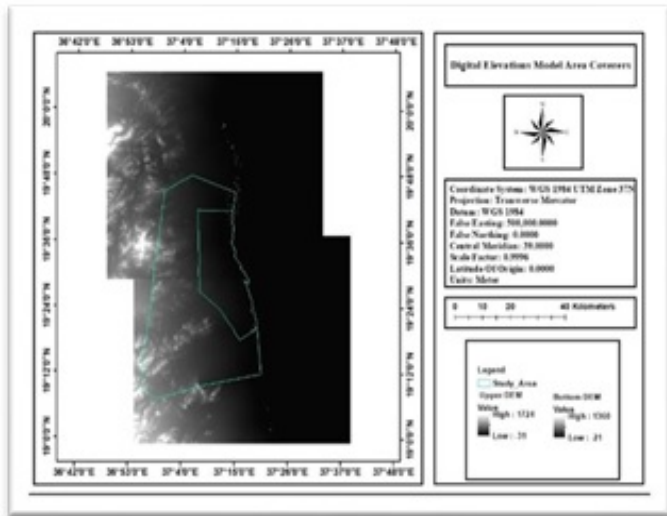


Fig. 7: Elevation Model of the Study Area

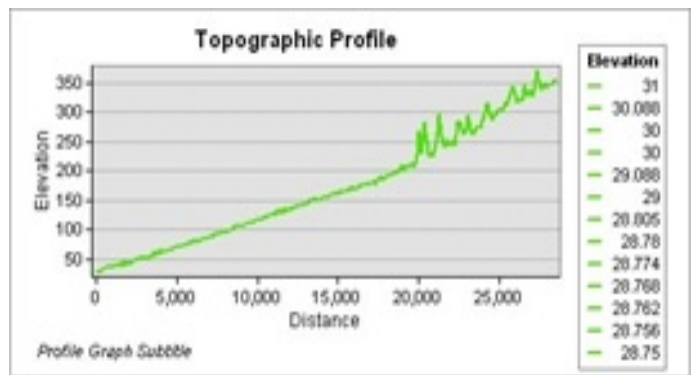


Fig. 9: Digital Elevation Model Profile

C. Data Analysis

The data were analyzed in two stages using a program (ArcGIS10.8), the first stage is the hydrological analysis and the second one is the selection of the best site for damming (spatial suitability).

1) Hydrological Analysis:

- 1) The two models of digital elevation model covering the study area were added and then merged (Mosaic) and after obtaining one complete the model was cut according to the study area as shown in Fig(8)also, a profile of the study area was extracted as depicted in Fig(9).
- 2) Fill: The height file is in the form of a grid (Raster). Each cell has three dimensions (X, Y, Z), and the cell with the highest height flows into the cell with the lower height in a sequential series. This sequential series continues from a greater height to a lower height. So on, if an anomaly occurs in this sequence, such as the presence of a cell with a height or a low, such as the presence of a hole, it means the end of the valley and the beginning of a new valley. What is only the same valley, so this abnormal height or this hole must be removed, by giving it the average values of adjacent cells. The DEM

was processed from the anomalous values as shown in Fig(10). Fig(11) illustrates the profile created for the study area after processing the anomalous values.

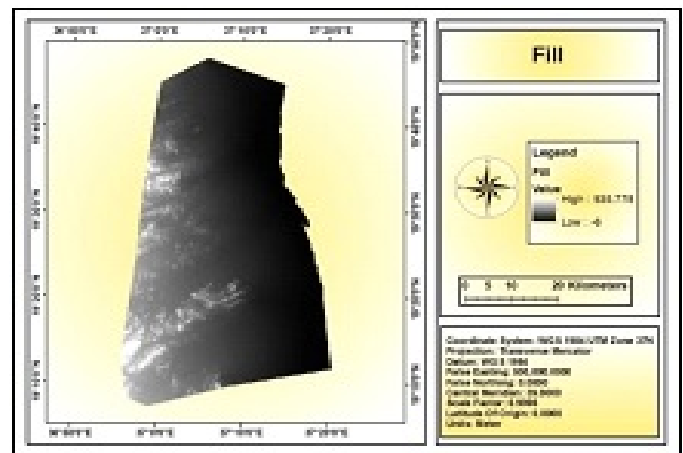


Fig. 10: DEM after removing outliers

- 3) Flow Direction: Determine the direction of flow of the cells based on the height, and we note in this step that the analysis is carried out at the level of the cell and not at the level of the tributary, meaning that each cell leads to a neighboring cell that is less high than it. One

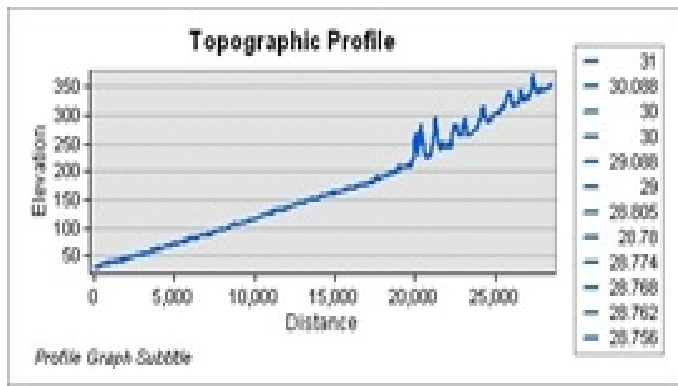


Fig. 11: Digital Elevation Model Profile after Fill

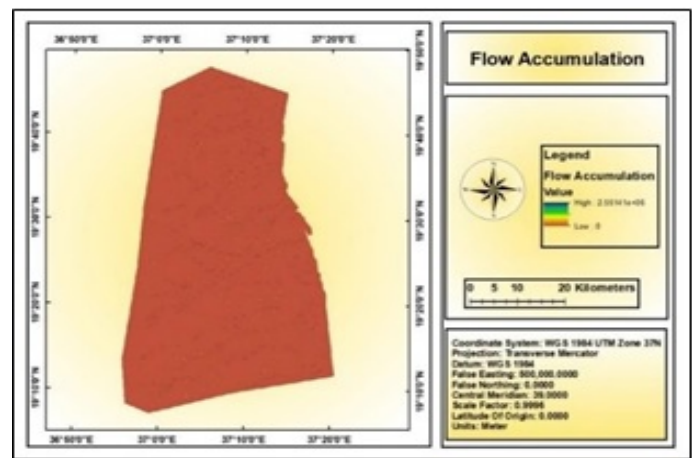


Fig. 13: Flow Accumulation

of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster , as shown in Fig(12).

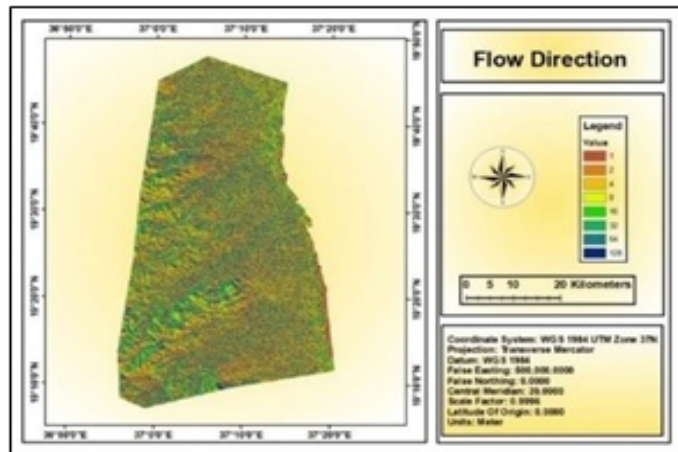


Fig. 12: Directions of Flow

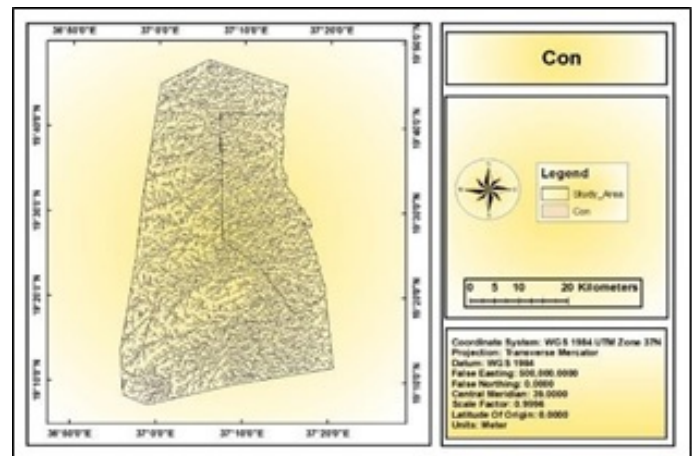


Fig. 14: DEM after eliminating outliers

- 4) Flow Accumulation: The maindrains were extracted as shown in Fig(13) by collecting the flow at each cell by calculating the number of cells in which the water will be poured, where the areas containing the water were given a value of (1) and the rest of the areas take (0), the main sewers appear in white and the rest of the areas in black. The result of flow accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight of all cells that flow into each downslope cell
- 5) Con: In the previous step, only the main sewers were extracted, so the branch sewers must be identified as shown in Fig(14).
- 6) Stream Order: Fig (15) classify the river ranks in the basin area, the river ranks were calculated and their number was known, as the number of ranks of the valley is significant on the strength of the valley.
- 7) Raster To Vector: The waterways were converted from Raster to Vector as shown in Fig(16) to become a layer of lines that we can deal with in calculating the lengths and density of river tributaries and making the necessary analyses for them

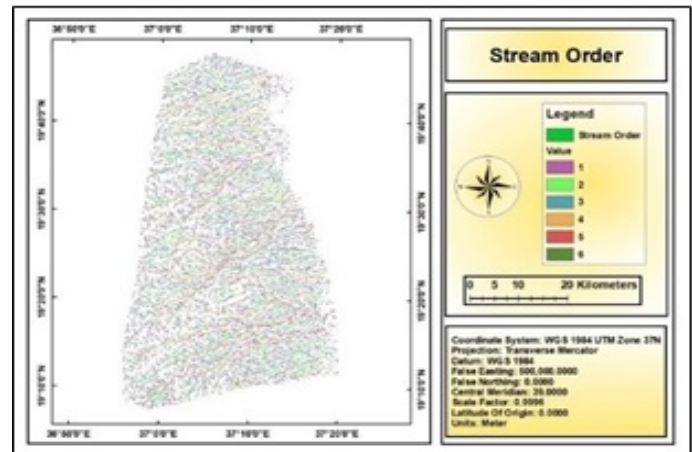


Fig. 15: Streams Order

- 8) Basins: This layer as depicted in Fig (17), which represents the boundaries of the drainage basins, was produced by inserting the water- flow direction layer
- 9) Snap Pour Point: A linear file has been created (Feature) of the type (point) made in which the assembly points were determined, and then the points identified in the

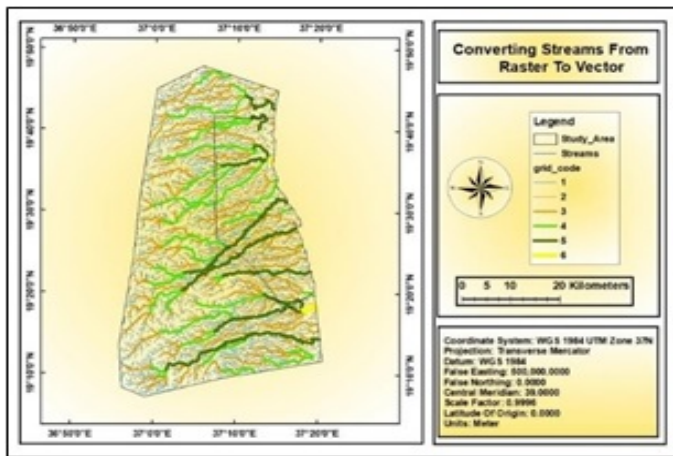


Fig. 16: Streams in Vector form

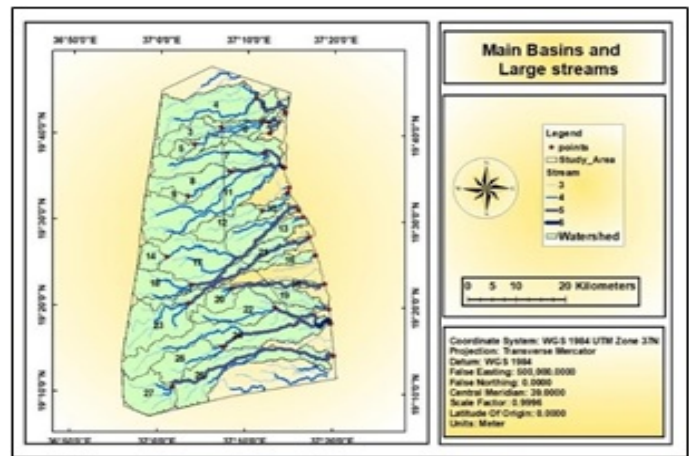


Fig. 18: Main Basins and Large Streams

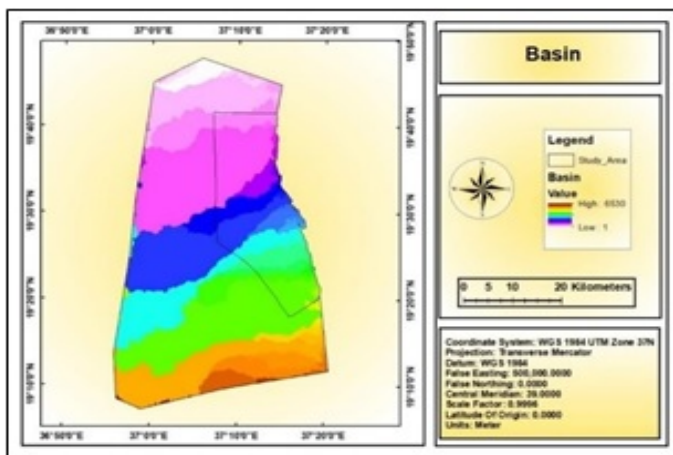


Fig. 17: Basins

linear file were placed on the main flow layer (grid file), this tool is used to clarify the casting of points with the highest flow accumulation within a specified distance.

- 10) Watersheds: This step was done to identify the contributing areas (basins) in the water pool around specific points, and then the basins were converted from Raster to Vector as shown in Fig (18); so that the area of each basin could be calculated.

D. Spatial suitability

Spatial suitability was carried out based on several bases that would support the decision to choose the most appropriate sites in the study area For the construction of dams, the influential foundations were identified from previous studies and the opinions of experts in the Sudanese Dams Implementation Unit (Water Harvesting Section).

- 1) The foundations affecting the selection of the best sites (place): Water storage dams are of great importance, as they store the flood water of the valleys on the surface of the earth and between the mountains, and it is stored for use for domestic use, agriculture and to protect against floods, and before starting the construction of the dam, studies must be conducted to ensure the safety

of the dam and not to destroy it, as the GIS program provides the necessary tools to choose the best sites based on the criteria that are determined as shown in Fig(19),(20),(21), and (22). Ten bases were represented in the form of ten layers of the Raster type classified for inclusion to analyze the spatial suitability of the construction of embankment in the study area as shown in Fig(23).

- a) Slope: The slope has a big role in choosing the sites for the construction of dams and therefore because of its effect on the runoff of surface water, the lower the speed of flow and thus the greater the ability of the basin to retain the largest amount of running water, the slope (slop) was extracted from the DEM, and then it was reclassified
- b) Soil quality: The soil acquires its importance as a criterion for selecting dam construction sites from the degree of permeability, whenever the soil is of high permeability it is unsuitable for the establishment of dams on it and vice versa, soil data was obtained from the presidency of the Sudanese Dams Implementation Unit, and it was divided based on the percentage of clay (40% and above clay soil) and sand and silt in it, and then it was classified (clay represents the least permeable and sandy with high permeability).
- c) Area of drainage basins: A very large area increases the cost while reducing it too much means not collecting a large amount of water, the map of the basins resulting from hydrological analysis is in the form of Raster, it was converted to Vector, then it was classified by area and then converted to Raster again.
- d) Railway tracks: Since the railway is a major economic link between the port of Port Sudan and numerous cities in Sudan, it is important to consider that the proposed sites are distant from it. To prevent potential damage, the distances from the railway line have been categorized and calculated.

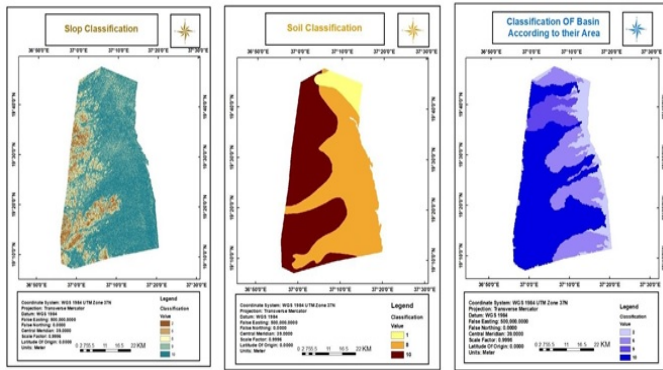


Fig. 19: Reclassification of Slope, Soil and Basins According To Their Area

- e) Road: Given how crucial the road network is for getting to the dam, one of the variables influencing its position is its proximity to the highways; the distance between the dam and the roadways was estimated and subsequently classed.
- f) Proximity to valleys: Given the significance of the dam's financial decision, the valleys' closeness plays a significant role in the selection process. Specifically, the dam must be situated no more than one kilometer from the valley's midline. After computing and classifying the distance from the valleys

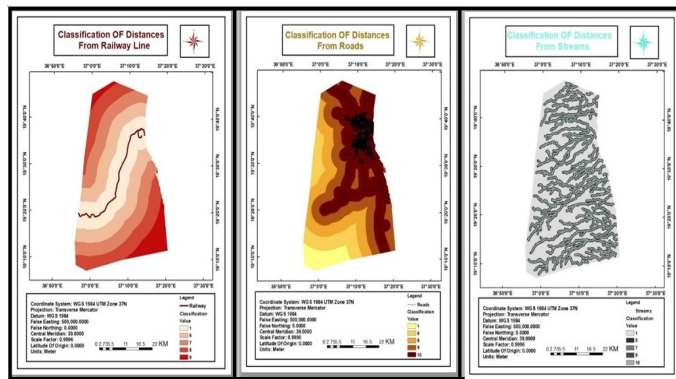


Fig. 20: Reclassification of Distances from Railway, Roads And Streams

- g) Distance from buildings: The dam must be at an appropriate distance from the residents so that they can be evacuated in the event of the collapse of the dam, the distance from the buildings was calculated and then classified.
- h) Agricultural areas: The proximity of a dam can assist in supplying water for agriculture for a longer length of time since the region is regarded as a seasonal agricultural area, where the people cultivate after the conclusion of the flood period. The distances from the agricultural area were computed and eventually categorized.
- i) Straits: Since the valleys' narrow passages serve

as natural water retention areas, they are ideal locations for dam construction. After analyzing the study area's image (Base Map) and counting the number of straits, a linear file (Feature Class) was created, containing the locations of the straits that met the criteria, their distances from one another, and their classification.

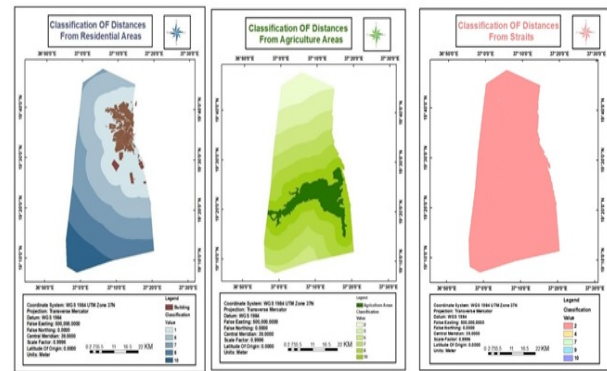


Fig. 21: Classification of Distances from Buildings, Agriculture Areas, and Distances From Straits

- j) Distance from the Sea: As mentioned at the beginning of this section, the study area is located on the strip of the western coast of the Red Sea, so this matter must be taken into account, provided that the proposed dam is as far as possible from the sea, a map of the Red Sea coast was drawn and the distance from it was calculated and then classified.

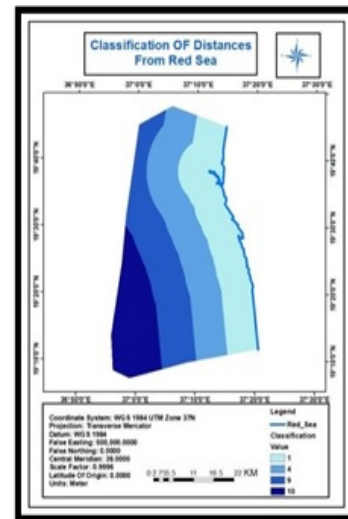


Fig. 22: Classification of Distances from Red Sea

E. Model builder

Models have been built (Model builder) for hydrological analysis and spatial suitability by calculating distances from the standards reclassifying them and then intersecting all layers according to their weights in a program (Arc GIS 10.8) to

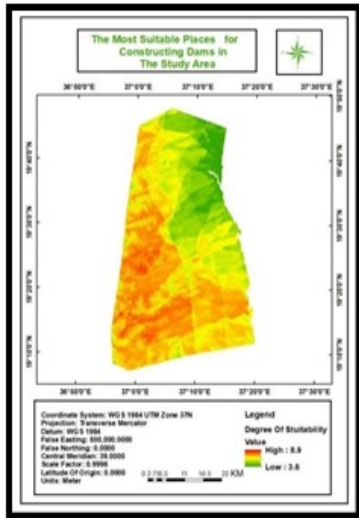


Fig. 23: The Most Suitable Places for Constructing Dams in The Study Area

simplify the problem and formulate ways to solve it, and also to facilitate work and project application in other areas as depicted in Fig(24),(25), and(26).

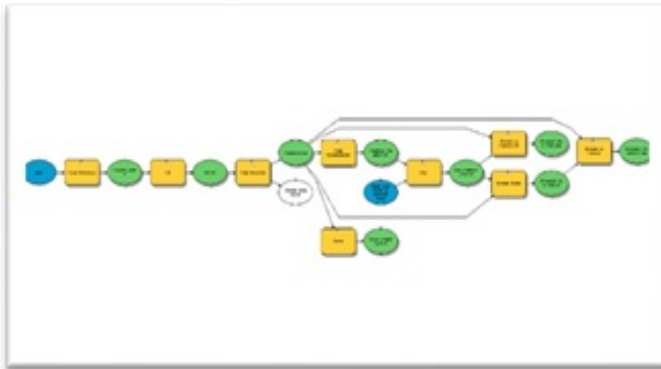


Fig. 24: A model of hydrological analysis steps from treatment to access to watercourses in the form of a linear file and all basins fed by them

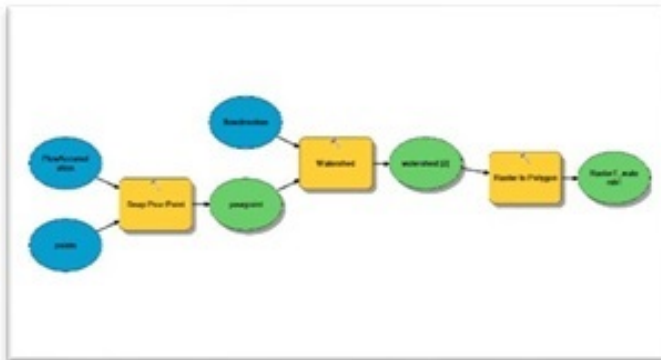


Fig. 25: Sample Steps for Extracting Collection Basins

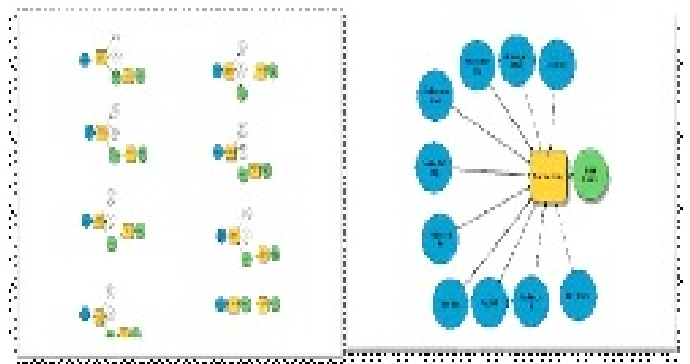


Fig. 26: is a model for calculating distances from the criteria reclassifying them and then intersecting all layers according to their weights to obtain the result of relevance

IV. RESULTS AND DISCUSSION

A. Result of Hydrological Analysis

After conducting a hydrological analysis of the study area, it was found that it contains a large number of valleys, where these drugs start from the Red Sea ridge, which is located west of the city and heads east to flow into the Red Sea. A number of these valleys pass through the center of

the residential area, which causes floods in the city's neighborhoods as shown in Fig(27), and since this area is expected to expand in the south and north on the coastline, we must think about making a study for this area to develop proposals for the construction of dams in it or avoid these medicines when planning.

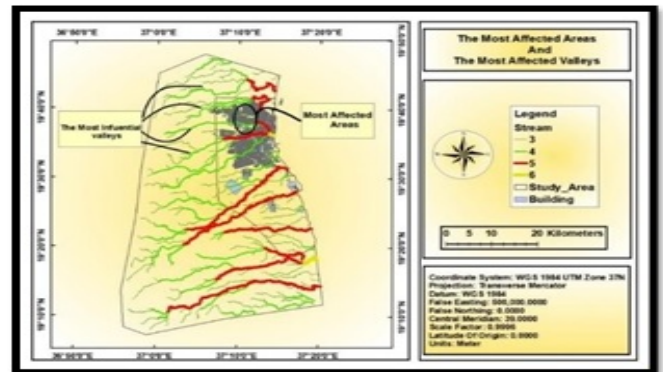


Fig. 27: The Areas most affected by the floods

After conducting spatial suitability, it was found that the area contains several basins contributing to the nutrition of the main valleys (27 basins) ranging in size from 232.04 Km^2 to 11.43 Km^2 , (10) of these basins feed the valleys passing through the most affected areas as shown in Fig(28).

B. Result of Spatial Suitability

A map was produced by Model Builder in geographic information systems showing spatial suitability based on a set of variables with a spatial dimension that affects the selection of dam sites (hydrological modeling) as depicted in Fig(29),

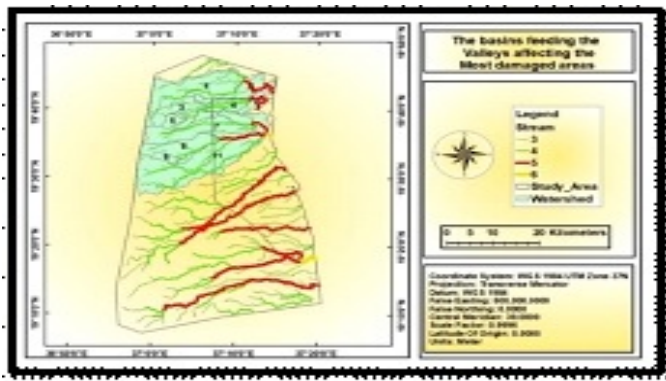


Fig. 28: The Basin feeding the valleys affecting the most damaged areas

where 11 sites were selected within the scope of the criteria that were used, which are (slope, proximity to valleys and roads, railway line, soil quality, basins area, fjords, distance from the Red Sea, agricultural areas).

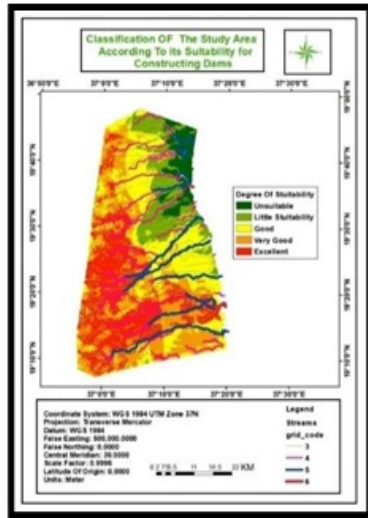


Fig. 29: Classification of the Study Area according to its Suitability for Constructing Dams

C. Discussion

Based on the study of the risks of floods and water scarcity to which the people of that area (Port Sudan city) are exposed, and by analyzing the data hydraulically and then spatial suitability, the areas that may be exposed to the risk of floods were identified and then proposals were made for the establishment of dams to avoid flood risks, where the most appropriate places were chosen for the construction of dams based on many criteria as depicted in Fig(30), which were formed in the form of layers based on GIS technology, where each layer represents a variable characteristic, Where weights are given according to the importance of the attribute and the total Weights is 100%, and through the process of spatial suitability as shown in Fig(31) eleven sites have been allocated to establish dams on the streams of the basins that are located

in the study area, where the site was chosen (3,4,5,6,7,8,9) because it is considered sites that serve the region directly if dams are established on it, where the two sites (5, 6) are located in the same basin. The basin represents the largest in terms of area allocated for water reservation, with an area of 232.039 km^2 . The two sites (7, 8) are In the same basin with an area of 189.763 km^2 . There is also site No. (10), which is the second largest water reservation site in terms of area, with an area of 208.106 km^2 . However, it is located a long distance from the city, but urbanization of the area has been considered (expansion occurs north and south on the Red Sea coast).

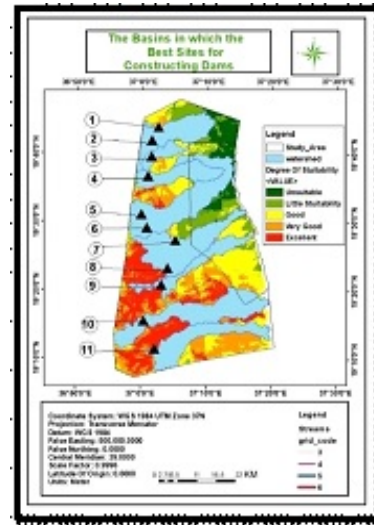


Fig. 30: Proposed Dams in the Study Area

Constructing Dams

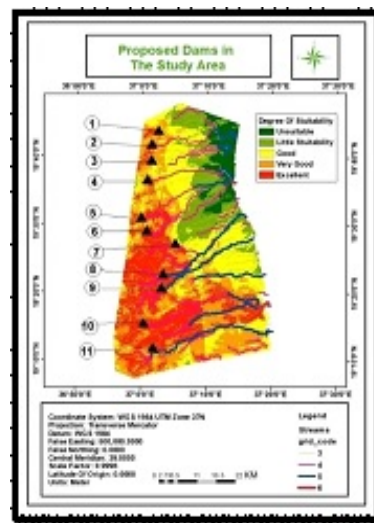


Fig. 31: The Basins in which the Best Sites for

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The importance of this study comes through disseminating knowledge about hydrological analysis in geographic informa-

tion systems to clarify the flow currents and catchment basins. Hydrological modeling

then provides a set of alternatives to compare and also helps researchers and decision-makers to know the best sites to build dams to manage and ward off the risks of floods in their areas and how to benefit from this water because it is an important vital resource in dry areas that suffer from freshwater scarcity, such as the pearl of the Red Sea (Port Sudan) The study showed that the area contains a very large group of valleys originating from the Red Sea mountain range west of Port Sudan, which eventually congregate into ten main valleys flowing into the Red Sea, and fed by 27 main basins ranging in size from 232.04 km² to 11.43 km². The study showed that the best sites for the construction of dams are (4,5,6) because they work to protect the areas most affected by floods, which are squares (2,3,4,5,6) belonging to the Sallab district, Jenin area, and parts The northern district of Dar es Salaam and the valleys that cause this damage are located in the northwestern part of the study area. Then the proposed sites were identified, which showed that the two sites (5 and 6) are located in the same basin with an area of 232.039 km², and also (7, 8) are located in the same basin with an area of 189.763 km², so it is necessary to compare and choose one site and establish the dam on it. As well as the proposed site No. (10) It is located in the southeastern part of the residential area with an area of 208.106 km². However, it is considered of great importance because it is considered the second basin in the study area in terms of area and because of the expected population increase in the northern and southern direction of the coastline.

B. Recommendations

Based on the results of the study, the following recommendations were made:

- 1) Benefiting from GIS techniques in achieving the objectives of geographical studies and setting a fixed order of standards according to their importance by experts and researchers and circulating them to all similar studies.
- 2) GIS software can be relied upon in hydrological studies, as it saves time and effort well, especially if it relies on updated topographic maps and high-resolution aerial photographs.
- 3) Using a high-resolution digital height model such as Lidar DEM to achieve results with a high accuracy of one meter or less.
- 4) Implementation of at least one dam in this area due to its strategic location, which connects Sudan with the Arab world, which made it a region with a population weight.
- 5) The city of Port Sudan has become the administrative capital after Khartoum in Sudan, which made it densely populated and needs a large amount of water suitable for domestic and agricultural use.

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