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Application of GIS Raster Calculator for determining Rain water harvesting Suitable sites In Wadi Soba - Khartoum - Sudan

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Abstract:
The relationship between water security and rainwater harvesting is negotiated as vital for water management system. Recently, the Sudan's water management system adopted new implementation trends, which seek better utilization and suitable conservation. The main aim of this research is to apply raster calculator in the spatial analyst tools for determining the optimal locations for Rain Water Harvesting Reservoir (RWHR). Key criteria for operating the suitability analysis are four spatial thematic maps prepared as dataset (layers), which are, land cover, soils, slope, and settlements (villages). The key spatial layers processed using multi weighted criteria were depicted the suitable location where the reservoir can be constructed. Suitability scale ranges from suitable, moderate and low suitable areas over the catchment area. The capabilities of GIS functions in suitability analysis for RWHR site selection is optimized as far as more multi weighted criteria will have obtained for high optimal level

Keywords: Hydrology, Water harvest, Weighted, Catchment, DEM,

1- Introduction:

One of the vital requirements for life, economic, and social development is water. Water is required by human beings, plants, animals and for ecosystem functions. Adequate water is critical in the development of drinking water supplies, agricultural and industrial activities. Water is one valuable resource that is required for everyday life but is fast depleting The demand of water increases linearly as population and human activities increases. The ever increasing world population is threatened by the ever continuing water shortage problem. According to World Water Council (WWC, 2010), the consumption of renewable water resources has grown six-fold in the 20th century responding to three times increase of the world population. Water harvesting is the collection of runoff for different purposes. Instead of runoff being left to cause erosion, it is harvested and utilized to minimize surface runoff adverse impacts. In the semi-arid drought-prone areas, water harvesting is a directly productive form of soil and water conservation. Both yields and reliability of production can be significantly improved with this method (FAO, 1991).

Rain Water Harvesting (RWH) is usually employed as an umbrella term describing a range of methods of collecting and conserving various forms of runoff water originating from ephemeral water flows produced during tropical rainstorms. In its broadest sense, RWH can be defined as the collection of water for its productive use. WH includes a sample methods used to improve the use of rainwater at a specific site before it leaves a geographical region. (Siegert, 1994)

Climate change has influenced the magnitude and the distribution of the most important driving force of the hydrological cycle, i.e. rainfall, some regions may receive more rainfall while others may become drier (IPCC, 2007). The scope of hydrological applications has broadened dramatically, although the problems of flood protection and water resources management continue to be of importance and relevance for the security of communities and for human, social and economic development

Remote sensing data used techniques provide access to spatial and temporal information on watershed, for water harvesting appropriate sites. New sensors and imaging technologies are increasing the capability of remote sensing to acquire information at a very high spatial and temporal resolutions.

For the selection of suitable (RWH) rain water harvesting reservoirs locations, topography (slope) remains as a limited factor. For instance, steeper slope with shallow soils are favorable for catchment areas (Oweis et al., 2001). On the other hand, the dense the vegetation cover the less is the runoff generation of a rainstorm, consequently vegetation increasing the infiltration capacity. The vegetation cover holds the surface water giving enough time for water to infiltrate through the porous soil; the roots and organic matter increase the porosity.

For the planers and decision makers, water harvesting is crucial in both the process of planning and flood risk assessment. The assessment and identification of the potential surface rainwater harvesting site is aimed at increasing the efficient use of rainfall where it falls and can help to facilitate catchment development planning, implementation and promotion of rainwater harvesting initiatives, as well as monitoring and continual evaluation of land and water resources in interest areas.

2- Previous related studies:

Some of these studies were tackled the issue from the perspective of using spatial technologies such as GIS & RS. **Mbilinyi and Tumbo**, **2013** was Studied the potentiality of the GIS and RS , in RWH. using GIS for modeling RWH. While **Senay and Verdin (2004)** and **Mwenge et al. (2007)** used runoff data acquired from monthly point measurement rainfall data and used the SCS curve number model to generate baseline maps for surface rainwater harvesting potential in South Africa. **Elagib (2010a**) has analyzed the rain days in central Sudan revealing that a few rainstorm events characterize the rainy season; they count for most of the annual magnitude, i.e. high intensity rainfall. An earlier study by **Elagib and Mansell (2000)** referred to research studies during the 90's where heavy and extreme rainfall showed increase in the amount, frequency and intensity. Used GIS based decision support systems for identifying suitable locations for water harvesting.

Oberle (2004) applied the index method to predict the runoff in a watershed in Syria. Data layers for the runoff generation parameters, slope, soil texture, vegetation cover, stoniness and roughness of soil, antecedent soil moisture, and flow length were created. Values of each layer were classified and assigned an index weight according to their importance to runoff generation. Two scenarios were applied for evaluating potential areas for floodwater harvesting: A scenario including all layers; and B scenario where the flow length layer was excluded. **Mati et al. (2006) and Mbilinyi et al. (2006)** used baseline thematic maps such as soil depth and texture, rainfall, topographic maps, limited field surveying and population density to produce composite maps that show attributes that serves as indicators of suitability for location specific rainwater harvesting projects. **Jasrotia et al. (2009)** applied the water balance method introduced by Thornthwaite and Mather (TM) model together with remote sensing and GIS. Long term average monthly rainfall and evapotranspiration, soil and vegetation characteristics were used to find out the periods of moisture deficit and surplus.

(Forzieri et al., 2008). Weerasinghe, Schneider, and Loew (2011) focused on using a geographic information system (GIS) and remote sensing (RS). They developed an integrated methodology for assessing water management. The model accordingly specifies potential water-harvesting and -storage sites for water storage and soil-moisture conservation on farms, **(Weerasinghe et al., 2011)**. Ammar, **Riksen, Ouessar, and Ritsema (2016)** reviewed the methodologies and the main criteria that have been applied in arid and semi-arid regions (ASARs) during the last three decades. They categorized and compared four main methodologies of site selection, identified three main sets of criteria for selecting RWH locations, and identified the main characteristics of the most common RWH techniques used in ASARs. The methods were diverse, ranging from those based only on biophysical criteria to more integrated approaches, including the use of socioeconomic criteria, especially after 2000. Most studies now select RHW sites using GISs in combination with hydrological models and/or multi-criteria analysis (MCA).

3- Topic overview:

Local access to water sources becomes one of the international issue that needs real attention for the benefit of the rural societies. Water service availability (number of sources) and accessibility (distance from sources) are the main directions to be evaluated in water management issues. Less authorized attentions have emerged to act master plan includes actions towards water resource distribution over the study area. With the advanced of the water shortage crisis in the arid and semi-arid areas, the spatial techniques such as GIS and RS have been effectively applied in waster management sectors. GIS provides suitability modeling for solving the problem such as RWH site election. In Sudan still there are crucial gaps that should be filled in the domain of water resource management. A lack of managing water sector properly, created chronic problem within the strips of the River Nile main flow tributaries. There is a great opportunity of seasonal rainfall in Sudan, but the weakness is behind how to utilize and manage the huge millions cubic of waste water.

4- Study area:

Wadi Soba is a part of the Khartoum State, where an average annual rainfall is about 140 mm. The study area (Wadi soba) locates approximately about 42 km east from the central Khartoum city, lies in the western part of the Eastern Nile locality which bounded by longitude (33˚ 14`E) - (33 ˚ 37`E) and latitude (15 ˚ 21`N) - (15 ˚ 48N) Fig. (1). Catchment covers 7586 km² in the semi-arid region of central Sudan. Sharq El-Neel locality considered as a dense populated area, where the population is approximately 956,030 according to 2012 census.

The climate is typically semi-arid with short dry winter season and long dry hot summer season. Rainfall annual average is about 140mm, the maximum rainy months are July, August and September, while the lower rainy months are June and October with one peak rainfall. In hot summer (April to June) the degree of temperature is range between 30 -400c. While in autumn the temperature decreases ranges between15-300c. The lower temperature months are February, December and January when it is lowest trend ranges between 15 -200 c. Though the rain is not precipitated torrentially and unequally distributed over the State; waste water from rain has its meaning in the domain of surface water control.

Fig (1): The location of the study area

5- Methodology:

5.1 Data used:

In this paper, the researchers prepared and generated data that relevant to be analyzed in GIS environment to determine suitable sites for RWH. The study depends on many sources of data to generate the required dataset. Digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) of Earth 30-meter resolution and Landsat- 8 imageries are downloaded from (USGS free down sources) used to generate the land cover. Soil and settlements (villages) were extracted from Sudan base maps shape files. Table (1) presents the data set used and sources of their generation. Data used for this paper are projected to UTM-WGS 1984 Zone 36 N.

Table (1) data set used and sources of their generations.

Data set	Source	Derived data features
DEM(SRTM-30m)	http://SRTM.csi.cgiar.org	DEM(SRTM-30m)
Satellite image	LANDSAT8-(OLI-2018)	Land use/land cover and settlement.
Soil	Sudan data shape files	Soil types
settlements	Sudan data shape files	Villages distribution

5.2. Methods of Analysis:

ArcGIS in its spatial methodological revolution, provides an updating functionalities, a set of spatial analyst tools to guide researchers to perform many processes for solving spatial problems.

Arc Map GIS version10.4 was used to analyze the proper sites for RWHR, based on spatial key criteria.

All analytical processes had been done using spatial analyst extension.

A technique most useful for this study is Multi Weighted Criteria. This method depends on the combination of the information from various criteria to conclude final individual evaluation.

Weight sum tool in the raster calculator was assigned to give the data set used their relative importance to be contained for the rainfall suitability sites.

Layers' classes had been organized and matched according to the importance of the class within a category.

Weight overlay was used to determine the importance of the criteria and prepare for the final suitability map. Table (2) presents the dataset used and weight estimated for each of the three layers.

Table (2) Criteria Weighting suitability

Criteria	Weight%	Description
Slope	30	Avoiding steep slope
Soil	40	Avoiding sandy soils
Settlement	30	Preferring the closet source
total	**100**	

Raster calculator is used to process the final suitability map by multiplying the weighted output file by the reclassified land cover layer to get by the final suitability sites.

5.3 Data set pre-processed:

Data were generated from different sources and clipped to fit the study area. Buffer analysis was used for villages that represent rural settlement and then converted to raster format. The pre-processed steps, prepared the layers to be reclassified using spatial analyst tool box. The distance needs from villages is an important factor for population to be as close as the other criteria allow for that. Geographically, the villages in the study area have dispersal distributional pattern that may cause some sort of complexity in finding maximum centroid sites to meet all the villages demand equally.

5.4 Criteria explanations:

The potentiality of the GIS technology emerged in managing the rainfall in an economical perspective to be relevant in SDSS Spatial Decision Support system framework. Water harvesting factors and criteria used are; slope, (topography), soil, settlement (villages) and land cover and. Dataset criteria in their different phases have been organized in a layout frames presented in their places as required. Fig (2) presents the main layers generated for the analysis.

1. Topography:

The variation of topography in the study area is not large, it is a low-lying and flat area with a slightly variation in slope which is decrease gradually from the east to west in the Blue Nile direction.

2. Slope density classes:

The main source for generating slope raster data is the Shuttle Radar Topography Mission (SRTM). Slope is one of the important factors for water harvesting site and systems selection (Critchley and Siegert, 1991). The Standard slope is accepted from 0.1 to 5 degrees according to (FAO, 1994). The slope investigation for the study area proves the flat topography of the area, as the slope classification histogram shows that the 80% of the Wadi watershed area fall within the nearly gentle to flat sloping classes. Areas with low slope values are classified as suitable because high slope values generate the problem of washing.

3. Soil Type:

The soil of the study area is distributed within three soil classes that vary between plains formed on the Nubian Sandstone, plains formed on the Basement Complex, Wadis alluvial the recent and old deposits of the Blue Nile and the Nile classes. It is found that the soil texture in the study area is of clay loam, sandy clay loam, and sandy loam.

4. Settlements (villages):

Water source is one of the most important public service in urban and suburban areas. The geographic distribution of the water sources mainly in limited source areas, is of high priority in water resource management agenda. So, easy access to water sources indicates some improvements in fetching water without burden from ideal distances. In this paper, villages data are used and distance for accessibility is assigned for the layer's 3 classes. The minimum distance from the village is the suitable and has a value 3, while value 1 indicates least suitable. Also, in a relationship between distance from water sources and population settlement, cost- effectiveness is considered mainly in rural areas.

5. Land cover:

Land cover includes man made features are essential factors that directly affect surface the runoff process. Relationship between land cover/land use and the runoff generated at a particular known area after any rainfall event has occurred. According to the Land Use Map of Khartoum State (2000), the vegetation cover is limited to the range land natural vegetation, which is mainly Acacia and desert Scrub. 95% of the study area is of poor vegetation cover with exception to the Wadi courses, where the cover is relatively denser; it represents 5% of the Wadis watershed. There are two type of land cover in the study area the majority is natural vegetation cove and the second is agriculture. Land cover layer is used in the final analysis to be multiplied by the weighted output layer to produce the final suitability map.

6- Results and discussion:

Suitability analysis techniques can optimize results and help to promote the qualities of the scientific research by improving the methodologies and approaches can be used. Rain water harvesting site selection becomes one of the recurrent studies using GIS spatial techniques. In this core section, the analysis requirements are organized in a sequential manner including dataset pre-processing, reclassifying data set, weight analytical function, raster calculator analytical function and viewing and final analysis suitability map. Criteria used in this paper are the minimum in number to be used. Many other ways with various number of criteria were applied in studying RWH by different disciplines. The maximum ideal data set for practicing suitability analysis is still remains to a limiting factor for reaching the desire data set.

6-1 Reclassify Dataset:

The four data set criteria were reclassified as each criterion reorganized on a scale of 1 to 3. The most suitable for the for water harvesting site is closer to 3, while 1 being least suitable. More or less, this scale used by the researchers may altered by others for the same purpose. Table (3) represents the layers' classes and their importance values that meet the suitability criteria within the class preferences. The distance is reclosed on scale of 1 to 3, with the closer being most access; therefore, they are considered of high favorability has the value 3. On the other hand, as the distance getting far away, it has value 1 (less value in scale). In reclassification set up dialog box, we change equal interval as reclassification method for the reclassified layers.

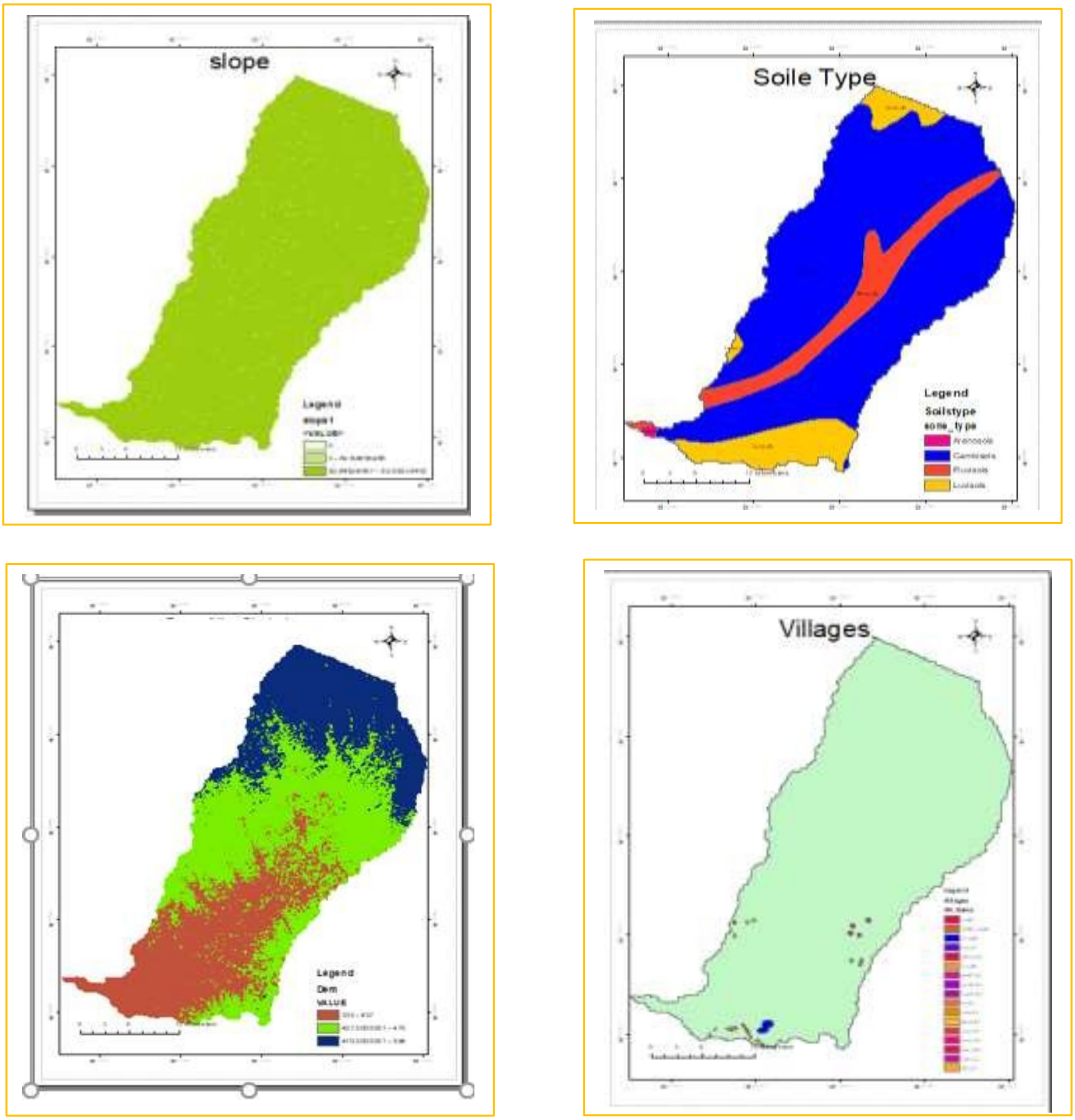

Fig (2): The main dataset criteria used

Table (3): Layers classes scale of importance

Layers	Classes	Rank	suitability
slope	1	3	High suitable
	3	2	Moderate
	89	1	Low suitable
soil	Luvisols	3	High suitable
	Cambisols	2	Moderate
	Fluvisols	1	Low suitable
settlement	300	3	High suitable
	400	2	Moderate
	500	1	Low suitable

6-2 Weight overlay analysis:

Relative importance weight of each criterion is basic step for suitability preferences, since each factor has a varying importance. Decisions made on multi criteria analysis is based on relative importance weight of each criterion. Several methods are available for the determination of these weights. In this study (Weighted overlay) is used in the model sequential procedures to finalize suitable area of RWH reservoir. Fig (4) presents the model built for determining the suitability based on the weights given to each criterion. Reclassified layers are the main inputs for the model processes. For this study 4 Criteria were prepared as spatial data used in analyzing the suitability of RWHR in the study area. Based on the role of weightage analysis that the criteria shouldn't be equally in their importance for suitability analysis, table (2) shows the varying weights percentages of the criteria used that depends on the criterion's importance in location of RWHR.

6.3 Raster Calculator analysis:

GIS provide good combine functionality that help in creating the suitability based on the interpretation of the criteria generated. Raster calculator tool applies in spatial analysis for combining multi weighted criteria in a single analysis to solve site selection problems. All parameters were integrated and sequentially processed to finalize the suitability map for site RWHR.

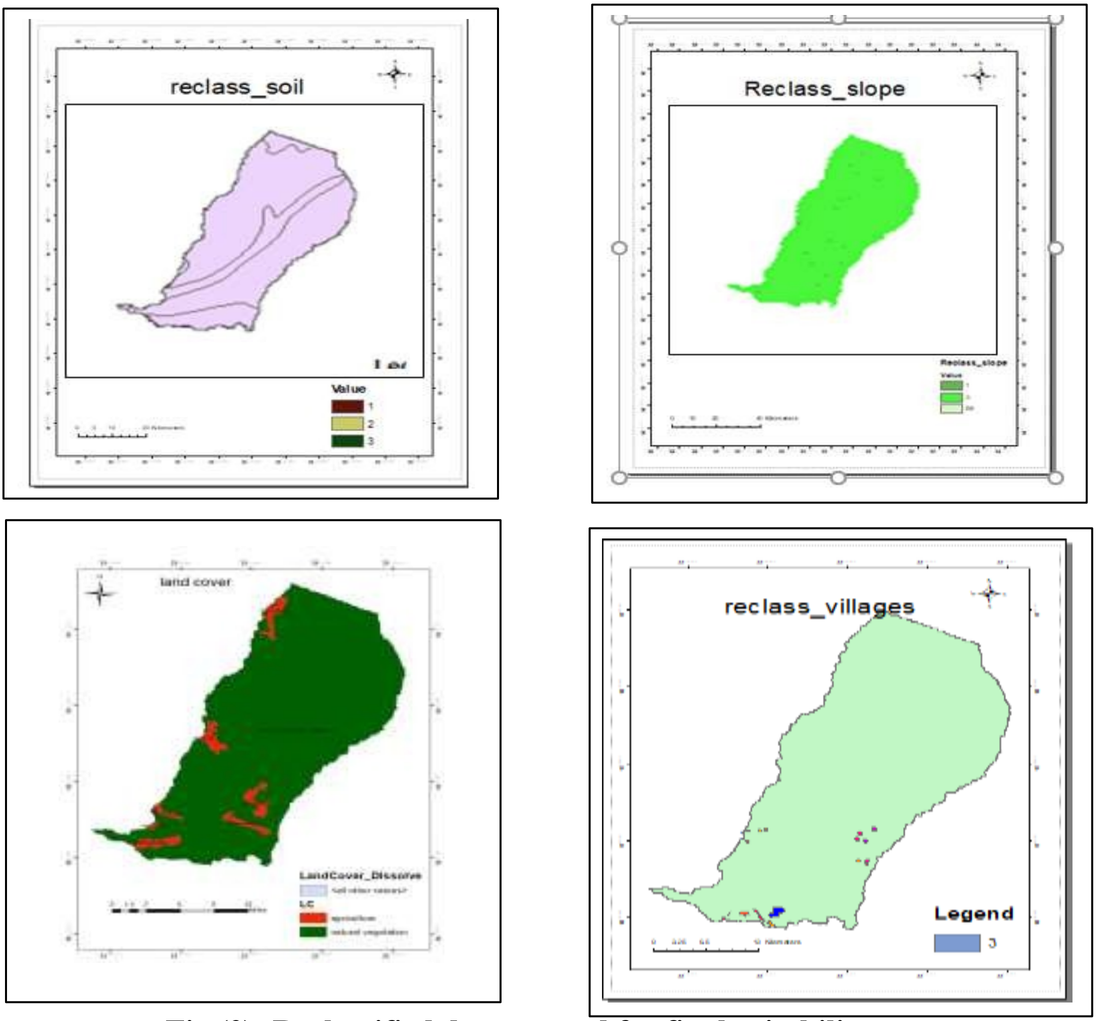

Fig (3): Reclassified dataset used for final suitability

6-4 Final suitability analysis:

The aim of this paper is to apply suitability analysis methods using criteria summation to determine an appropriate site for RWH for domestic purposes in one of the Khartoum suburb catchment. The main criteria used to maintain the optimal site should be close to settlements (villages), should be on flat slope to avoid the impacts of the steep slope and should be in fluvial or clay loamy soils. By setting the criteria' weightages, we agree that how criteria have different importance weights that given a specific indicator for final suitability map. Fig. (4) illustrates Suitability Sites for RWH Suitability Sites which most concentrated in central and Sothern east part within the catchment of the Wadi.

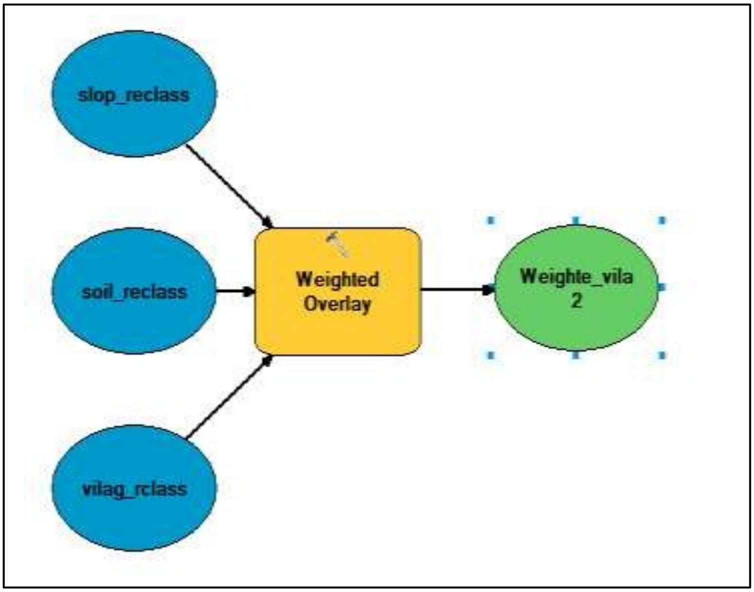

Fig (4): The process of weight overlay using Model Builder

As far as settlements criterion is concerned in suitability analysis, the least suitable sites are those away from the villages. So, water resources closet to settlements satisfy the objective of construction reservoirs for domestic purposes.

The researchers used 3 colors to visualize suitability rationing as presented in final map. Green color indicates the suitable areas, while red color used for least suitable areas.

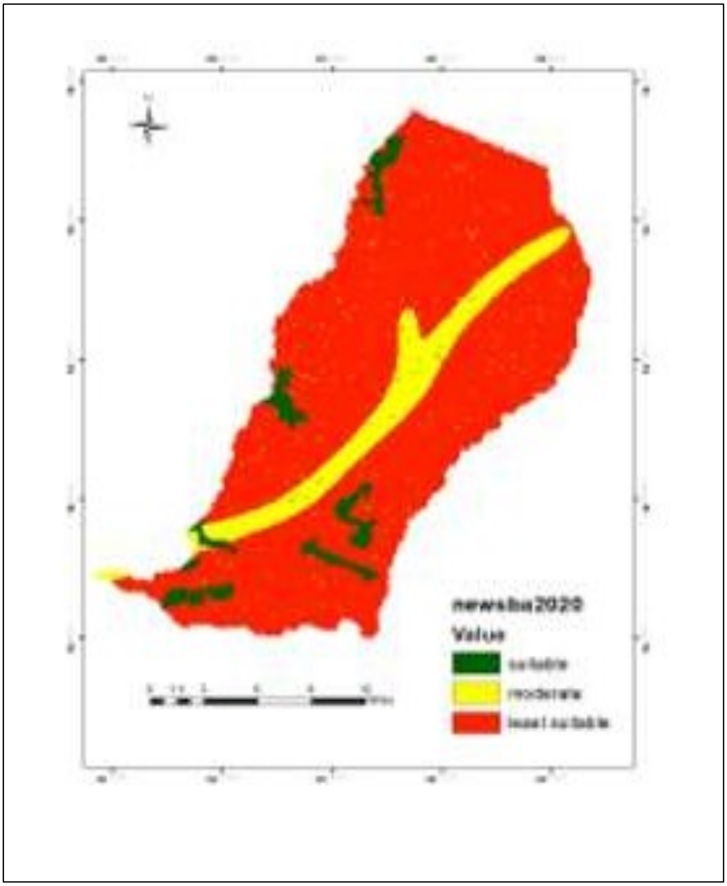

Fig. (4): RWH Final Suitability Map

7- Conclusion:

This paper is based GIS spatial analyst tools and dataset available about Khartoum State. For analysis these paper used a raster calculator tool in GIS to combine spatial key factors for locating RWH reservoirs. Multi criteria of land cover/ land cover, slope, soils and resettlements were analyzed. Then image of land suitability is mapped and spatial classes of suitable, moderate suitable and low suitable were assigned.

The main methodologies used in this paper were potential, effective and high applied to study RWH system. The spatial analysis involved determining the GIS potential applications of the modeling using factors that widely accepted such as physical and human characteristics. The three main factors (criteria) of varying importance are used to determine the suitable sites. Based on these multi weighted criteria, we can perform suitability analysis.

The responsibility of locating public service is a multi-contributor includes governors, academicians, planners and stakeholders. Different views should be formulated in one single statement that operated by GIS specialist for optimal decision. Unlike other public facilities, RWH service needs more natural and climatic investigations. The result opens the research gate for the coming more works of multi criteria that given the wide view in modeling RWH system. Many other criteria and tools will enable researchers to validate the RWH on DSS (Decision Support System) to show more reliability and optimal recommendations. In advance way, coming research should add more criteria and use MCE in fall functionalities (in term of spatial processes) that enhanced the model of RWH system. Also result should analyzed including other DSS software for RWH and to integrate the results of suitability sites with the natural water management policies. Here we can say that an appropriate done will be realized with the use of the GIS model.

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تطبيق تقنيات الدمج (Raster Calculator) لتحديد مواقع حصاد المياه الملائمة في وادي سوبا - الخرطوم - السودان

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ملخص البحث:

تعتبر العلاقة بين الأمن المائي وحصاد مياه الأمطار أمرًا حيوياً لنظام إدارة المياه في السودان. قبل عشررين عاماً ، تبنت هيئة إدارة المياه في السودان اتجاهات تنفيذية جديدة، تسرعى إلى اسرتخدام أفلرل طررر تريريدية فعالة لمياه الأمطار. الهدف الرئيسي من هرذا البحرث هرو تطبيرق أداة الردمج (Raster Calculator) ضرمن أدوات المحلل المكاني في بيئة نظم المعلومات الجغرافية، لتحديرد المواقرع المثلرى لخر ن وتجميرع ميراه الأمطرار (RWHR). بنيت المعايير الرئيسة لمعالجة حلليل الملاممة على الطبقات الأربرع الر تمرل مجموعرة بيانرات ا اوصرول علي را من مصادر بيانات مختلفة، وهي الغطام النباتي والتربرة والإنحردار والاسرتيطان (القرر(). تمرت معالجرة طبقرات مجموعرة البيانرات المكانيرة الرئيسرة باسرتخدام مجموعرة المعرايير المتعرردة الموزونرة. وقرد وترفت النترائج الموقرع المناسب لإمكانيرة إنشرام ار ان لتعميرع ميراه الأمطرار. يرتراو, مقيرا, الملائمرة مرن منراطق مناسربة ومتوسرطة ومنخفلة الملائمة داال منطقة المستعمع المائي. يتم تعيين مناطق الملائمة (اللون الألر) في الجر م الأوسر£ والجنوب الشرقي ضرمن حردود الروادي. يمكرن حلسرين إمكانيرات وطرائ نظرم المعلومرات الجغرافيرة في حلليرل الملائمة لاتيار موقع RWHR بقدر ما تتوفر المر يد من المعايير القياسية لتحقيق أفلل النتائج.

الكلمات المفتاحية: المعايير - حصاد المياه - الموزون - المستعمع - نموذج التلر,