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Geospatial Hydrological Analysis in GIS Environment for Selecting Potential Water Harvest Sites: The case of Badrah –Wasit

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Abstract

In this study, GIS technique and remote sensing data have been integrated to create a suitability map for the probable sites of water harvesting in Badrah-Wasit, Eastern Iraq. Hydrological analysis used to find the potential water-harvesting sites, as well as to improve the water resource management. In this research, five criteria have been used, which is a stream order, slope, distance to roads, rainfall and Normalized Difference Vegetation Index. These thematic layers were evaluated with the multi-criteria analysis method, then combine and process together using weighted overlay method, then assigned suitable weights and integrated into a GIS to generate a suitability map. As a result, the region has been classified into three zones: high suitability zone (2%), moderate suitability zone (27%), and low suitability zone (35%) depending on the specific criteria used for this purpose and have high potential in terms of their suitability for water harvesting.

Keywords: GIS, Weighted overlay, Water-harvesting, Flow discharge and Watershed.

الخلاصة

في هذه الدراسة، تم دمج تقنية نظم المعلومات الجغرافية وبيانات الاستشعار عن بعد في هذه الدراسة لإنتاج خرائط للمواقع المحتملة لجمع المياه في بدرة –واسط، شرق العراق. وتستخدم هذه الطريقة لتحديد مواقع مناسبة لتجمع المياه وكذلك لتحسين إدارة الموارد المائية. تم استخدام خمسة معايير في هذا البحث لتحديد مواقع تجميع المياه وهي: الرتب النهرية، الانحدار، المسافة إلى الطرق، الهاطل المطري ومؤشر الغطاء النباتي. تم تقييم هذه الطبقات الموضوعية باستخدام طريقة تحليل القرار متعدد المعايير ثم دمجها ومعالجتها معا باستخدام طريقة التراكب المرجح، ثم تم تعيين أوزان مناسبة ومتكاملة في نظام المعلومات الجغرافية لتوليد خريطة ملائمة. ونتيجة لذلك، تم تصنيف المنطقة إلى ثالث مناطق: منطقة ذات ملائمة عالية بمساحة 2٪، ومنطقة ذات ملائمة متوسطة (27٪) ومنطقة ذات ملائمة منخفضة (35٪) وفقا للمعايير المحددة التي استخدمت لهذا الغرض.

الكلمات المفتاحية: نظم المعلومات الجغرافية، دمج الطبقات، حصاد المياه، تصريف الجريان وحوض المياه.

1. Introduction

Water, a precious resource on earth, forms the foundation of life and plays a vital economic and social role. However, its circulation varies with space and time. Water is one of the essentials of the life continuity on Earth (Sanctuary and Tropp, 2005). However, it is estimated that (33 %) of the developing world will face water shortages in the twenty-first century (Keller *et.al.,* 2000). Moreover, the current water scarcity associated with population growth may increase due to climate change and lack of rainfall, which reduce the agricultural product and have a significant impact on the livelihood, especially farmers (Misra, 2014). Iraq suffers from limited precipitation and the poor water management for agricultural use. Water harvesting technique defines as collect excess runoff water during the rainy season and stores it for agricultural purposes during dry spells (ETW, 2010). To treat the drought problem, the water-harvesting approach must be adopted in order to enhance the water management systems. Water harvesting significantly improves agricultural productivity by directing surface water during the filtration process to plants. Geographical Information Systems (GIS) techniques consider being the most important way to locate the water-harvesting sites and allows the researchers to identify the appropriate location using remote sensing data. GIS is used to assist decision-makers in their decision to study water harvesting (Al-Ardeeni and Robinson, 2013). In addition, that consider being an effective useful tool when it combine with geo-spatial data (Shirke *et.al.,* 2010). In addition, GIS could be used for processing and analyzed the driven data from Digital elevation model (DEM). The advanced GIS technology and the availability of DEM have greatly extended these applications in hydrologic modeling and water resources investigations (Moore *et.al.*, 1991). Many studies have been conducted to extract drainage networks, for examples (Planchon and Darboux, 2002; Jana *et.al.*, 2007; Wang and Yin, 1998). DEM have been used in watershed delineation and determine stream orders then to detect the most probable sites for the collection of water. As well as, to locate the basin, which gives the basic information for Run-off analysis (Mandlburger *et.al.*, 2009). For each cell, run-off could be determine by watershed parameters (flow direction, flow accumulation and drainage network) which derived from DEM (Turcotte *et.al.*, 2001).

This research is significant because identifying water-harvesting sites on Badrah - Wasit will help to enhance the water management, that lead to improve the environment.

2. Methodology

2.1 Study Area

The study area includes the Badrah basin in Wasit province, east of Iraq, which located between latitudes (32° 30' - 33° 30' N) and longitudes (45° 30' - 46° 15' E) and covers an area of about 2850 km^2 (Fig. 1). The area is differentiated by topography, with the highest altitude reaching 962 meters above mean sea level in the northeast of the region, while the lowest elevation is about 6 meters above mean sea level in the southern parts of the region (DEM Value).

2.2 Location and Geological Description

Many geological formations are revealed in the region, with ages ranging from Lower Miocene to Holocene, start from Euphrates, Fatha, Injana, Mukdadiya Formations, as well as Quaternary depositions sequentially from the oldest to the youngest (Ali and Ali, 2014). Where the most recent can be seen along the northeastern border of the basin, while the Quaternary deposits cover all the central and southern parts of the basin (Hassan *et.al.*, 1977). Quaternary depositions include the alluvium deposits, which represents a mixture of conglomerates, gravel, sand, silt and clay, in addition to the Post-Pliocene deposits, (Hamza *et.al.*, 1989).

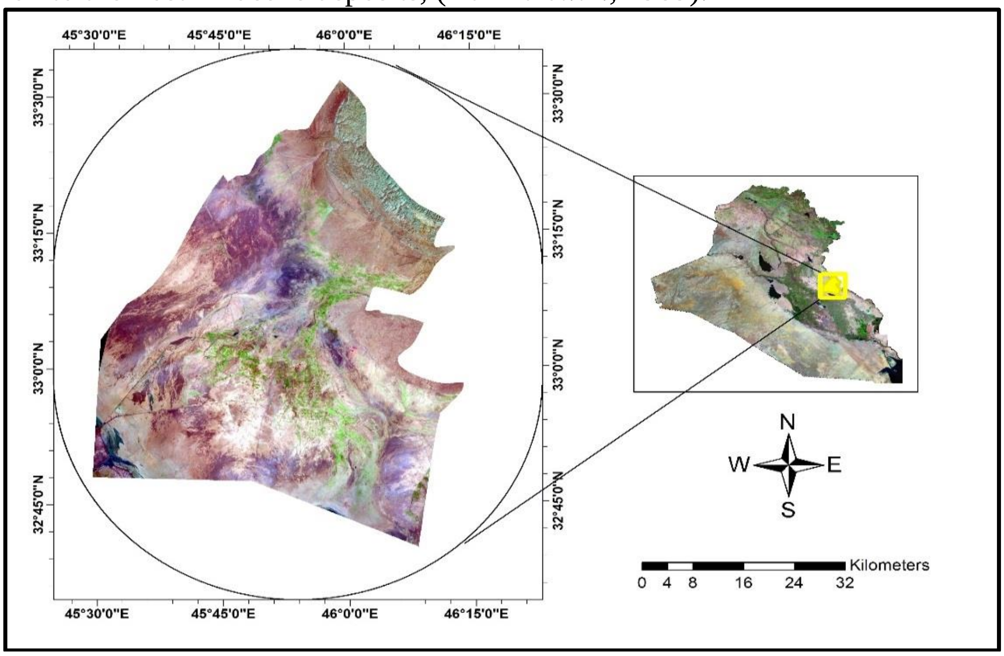

Figure 1: Study area location (Landsat 8 Image).

2.3 Dataset

Among advanced data collection technologies, the satellite has emerged as an effective tool for monitoring and assessment remote areas. In this study, satellite images, DEM and climate data was collected and analyzed in GIS. The hydrological analysis was performed using DEM and hydrology tools. ArcGIS version 10.5 used to analyse the Landsat 8 image, DEM, Road layer (Fig. 2) and Rainfall data (Table 1).

Table 1. The dataset details.

Data	Resolution	Date
Landsat 8 Image	30 m	2017 may
DEM STRM V3	30 m	2015
Roads (Land use map)	Shapefile (Scale 1cm=5 Km)	2017
Climate Data	Rainfall	2015- 2017

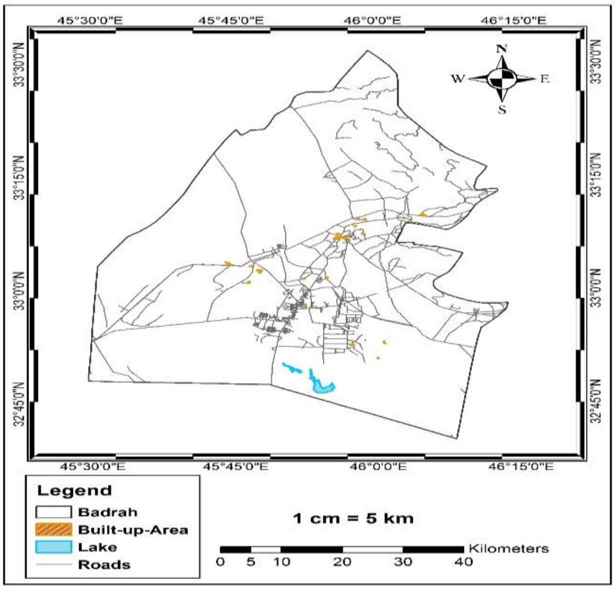

Figure 2: Land use Map

2.4 Weighted overlay model

Based on the literature on identifying suitable water harvesting sites, thematic layers have been selected using the available data. In this study, five criteria have been used to product the suitability map, which is stream order, slope, rainfall, NDVI and roads. The Universal Transverse Mercator (UTM) have been used to rectify and geo-reference these layers. Table 2 shows the thematic layers and criteria. After the preparing all the thematic layers, All these layers have been standardized in uniform scale ranging between 0 to 1 using membership function in ArcGIS, where zero is the least suitable while 1 is the best. Two types of sigmoidal linear membership used which is linear increase or linear decrease according to the highly important and lower important values.

Table 2: The criteria used to standardize the layers.

Layers	Criteria	Standardize
Rainfall	> 250 mm	Maximize
Stream	> 3^{rd} Ord.	Maximize
NDVI	More than 0.1	Maximize
Roads	Distance more than 100 meter	Minimize
Slope	Less than five percentage	Minimize

2.4.1 DEM

The DEM (Fig. 3) used to generate watershed and stream order illustrated (Fig. 4) in the major steps:

a) The depressions fill

Because of the existing noise in sensors, DEM data could generate depressed cells when extracted watershed parameter from the dataset. Depressed cells can be defined as the cells that have elevations lower than the neighboring cells (Jenson and Domingue, 1988).

b) Flow direction

The filling process must identify flow direction. One of the simplest methods to identify the flow directions is to specify the flow from each cell to any one of its eight surrounding cell (Martz and Garbrecht, 1993; Tarboton, 1989).

c) Flow accumulation

In the flow accumulation process, each cell assigned to value that equal to the number of cells that flow into it (O'Callaghan and Mark, 1984).

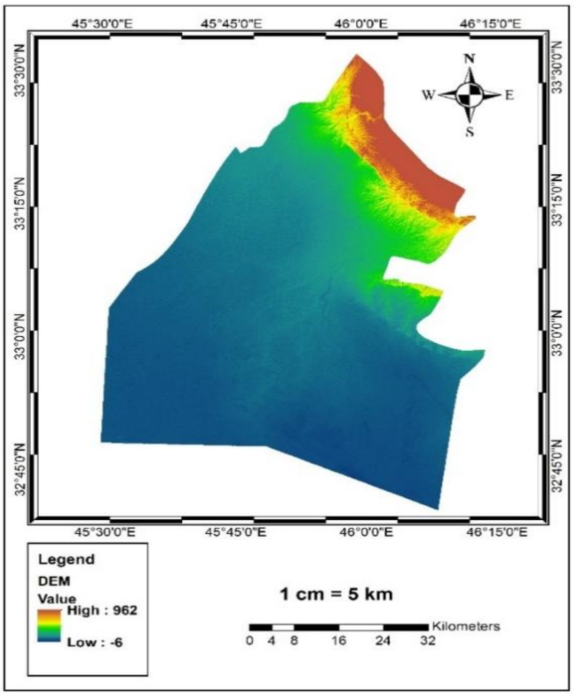

Figure 3: DEM of the Study Area.

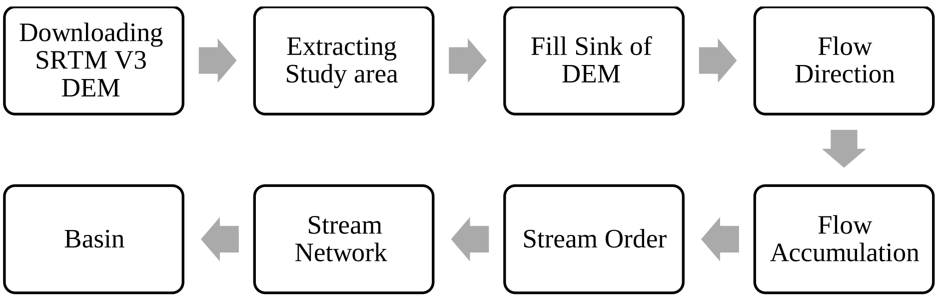

Figure 4: DEM processing flowchart.

2.4.2 Rainfall

This study was based on the monthly average rainfall for the last three years (2015, 2016, and 2017). The data were obtained from the website of European Drought Observatory (EDO), another data collected from Badrah Station and its adjacent stations as an Excel file to use for drawing the map of the rainfall. The Rainfall value varying between 250-447 mm. in order to standardize rainfall map, the criteria of rainfall must be more than 250 mm and the linear increasing equation have been used (Fig. 5).

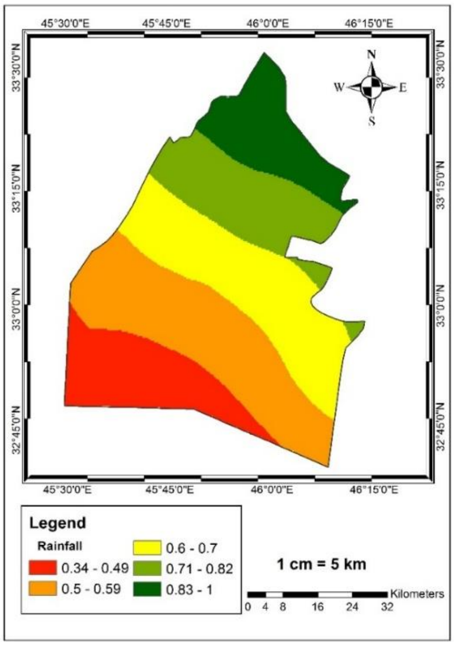

Figure 5: Standardize rainfall layer.

2.4.3 Roads

The Euclidean distance formula used to measure the distance between two points in the plane with coordinates (x, y). Road layer were input as polyline shapefile, then using Euclidean distance function, the road distance layer have been produced, the distance from roads varying between 0-13000 m, the criteria of the road must be more than 120 m. to standardize this layer, and linear decreasing equation were used (Fig. 6).

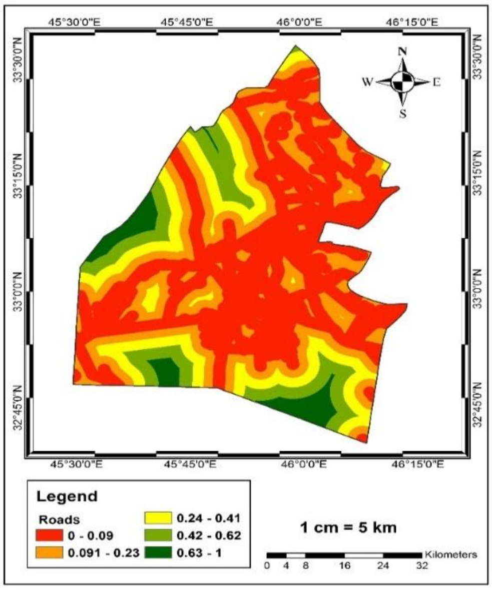

Figure 6: Standardize Euclidean road distance layer.

2.4.4 Slope

The slope map produces using slope tools based on DEM using Arc Map .The slope value was varying between 0-56 percent. In order to standardize the slope map the criteria of the slope must be less than 5 percentage. The linear decreasing equation were used (Fig.7).

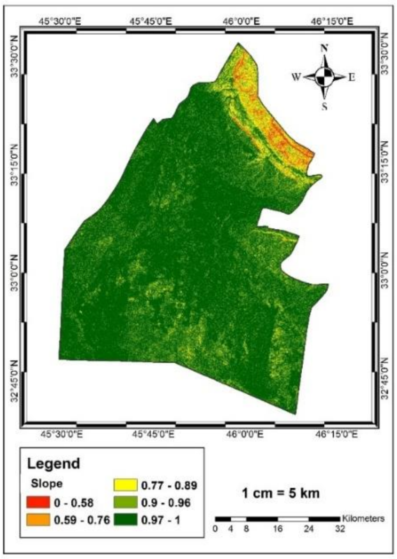

Figure 7: Standardize slope layer.

2.4.5 Stream Order

The procedure to generated stream order based on DEM was described in figure 4.The results stream order varying between 1-10, the proposed criteria of stream order must be greater than third order. To standardize stream order layer, a linear increasing equation was used (Fig.8).

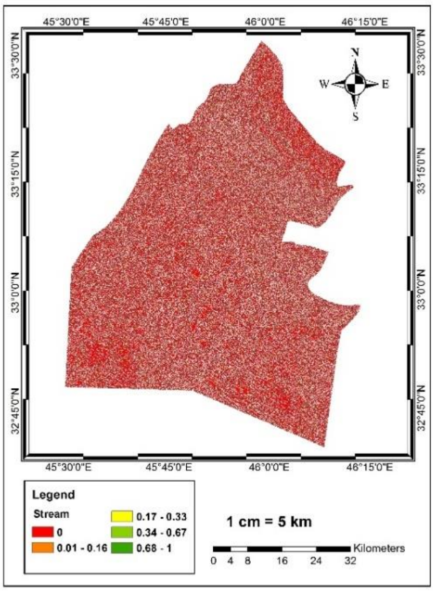

Figure 8: Standardize streams order layer.

2.4.6 NDVI

NDVI is a standardized vegetation index that calculated using Red band and Near Infrared band (NIR) using raster calculator in Arc GIS by applying the equation (Lillesand *et.al.,* 2014):

NDVI= (NIR-Red)/ (NIR + Red) …. (1)

NDVI calculated from Landsat 8 (Operational Land Imager OLI) image obtained from USGS with a spatial resolution of 30 meters. The obtained NDVI value ranging from -1 to 0.8. The linear increasing equation were used to standardize NDVI layer, in which the criteria of NDVI must be greater than Zero (Fig. 9).

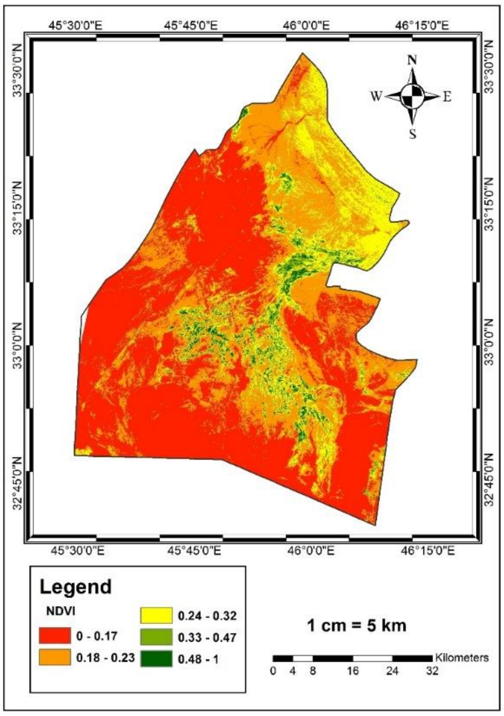

Figure 9: NDVI standardize layer.

3. Results and discussion

In this study, the data showed variation in the elevation of the study area; to determine the flow direction based on DEM iterative process of the cell were conducted. The Flow Direction tool is an integer raster whose values range from 1 to 255, this tool based on D8 approach which commonly referred to as an eight-direction flow model (Jenson and Domingue, 1988).The flow direction determined by using the D8 model, in this approach the stream flow would flow in the eight directions. Then, pour point is identified using flow accumulation layer in the contributing watershed. The point defined as the lowest elevation value on the watersheds. The basin of the study area was delineated using the pour point by computing the flow direction and using it in the watershed function (Figure 10). Finally, after identifying the stream order; all the produced thematic layers were combined using weights overlay method from the literature to produce the potential suitability map. As a result, the study area divided to three classes: good, medium and bad. The final suitability map of identifying potential water harvest sites illustrated in Figure 11.

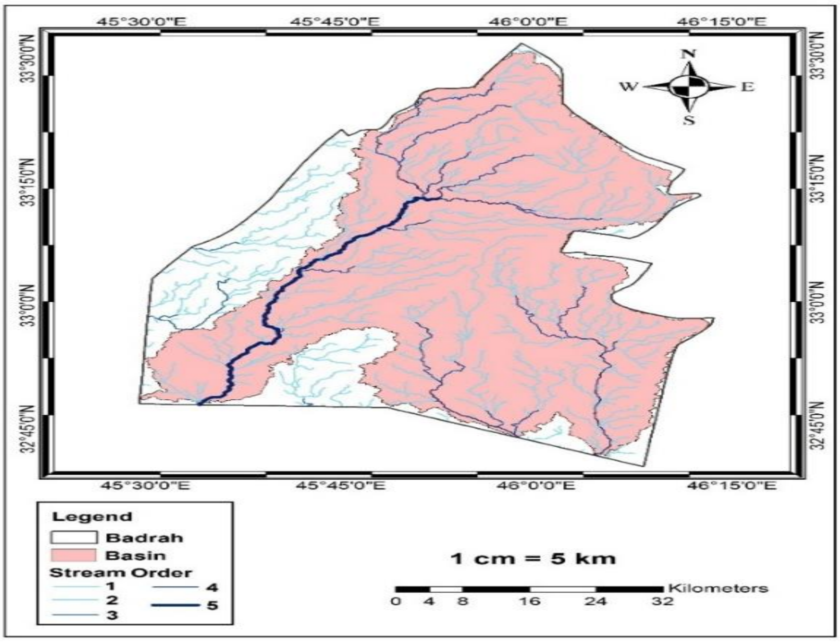

Figure 10: Watershed and steams order.

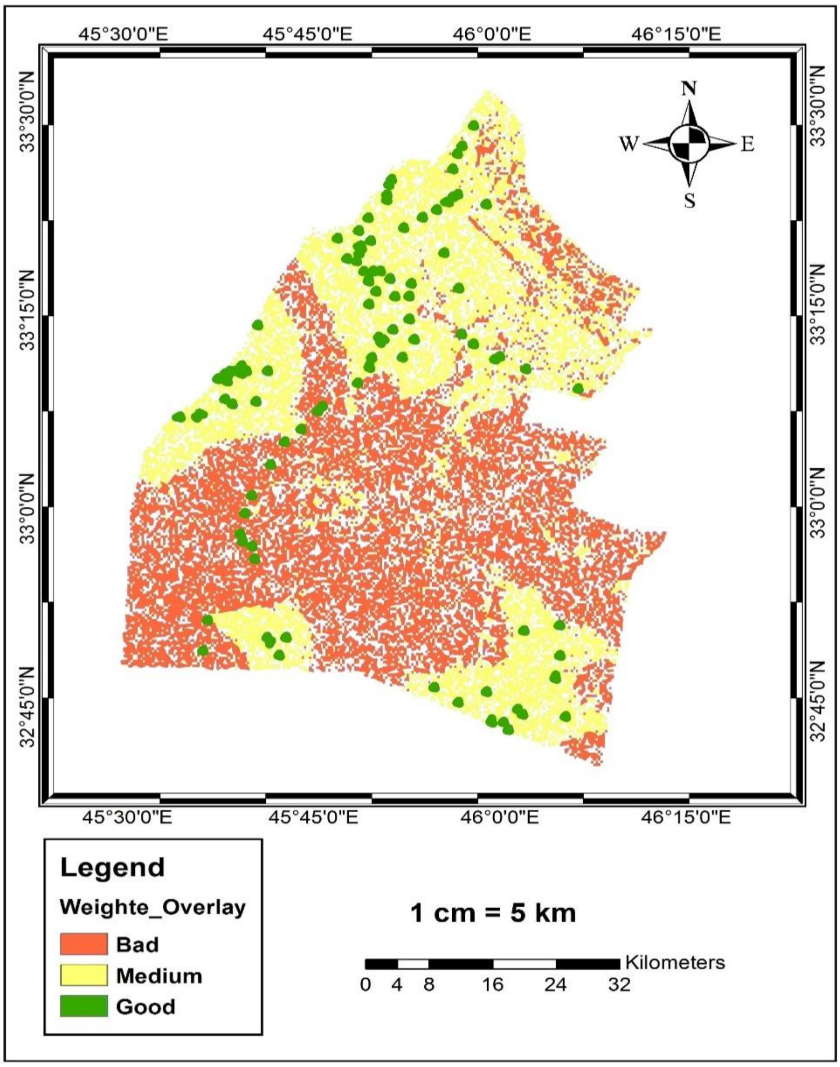

Figure 11: Final suitability map.

4. Conclusion

Iraq suffers from limited precipitation and the poor water management for agricultural use. To treat the drought problem, the water-harvesting approach must be adopted in order to enhance the water management systems where the water harvesting technique significantly improves agricultural productivity by directing surface water during the filtration process to plants. GIS is used to assist decision-makers in their decision to study water harvesting. The integrated remote sensing data, GIS, and multi-criteria analysis techniques were found to be a cost-effective and environmentally friendly way to recover rainwater and select suitable water-harvesting sites. The results of this research are the preparation of a water harvesting suitability map in Badrah / Wasit / Eastern Iraq. This will provide an opportunity to build dams to store water in drought areas. The study area can be classified into three potential zones: high suitability zone (2% or 7.9 $km2$), moderate suitability zone (27 % or 1054.1 $km2$), and low suitability zone (35 % or 1349.5 $km2$). These zones have been selected according to the proposed criteria that's used which have high potential for water collection.

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