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Geospatial Information: A Success Factor for Sudan's Hydrologic Investigations

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ABSTRACT

Hydrologic investigations and analyses are essential components of any water resources assessment. Traditionally, these investigations require significant time, effort, and financial resources. However, the emergence of remote sensing techniques, along with geospatial data and information, has provided new sources of hydrological data and significantly enhanced the capabilities of water resources assessments. The primary objective of this article is to highlight the significance of geospatial data and information in the success of hydrologic investigations and hydraulic designs. The study also provides valuable insights for assessing the current situation and guiding future research. Elevation data are derived from the local surveying measurements and the default Advanced Land Observing Satellite (ALOS), World3D (AW3D), and Digital Elevation Model (DEM) readings. This paper demonstrates that feasibility studies for water harvesting projects can be effectively conducted using geospatial and remote sensing data. As an illustration of the potential of these technologies, a case study is presented, detailing hydrologic investigations and engineering designs for multiple water harvesting projects and water supply systems serving 14 towns and 26 villages in West Kordofan State, Sudan. Based on the outcomes of this study, the authors recommend the development of a unified geospatial information system for hydrology, water resources, water harvesting for agriculture and animal production, and for the production of flood risk maps in Sudan

1. INTRODUCTION

In recent decades, the impacts of drought and climate change have been realized in many parts of Sudan. The competition for water resources has increased significantly, necessitating comprehensive water resource assessments for all Sudan states. Great pressure was exerted on the federal and state governments to seek immediate action. West Kordofan State selected the University of Khartoum Consultancy Corporation (UKCC) to conduct hydrographic investigations and detailed engineering designs for several water harvesting projects and water supply systems for 14 towns and 26 villages between Al Nuhood and Al-Odayia towns. This article outlines the methodologies and techniques adopted in the study.

The geospatial information collected and used in this study was related to topographic survey data collection, vector and raster maps, and GIS preparations for spatial information, together with socioeconomic data, hydrology, ground and surface water sources, water supply networks, and solar energy information. This geospatial information has been used to conduct the hydrologic investigations and designs to provide accurate feasibility information that will be fully utilized to perform the hydrologic detailed engineering designs for water supply and water transmission systems, as well as the design of the required structures. The available West Kordofan State collected geospatial information includes:

Data and information were collected from State GIS systems and remote sensing imagery. Collection of topographic maps, hydrologic and hydrogeologic data, water supply sources, and distribution networks

Socioeconomic and environmental data and studies documents from the relevant State departments.

The general geospatial data requirements considered are: The coordinate system for data was WGS 1984 UTM [1], with the relative accuracy of the topographic surveys and measurements in the range of ± 5 cm; data collection of any kind included the location coordinates and topography, maps, and plans. The geospatial data collected were overlaid in the GIS format. These requirements logically fall into the following areas, as illustrated in Table 1. In Sudan, the Sudan Survey Authority (SSA) stands to maintain the United Nations Global Geospatial Information Management (UNGGIM) Initiative [2] that includes the unification of the reference system and integration of geospatial information. Based on the adoption of this initiative, the Sudan Survey Authority has developed the Sudan National Digital

Table 1. Illustrates some outlines of the mapped geospatial information

No.	Outlines of the study mapped geospatial information
1	Survey of existing surface drainage and water distribution networks and new routes. Provision and supply of suitably calibrated equipment, Establishment of horizontal and vertical Control Stations, and Production of longitudinal profiles, contour maps, and DTM.
2	Socioeconomic requirements and characteristics of West Kordofan State
3	Hydrologic investigations for surface water drainage for the targeted cities, hydrological analysis, and computation of the geometric volume of catchment areas.
4	Topographic survey, surface and groundwater survey for the route selection and design of a water Transmission Line from Al Nuhood basins to Al Odia.

Basemap [1, 2] to be used as a base for all geospatial information in the country for the public government and private sector organizations.

Current geospatial systems in Sudan lack an accurate geodetic reference framework to be used for the integrated geospatial information framework [1], [2], [3]. This framework is essential for sharing, integrating, and exchanging geospatial data, and this will also help every institution in Sudan, including the Ministry of Irrigation and Water Resources and hydrologic institutions, to expand their capabilities for enhancing water and hydrology data collection and management. As well, it will raise the level of support for geospatial data activities and provide solutions that enable the effective implementation of operations in the water and hydrology sectors.

Geospatial data in hydrology is a data technique used to extract information from the data that belongs to a particular area and contains information about the boundaries, location, area characteristics, topography, soil, hydrology, water courses, catchment areas, environments, and population. The basic topographic data and information can be obtained from ground surveying measurements, extracted using geographic coordinates, satellite imagery data, photogrammetric, Unmanned Aerial Vehicles (UAV), Lidar, and line and thematic maps. For example, considering the context of geospatial information for hydrology analysis in one unified reference frame [1] allows for better investigation of the soil, water resources, socioeconomic and environmental impact, and decision-making in the areas related to urban planning, transportation, communication, public health, and agricultural production.

2. GEOSPATIAL AND SOCIO-ECONOMIC DATA

2.1 Sudan Digital Basemap

The national base map of Sudan serves as the main sourc and the core of geospatial information in the country, and as a main hydrology and water source data (Figures 1 and 2). The Sudan Basemap is an important component of the spatial data infrastructure and River Nile basin information for public, private sector, and water sector organizations [2], [3]. It represents a national strategy aimed at framing foundations in which the benefits of geospatial data infrastructure are shared to build a national geographic information infrastructure for all sectors at the national level.

The national Basemap also represents a key element for providing geographical information that enables the management, monitoring, and tracking changes occurring on the land of Sudan and hence the Sudan hydrology (Figures 1 and 2). In addition to that, it can be used to form exchange links for the geospatial information system between the Ministry of Irrigation and the relevant water sectors in an integrated framework that provides the opportunity to find the complex hydrology intersections and interrelationships with the spatial information infrastructure. Figures 1 and 2 show the basic hydrologic layers of the national Basemap system [2]. These layers were included in the base map and served as a unified hydrology basis and frame of reference [1, 4].

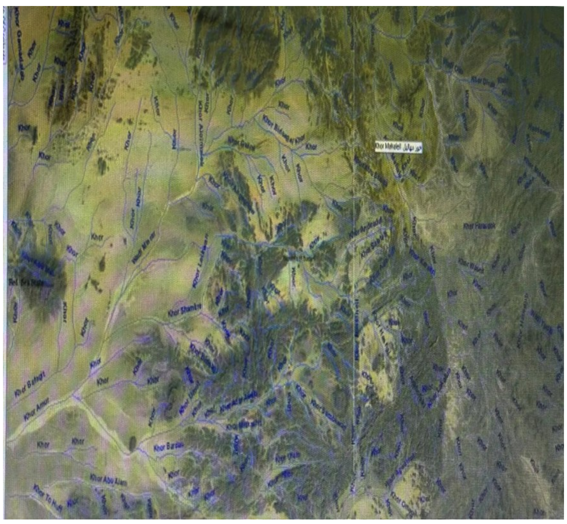

Figure 1: Sample of Sudan Basemap Natural Drainage Layer

The Sudan National Base Map System (SNBS) will ensure the delivery of the hydrology information at an acceptable level of confidentiality, availability, and performance. This will contribute to the effective management of hydrology and water resources by maintaining acceptable levels of data sharing, quality control procedures, confidentiality, secure service, and performance [1, 5, 6].

To create an effective nationwide, unified hydrologic geospatial information, collaboration between the Ministry of Irrigation and Water Resources, the Sudan Survey Authority, the water research centers, and the water sector's community is essential [7].

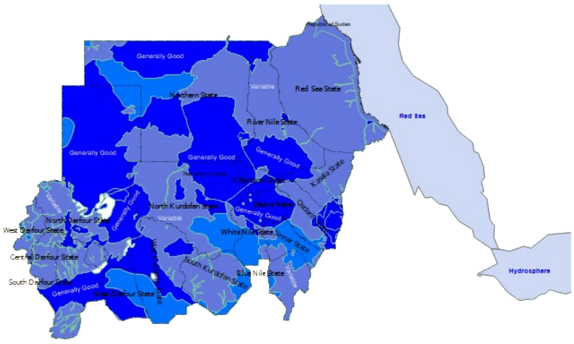

Figure 2: Sudan Basemap water bodies Information

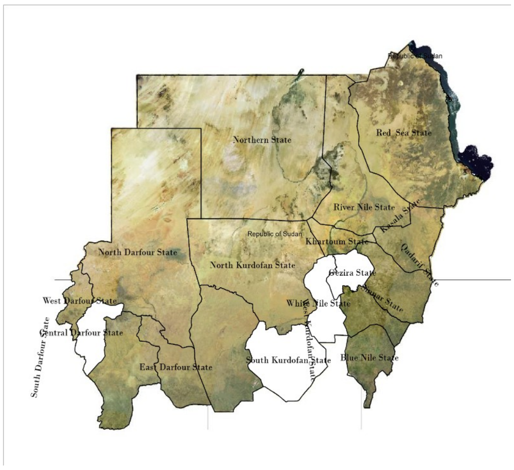

Figure 3: Satellite Image of Sudan States showing the case study area

The WGS84 UTM projection - zone 35 was adopted as the reference system for the West Kordofan geospatial information, GIS, Maps, and planning data. The Topographic, hydrology, and water supply facilities data were used to propose new water source locations, routes, and options for the village's water supply transmission lines.

Establishing ground control points (GCPs) for hydrographic investigations will depend on the arrangement of the existing GCPs and their accurate locations within or near the targeted towns. The procedures and methods used were to verify that the locations of the GCPs will significantly impact the efficiency of the required activities, the accuracy of the survey, and the future usability, performance, and stability of the established monuments. The main study activities were primarily focused on:

1. The town's maps, contours, and ground horizontal and vertical control coordinates.
2. The location of water supply sources and the existing plans of the water supply distribution networks for 14 towns.
3. The digital elevation models (DEM) and satellite imagery of the targeted towns and along the water transmission line route.
4. The existing hydrologic infrastructure in and around the targeted towns.

2.2 Detailed Topographic Surveying Data

A range of geospatial data was gathered for the research activities and operations, that are collected from the Ministry of Infrastructure and Urban Planning (MIUD) of West Kordofan State including the State and its administrative boundaries, topographic maps, contour and DEM, West Kordofan geologic map, groundwater map, land cover, health and education services, soil type, and total-average-annual rainfall. The study was conducted based on in-depth discussions with the West Kordofan authorities and the stakeholders, taking into consideration the characteristics of each city, population, water quality, and existing limitations and drawbacks. The findings were compiled, analyzed and documented.

The detailed topographic survey services required will be outlined as topographic data collection and field survey measurements, the preparation of site plan drawings, profiles, and contouring, as well as the collection of technical information, the establishment of ground control points, hydrology site surveys, water distribution network routes surveys, and preparation of contours, profiles, and cross sections of each site.

Figure 4 illustrates the detailed topographic surveys conducted using the following flowchart, which briefly describes the procedures of the different components of the surveys.

GPS observations were conducted to determine the coordinates of the established ground control points (GCPs) using short-baseline methods at each site. All coordinates were recorded in the WGS84 UTM Coordinate System. Each site had at least two GCPs fixed for reference. These coordinates were subsequently utilized for topographic surveys, cross-section surveys, and alignment surveys.

The results of the topographic surveys included topographic maps, longitudinal and cross sections, contours, and Digital Elevation Models (DEMs). These products provide essential topographic information needed for hydrology, groundwater resources, and distribution networks, and are crucial for feasibility studies and detailed engineering designs.

2.3. Socio-economic Characteristics of West Kordofan

Western Kordofan State lies within the arid and semi-arid climatic zone, further divided into four sub-zones, from north to south: Semi Desert, Dry, Semi-Dry, and Semi-Humid. To ensure successful developments without compromising the sustainability of vital social aspects of the environmental ecosystem, the following issues were given the highest attention in developing the social study and providing geospatial baseline information for assessing the socio-economic infrastructure of the areas under consideration [6, 8, 9]. Based on the results of the Socio-economic Survey, households were interviewed to obtain water from public water supply services. The main objectives of the socio-economic study were to conduct:

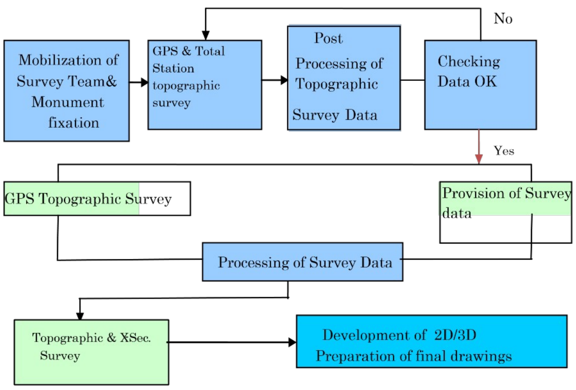

Figure 4: Flow Chart of the Topographic Survey Data Collection

Collection and analysis of considerable geospatial information about physical, biological, socio-economic, and environmental aspects of the study area. Identification, measuring, and assessing the potential environmental impacts.

The geospatial information collected for the study was acquired through qualitative and quantitative methods, creating the baseline of the Environmental and Social Features in West Kordofan State's Physical Environment, including the climate (temperature, wind), rainfall, soil, geology, hydrology, surface, and groundwater. Water supply systems for the 14 headquarters of the localities in West Kordofan State were classified into three groups, based on the potential water sources (groundwater or surface water) [4, 5] and the locations of water sources as follows [9]:

Group 1: Nine towns with groundwater sources located at a distance from the town boundary, namely Al Nuhood, Abu Zabad, El Foula, Babanousa, Muglad, El Deibab, Keilak, Meriam, and El Odayia. For this group, water supply transmission pipelines are required to convey water down to storage tanks for water distribution networks or to water points not exceeding 500m from the furthest household in the town.

Group 2: - Three towns with groundwater aquifers within the town boundaries, namely Ghebeish. Wad Banda and Al Khewai. Water can be supplied directly to the distribution networks or public water points in each town via groundwater storage tanks or elevated water tanks.

Group 3: - Two towns are to be supplied sustainably with surface water, namely Lagawa and El Sonout. An adequate supply of surface water sources was studied for each town, including suitable water treatment plants for treating the surface water.

3. HYDROLOGICAL ANALYSIS

3.1 General

West Kordofan State, particularly its northern region, has suffered significantly from droughts in recent decades. The impacts of drought and climate change are realized in the north and north-western parts of the West Kordofan State. The competition for water resources has increased significantly, and this necessitates the importance of the water resources assessment for the state [4, 10]. Great pressure was exerted on the federal and state governments to seek immediate action. The Government of Sudan must take effective measures to reform the water sector and institutional capacity development programs in all Sudan states. Its primary goal is to support the development of a durable and eco-friendly water and sanitation sector in Sudan that effectively serves all users and beneficiaries, in particular, West Kordofan State to contribute to peace-building, improving livelihoods, and building resilience against climate variability and change, which must align with United Nations initiatives [2] related to the international sustainable development goals (SDG 6 and SDG 13). In this regard, the current study is concerned with the role of geospatial data collection and analysis for conducting successful hydrological investigations and hydraulic designs, and consequently, for the implementation of certain water harvesting projects [2, 10] comprised of Hafeers, dikes, reservoirs, and earth dams.

Additional specific objectives of the geospatial information for surface water resources are to: identify and map hydrological risk areas, in terms of water resources development, variability, and susceptibility to depletion in the face of climate change and utilization;

1. Estimate the annual yields of the main Wadis in West Kordofan state [11].
2. design of earth dams (such as the earth dam near Lagawa town) [10],
3. Design of dikes across upstream branches (such as those entering Al Sunut's existing reservoir, to reduce siltation;
4. Design of Hafeers for water supply transmission line (along the Pipeline route for animal water supply).

3.2 Remote Sensing Images and GIS Data Sources

Satellite images and topographic data were collected and used in this study to obtain the relevant hydrological characteristics, land use [4, 11], and land cover. In particular, the following parameters and information were derived from the satellite image data:

- The required Information about the study area.
- Streamlines of the drainage system (khors and wadis).
- Catchment area of each khor or wadi.
- Contour maps or DEM at potential water harvesting locations.
- Development and processing of satellite imagery and GIS data to be used.

The first step of the hydrological analysis of any catchment area comprises the mapping of the drainage network and its extent. The network through which water travels to the outlet can be visualized as a leaf, with the base of the leaf being the outlet. The outlet is usually the lowest point along the boundary of the drainage basin (Figure 5).

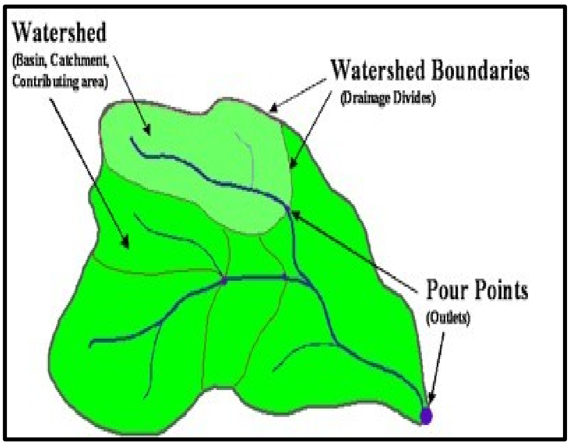

Figure 5: Typical Drainage System

The mapping of the catchment areas and drainage networks for the main Wadis was conducted by using the Digital Elevation Model (DEM) of the area obtained from remote sensing data. Remote sensing data comprised of the Shuttle Radar Topography Mission (SRTM), i.e., the data that has been generated in a joint project between NASA and the United States National Geospatial-Intelligence Agency (NGA) to map the world in three dimensions. Arc GIS hydrologic modeling tool Arc Hydro was used in conjunction with ArcGIS spatial and 3D analysts to derive and produce the drainage basins and network constituting the drainage system of the areas under consideration. The limit of the analysis was iteratively extended until all the catchment and sub-catchment areas associated with the Wadis were identified and delineated [10, 12].

3.3 The Rainfall Frequency Analysis:

The previous experience showed that the quality of the Wadi flow records in Sudan is unreliable. Therefore, hydrological methods have been used to estimate the annual and the maximum daily discharge [10]. The rainfall data were obtained the Sudan Meteorological Authority.

A rainfall frequency analysis was conducted at the Faculty of Engineering, University of Khartoum, for the major Sudanese cities. To choose the suitable frequency distribution for the annual rainfall in the region, the observed relative frequency curves were compared with the theoretical ones for the following probability distributions [13]:

- Normal probability distribution.
- Log-normal probability distribution.
- Extreme value type I distribution.

It was found that the normal probability distribution is suitable for regions; hence, the annual rainfall in the Wadi, X, with a non-exceedance probability is given by:

$$X = U + S \times y \tag{1}$$

Where U = mean annual rainfall; S = Standard deviation of annual rainfall; y = the variate obtained from the normal probability tables.

For the estimation of the Annual Runoff of the Main Wadis, the outcome of the rainfall frequency was used to estimate the annual runoff (V), using the Runoff Coefficient Method:

$$V = C \cdot P \cdot S \times 10^3 \qquad \left(m^3\right) \tag{2}$$

Where: V= total annual volume of runoff; P = total annual depth of rainfall (mm); A= Wadi catchment area (km^2), and C = runoff coefficient.

3.4 Design Considerations for Earth-dams

The following design considerations were adopted:
Crest Width: Usually, the crest width T is given by:

$$T = \frac{H}{3} + 3 \tag{3}$$

Where H is the height in meters. The crest width is recommended to be 5.0 m.

Upstream and downstream side slopes: The upstream side slope is usually 1:3, while the downstream side slope ranges between 1:2 and 1:5. The upstream and downstream slopes should be designed to be stable under the worst conditions of loading. The critical conditions occur for the upstream slope during steady seepage under full reservoirs, and to ensure that the slopes upstream and downstream are gently sloping to allow for an adequate base width at the foundation level. This will help to keep the maximum shear stress within safe limits compared to the shear strength of the soil, aiming for an appropriate factor of safety.

Slope protection: The upstream face should be properly protected against wave action by stone pitching in sand-cement mortar on the entire slope. Dry stone pitching is essential to shield the downstream face from rainfall.
Seepage forces.

A fundamental aspect of the fill embankments that is not always fully appreciated is that they are never intended to stop the seepage of water, but to slow it down. In most cases, the velocity of flow of the seepage through the soil is very slow and is only detectable with instruments. However, it is always present, and many of the important details of embankment construction are necessary to accommodate the forces it builds up. The seepage hydraulic gradient line (i.e., the seepage line slope) through the soil, for compacted clay, is taken as 1(Vertical): 6 (Horizontal).

4. RESULTS AND DISCUSSIONS

4.1 Estimation of Annual Runoff of the main Wadis in West Kordofan State:

The main Wadis have been divided into sub-catchments as shown in Figure 6. The geospatial and remote sensing data were used to determine the sub-catchments. Elevations were based on the local surveying measurements, default open-source data such as ALOS, World3D (AW3D), and DEM readings. Using a normal probability distribution, the annual rainfalls with reliabilities of 70%, 80% and 90% have been calculated [10]. The results are presented in Table 2:

Table 2: Annual Rainfalls with the Different Reliabilities

Station	Average (mm)	STD (mm)	Coeff. Of Var	Rainfall with 90% Reliability	Rainfall with 80% Reliability	Rainfall with 70% Reliability
Kadogli	699	145	0.21	512	576	622
Dilling	612	145	0.24	425	489	535
Khuwei	316	120	0.38	161	214	252
Abu Zabd	423	134	0.32	251	310	352
En Nuhud	372	106	0.29	236	283	316
Al Muglad	501	172	0.34	280	356	410
Al Fula	232	119	0.51	79	132	170
Babanusa	472	123	0.26	315	369	408

Figure 6 shows the drainage system, the isohyetal map of annual rainfall, and the main catchments for West Kordofan State.

The annual rainfalls with the different reliabilities presented in the above table were used to calculate the corresponding annual discharge for the main West Kordofan Wadis, using the Runoff Coefficient Method (eq 2). The results are shown in Table 3.The results shown in Table 3, indicate the high surface water resources potential for the four main catchments of West Kordofan. These potentials can be developed and utilized for the welfare and food security of the people of West Kordofan. Unfortunately, the majority of these surface water resources drain outside the State as a supply for Bahr Al-Arab.

The results shown in Table 3, indicate the high surface water resources potential for the four main catchments of West Kordofan. These potentials can be developed and utilized for the welfare and food security of the people of West Kordofan. Unfortunately, the majority of these surface water resources drain outside the State as a supply for Bahr Al-Arab.

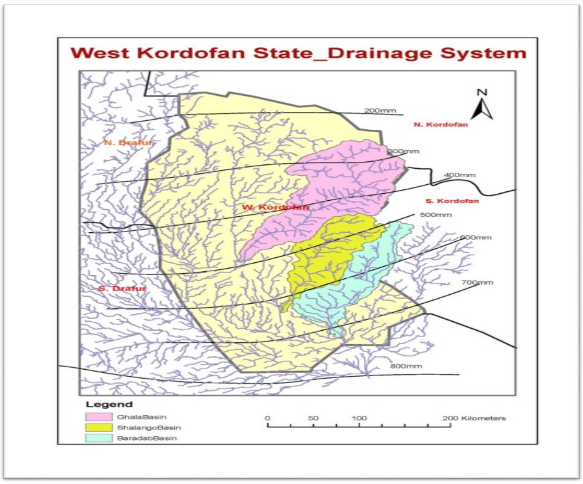

Figure 6: West Kordofan Drainage System

Table 3: Annual Discharge Reliability for Some Wadis

Wadi	Sub-Catchment	Area Km^2	Run-off Coeff. %	Average Yield m^3/y $*10^6$	80 % Yield m^3/y $*10^6$	90 % Yield m^3/y $*10^6$
Ghalla	1	7,000	2	55	45	39
	2	6,422	2	53	44	38
	3	1,570	2	12	10	8
	Total =	14,992		121	98	86
Bardab	1	1,108	3	22	19	17
	2	2,662	3	55	47	43
	Total =	3,770		76	65	60
Shallango	1	4,100	4	93	80	73
	2	3,119	4	78	67	61
	Total =	7,219		172	147	134
Bilal		1,186	4	25	22	19
			Total =14,992	394	332	299

4.2 Water Harvesting for the Major Towns*:*

The following water harvesting projects were proposed as a vital water supply for the following major towns and villages (Figures 7a and 7b):

1. Hafeer for water supply, for Al Sunut;
   Five Hafeers along the Pipeline route for animals' water supply;
2. Hafeer for water supply, for Al-Odayia
3. Lagawa earth dam for water supply, for Lagawa town,
4. Silt-Trap Dikes across upstream branches entering Al Sunnut existing reservoir;

The geospatial and remote sensing data were used to determine the possible locations of the Hafeers. Elevations were also based on the default Open Source, such as ALOS, World3D (AW3D), and DEM data. However, the exact locations of the Hafeers were finalized during dedicated visits for site verification. Figures 7a and 7b, show the locations of the Hafeers and the corresponding catchment areas.

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Wadi	Sub-Catchment	Area Km^2	Run-off Coeff. %	Average Yield m^3/y $*10^6$	80 % Yield m^3/y $*10^6$	90 % Yield m^3/y $*10^6$
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	Total =	7,219		172	147	134
Bilal		1,186	4	25	22	19
			Total =	394	332	299

Three silt-trap dikes were proposed across three major tributaries discharging into the Al-Sunut reservoir to reduce siltation. The technique of silt-trap dikes is used extensively in Algeria and Morocco and has resulted in excellent outcomes. Also, UKCC had constructed several silt-trap dikes across the major tributaries discharging into the Al-Shakhar reservoir [10]. The average height of these silt-trap dikes was one meter, and the average length was 100 m. The geospatial and remote sensing data were used to determine the possible locations of these silt-trap dikes. Figure 8, shows the locations of Silt-trap Dike No 2.

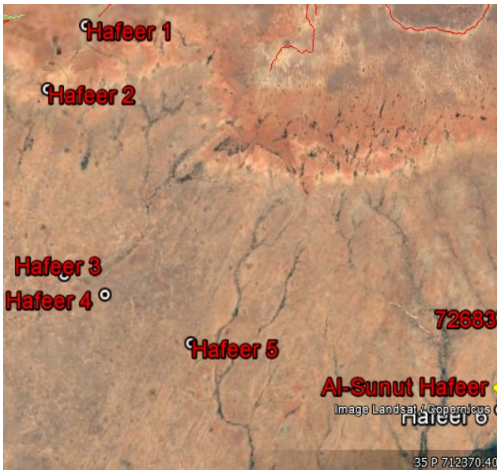

Figure 7a: Locations and Catchment Areas of the Hafeers

4.3 Lagawa Town Earth Dam:

According to the outcome of the groundwater resources study [12, 13, 14], there are no potential aquifers in the region, and the geology of the area is basement complex. Therefore, water harvesting is the only available option for the Lagawa water supply. An earth dam with a spillway and a deep sluice was proposed as an optimum solution. Four reservoir sites and the corresponding contour maps were drawn as shown in Figure 9. Figure 10 shows the stream networks of these four catchments. It should be noted that Catchment 4 is a sub-catchment of Catchment 2.

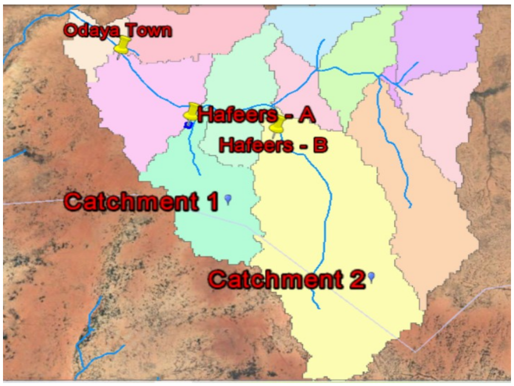

Figure 7b: Locations and Catchment Areas of the Hafeers

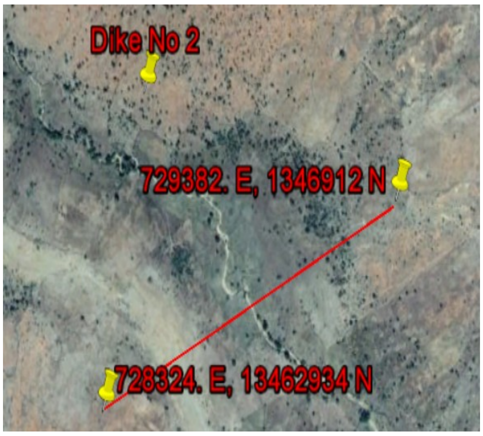

Figure 8: Locations of Silt-trap Dike No 2

Table 4: Characteristics of the Four Reservoirs

Reservoir No.	Min. Elevation (m)	Max. Elevation (m)	Depth (m)	Max. Area (m^2)	Max. Possible Storage (m^3)
1	518	525	7	2,856,380	8,239,000
2	522	535	13	18,151,843	79,109,000
3	536	545	9	3,844,857	13,135,000
4	539	549	10	8,449,336	35,700,000

Note: Elevations are based on the default ALOS World3D (AW3D) DEM readings.

The reservoir surface areas and the longitudinal profiles of the dam axes for the four sites were prepared. These reservoir surface area-elevation curves were used to prepare the reservoir storage-elevation curves for the four sites. Figures 11 and 12 show the reservoir surface area-elevation and the reservoir storage-elevation curves, for site 4, respectively. Figure 13 shows the longitudinal profile of the dam axis for site 4. All the characteristics of the four reservoirs, shown in Table 4, were computed using the geospatial and remote sensing data.

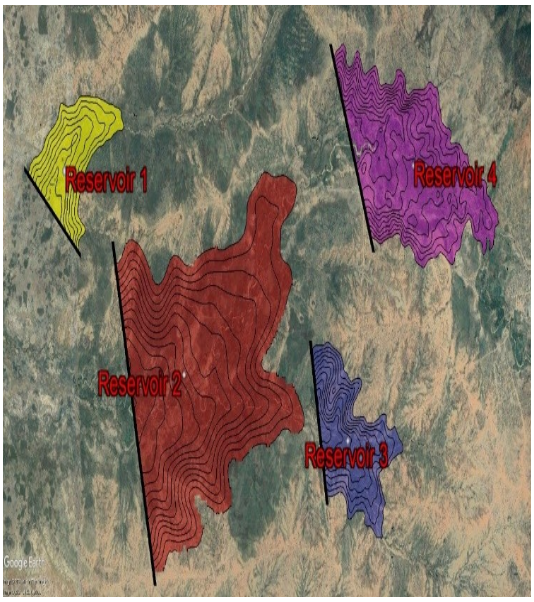

Figure 9: The Proposed Four Reservoir Areas

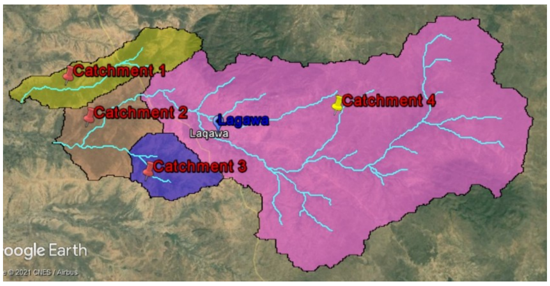

Figure 10: Streams Networks of the Four Catchments

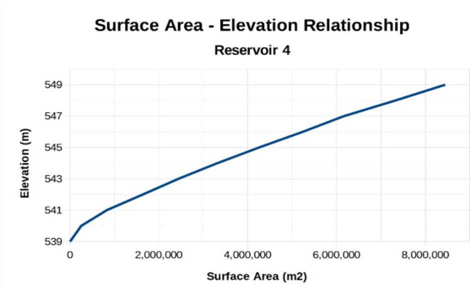

Figure 11: Surface - Elevation Curve for Reservoir No 4

Table 5 shows the annual rainfall, annual runoff, and the corresponding catchment areas for these reservoirs. The annual rainfalls were used to calculate the corresponding annual runoff, with different reliabilities, for the four catchments, using the Runoff Coefficient Method (eq 2).

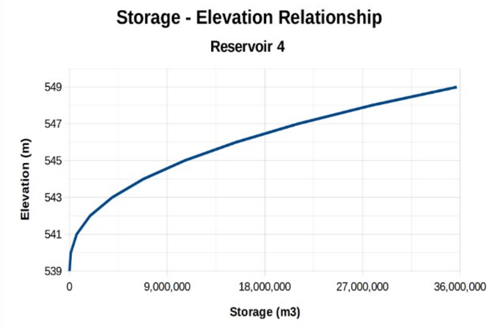

Figure 12: Storage - Elevation Curve for Reservoir No 4

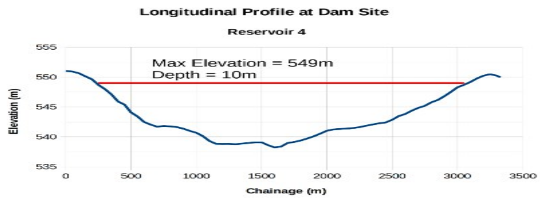

Figure 13: Longitudinal Profile of Dam Ax

Table 5: Annual Runoff for the Four Catchments with the Different Reliabilities

Catc-hment No	Area Km^2	Reliabi lity	Rainfall (mm)			Runoff (10^6) m^3		
			50%	80%	90%	50%	80%	90%
1	36		655	554	501	2.4	2.0	1.8
2	362					23.7	20.0	18.2
3	22					1.4	1.2	1.1
4	305					20.0	17.0	15.0

It is clear that catchments 1 and 3 have small areas and hence small annual runoffs, as shown in Table 5. Accordingly, catchments 1 and 3 were rejected. It was found that Catchment 4, which is a tributary of Wadi Shallango, has the best dam site. Moreover, it is closer to Lagawa, and therefore, Reservoir 4, was adopted. This will result in a shorter pipeline, a smaller pumping head and a lesser construction cost. It had a catchment area of 305 km^2, and an average annual runoff of 20 million m^3. The annual runoff with a reliability 90 is 15 million m^3. In other words, the annual runoff of 15 million m^3, is secured 9 years in every period of 10 years.

Therefore, using the longitudinal profile of the dam axis for site 4 (Figure 11), the computations were carried out for three options of dam heights: namely, 10 m, 9 m, and 8 m. For each dam height, the reservoir storage volume, the embankment volume, and the cost were calculated as shown in Table 6. All the computations were carried out using the geospatial and remote sensing data, which shows its potential use in hydrological investigations.

From the three options mentioned in Table 6, option 2, with a dam height of 9 m, is the optimum choice. Comparing options 2 and 3, the reservoir volume of option

2 is 50% larger than that of option 3, although the corresponding increase in cost is about 19%. Therefore, option 2 was recommended.

Table 6: Reservoir Storage Volumes, Embankment Volumes& Costs

Option	Dam Height (m)	Max Water Depth (m)	Reservoir Volume (m^3)	Embank-ment Volume (m^3)	Reservoir Cost (USD)
1	10	8	21,000,000	711,700	7,190,800
2	9	7	15,000,000	560,000	6,063,600
3	8	6	10,600,000	428,500	5,084,800

5. CONCLUSION

In this study, the paper highlighted the importance of geospatial information in almost all aspects of information required for hydrologic investigations and designs, including the conduction of a rapid assessment of surface water resources, and TotalTotaldevelopment of water resources capacity building, and the identification of hydrological risk areas, variability and susceptibility to depletion in the face of the climate change and utilization; as well as the estimation of the annual yields of the main Wadis in West Kordofan State.

The main activities of the case study were performed to achieve the above goals as specified by using geospatial information for rainfall data, surface water resources potentials, contour, DTM, and satellite imagery. Consequently, a feasibility study for the implementation of water harvesting projects was conducted as a vital surface water supply option for some major towns and villages in West Kordofan. The outcome of the groundwater resources study showed that there are no potential aquifers in some parts of West Kordofan, and the geology of the area is basement complex.

Based on the outcome of this study, the authors call for the development of a unified geospatial information system for hydrology, water resources, water harvesting for agriculture and animal production, and flood risk mapping in Sudan.

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