# Selecting Potential Water Harvest Sites Using GIS and Remote Sensing In Al-Tharthar Valley, West Nineveh, Iraq.

**Mahmood A. H. Al-Ardeeni**
*Faculty of Science and Engineering , Department of Spatial Sciences, Curtin University*
**Email: gism197@yahoo.com**

## Abstract
The main justification of this research is that integrate of GIS technique and RS data to generate maps for selecting the most potential sites of water harvesting in study area. This method helps to detect water harvesting sites in suitable places and improve the water resource management in the study area. The methodology was adopted in this study is using Fuzzy logic Modelling to standardise the layers and Fuzzy overlay method to combine and process these layers together. Specific criteria were used to standardise all these layers. Seven different criteria were used in this research to select the water harvesting sites such as slope (%), stream network (order), rainfall (mm), soil (type), distance to roads and urban centre and Normalised Difference Vegetation Index (NDVI). This research is significant because it is associated with several fields such as agriculture productivity, livestock husbandry, sustainable environment, soil fertility, water management, human livelihood and the agriculture industry. The outcomes of this research are to produce map of potential water harvesting sites in Al-Therthar valley, West Nineveh. This will give opportunity to build dams to store the water in particular in drought-stricken areas. This study found that there are 16 sites within the study area that represent the best potential water-harvesting sites. These sites were chosen according to the specific criteria that were used for this purpose and had a high potential in terms of their suitability for water harvesting.
**Keywords:** GIS, RS data, Fuzzy logic, fuzzy overlay, Drought, water harvesting.

## Introduction
### Study Area
Al-Tharthar valley, is a big valley situated in the Nineveh Governorate, North-West of Iraq, the study area extends between UTM coordinates 218308.122 E To 329909.595 E and 4034639.25 N To 3886144.20 N (Figure1). This region falls within the arid and semi-arid region. This region has long been known for agricultural activities such as cropping (wheat and barley), foresting and livestock husbandry. The study area in Nineveh is about 940,000 hectares. The top height of study area is about 520 meter and the bottom height is 140 meter from sea level. The average of annual rainfall is less than 350 mm per year (Al-Daghastani 2010). The average temperature in the study area are: in the summer between 22ºC min to 33 ºC max and in winter between 6 ºC min to 12.5 ºC max (Al-Daghastani 2010).

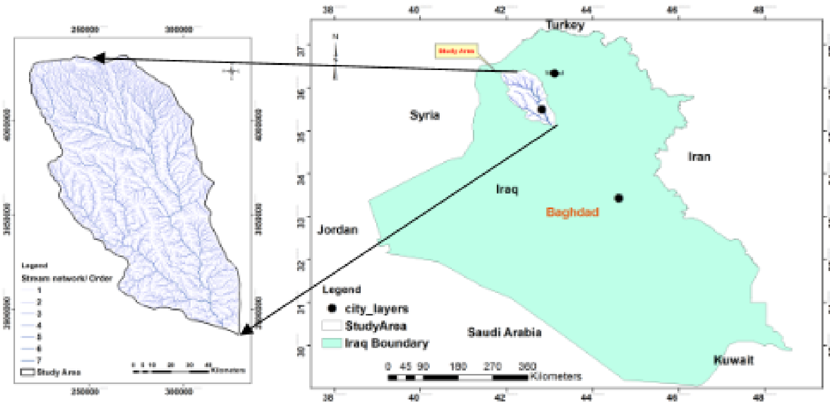


**Figure 1 The study area**

### Back Ground
Water is an important for the continuity of human life. However, it has been estimated that 33% of the developing world will face water shortages in the 21st century (Keller et al. 2000). In addition, the current scarcity of water coupled with population growth may be exacerbated by climate change (e.g. lack of rain), has limited agricultural production and had a huge impact on people's livelihood, in particular, the farmers (Zhaohui et al. 2003). For that, people who live in Al-Therthar valley area, Nineveh are suffering from water scarcity due to the lack of rainfall (droughts) and the general mismanagement of existing water resources (Al-Daghastani 2010).
To treat the drought problem and to change the conditions in arid and semi-arid areas, water harvesting method should be adopted effectively within the study area to solve the water management systems. One way to locate the water harvesting sites is to use Geographical Information Systems (GIS)

and Remote Sensing (RS) data and techniques. These techniques enable the researchers to select the suitable areas for constructing the suitable water harvesting sites using the satellite images and an available database of the study area. Fuzzy logic Modelling is one of the GIS methods used to help the decision makers in their decisions to study water harvesting (Al-Ardeeni & Robinson).

Water availability in any country has many impacts on commercial, social and practical uses (Oweis & Hachum 1999). Water harvesting significantly improves agricultural productivity by directing rainwater during run-off to the plants. Providing a water solution will improve the crops and livestock productivity and sustain the environment of the region. Reducing the agricultural productivity in arid and semi-arid areas will lead to increase migration to cities from rural areas and that will lead to associate high social costs (Owes & Ahmed 1999).

This research is significant because, building water harvesting sites on Al-Tharthar valley in West Nineveh will help the local farmers to improve their agricultural production, and that lead to limit farmer migration from rural areas to cities and enhance the environment.

The RS data and GIS techniques can provide useful methods in obligation the integrated resources analysis (Pandy et al. 2011). Also, they can be very useful tool when is used in combination with spatial data (Shirke et al. 2010). Fuzzy logic Modelling is one of the GIS methods that used to help the decision makers in their decisions to study water harvesting. The fuzzy logic modelling was first defined by Zadeh (1965). Over the past decade, much work has been done in the development of fuzzy set theory and fuzzy techniques for decision making (Robinson 2003). The fuzzy logic modelling was one of the common methods that used to standardise layers. The basic concept behind the fuzzy set is that remove the sharp boundary between non-membership and full membership of a set (Ahamed et al. 2000). It replaces data values by the continuous range of [0, …, 1],where 0 means “false” and 1 means ‘true” and all values between 0 and 1 represent a transition between true and false.

Present studies have used the fuzzy set method with GIS techniques and RS data to study different fields. For example, study from China using the fuzzy set method was carried out by Lu et al. (2012), the fuzzy membership was used to standardise layers under study. The data used in this study were a topographical map, climatic map and soil map. From these maps, several layers were generated and used. Another study from Nepal, the study used an integrated GIS-based fuzzy pattern recognition model (Pathaknad & Hiratsuka 2011) to compute a groundwater vulnerability index for decision making.

A Study from Tunisia was carried out by Ayadi et al. (2013). This study used the fuzzy sets method to standardise all of the layers. Criteria were chosen according to the local expert knowledge and a literature review. Another study using the fuzzy set was conducted by Reshmidevi et al. (2009). This study used GIS and an integrated fuzzy rule-based inference system for land-suitability evolution in an agricultural watershed.

Another study in Mexico was conducted by Malczewski (2006) employing fuzzy quantifiers and GIS-based MCE for land-use suitability analysis. The criteria were used on the data: the proximity to the (road, city, airport, rivers) and the distance from the wetland. A GIS-based fuzzy sets method has been used by Assimakopoulos et al. (2003) for mapping of agricultural soils according to the N-fertilizer use in West Greece. The fuzzy membership method was used to approach the soil map and to classify in terms of continuous soil classes.

The aim of this research: is to select potential water harvest sites using GIS techniques and remote sensing data, in AL-Tharthar valley, West Nineveh, Iraq.

The main objectives of this study are to identify water harvesting sites in suitable places, improve the water resource management and this will give opportunity to build dams to store the water in the study area.

## Material and Methods

This study adopted a fuzzy logic modelling method to standardise the layers. Also, the fuzzy logic modelling was used to improve cell-based information modelling within the GIS software system. The basic concept behind the fuzzy work is that, replaces all layers value using range from 0 and1,where 0 means “false” and 1 means “true” and all values between 0 and1 are represent transition between the true and false (Benz et al. 2003).

A Sigmoidal Fuzzy Membership Function (Sigmoidal FMF) was used to standardise all layers as: slope, soil, NDVI, urban, roads, rainfall and stream order. Two types of the sigmoidal FMF were used to standardise the layers: sigmoidal decreasing, and sigmoidal increasing, The Sigmoidal FMF standardised layers according to the high important (maximum) and lower important values (minimum) within the most potential areas. Two equations were used to standardise the layers:

$(Square\ (Cos\ ((1-((x-min)\ /\ (max-min)*(\pi/2))$……..(1) Sigmoidal FMF increasing. It was used with stream order, NDVI and rainfall layers.

$(Square\ (Cos\ ((x-min)/\ (max-min)*((\ \pi)/2)))$…………(2) Sigmoidal FMF decreasing. It was used with roads, soil, urban, and slope layers. Where X is a layer that used.

### Software

The ArcGIS version 10.1 was used to analyse the sources: Landsat image, DEM, topographic sheet map, soil sheet map. The Universal Transverse Mercator (UTM) system, WGS 84 and zone 38 N were used to georeference and rectify all layers.

## Data

The data has been obtained the necessary datasets from USGS Web (www.usgs.gov) and from Ministry of agriculture in Iraq (Table 1).

**Table 1. The data were used in this study**

| Data | More details | Scale and Resolution |
|---|---|---|
| Landsat 8 image | LC81700352013157LGN00 | 30 m Resolution |
| DEM | STRM | 30 m resolution |
| Topographic sheets | Paper map | 1:100,000 scale |
| Soil sheet | Paper map | 1:2000,000 scale |
| Rainfall data | Excel data | 1971-2008 |

These data were used to obtain NDVI layer from Landsat image, stream network and slope layers were obtained From DEM. Road and urban were generated from topographic sheets, and soil was generated from soil sheet. Rainfall data was used to generate rainfall map of the study area.

### Criteria Identification

In Iraq, there is no guideline or standard criteria for water harvesting study because using MCEDM is new method there. For that, all these criteria were evaluated according to other studies of water harvesting such as AL-Adamat (2008), Kallali et al. (2007) and Gayoumian et al. (2007). Seven criteria were used to select the suitable water harvesting sites in the study area. The criteria were used to standardise all layers using different conditions. The layers were (stream network, roads, urban, soil, NDVI, rainfall, and slope (Table 2).

**Table 2. The criteria which used to standardise the layers**

| Layers | Criteria |
|---|---|
| Distance from villages &cities | > 200 m |
| Stream order | > 3rd Order |
| Distance from roads | > 100 m |
| Slope % | ≤ 5% |
| Soil (gypsum %) | < 20% |
| Rainfall | > 100mm |
| NDVI | > 0 |

## Methodology

The research methodology mainly included the integration of the GIS technique and RS data with fuzzy logic modelling method and fuzzy overlay. Integrating these methods with GIS-based MCDA was used to locate the most suitable sites for water harvesting in West Nineveh. The standardisation processes of the layers were in the following steps:

### Roads Layer Standardisation

Road layer was digitized from topographic sheet as polyline feature. Then this feature was changed to distance layer. Road distance layer value was between 0-62592.4 m and the criteria of road should greater than 100 m. The sigmoidal decreasing equation was used to standardise this layer, 100 m was used as the maximum distance and the minimum distance was 62592.4 m (Figure 2).

### Urban Layer Standardisation

Urban layer was digitized from topographic sheet as a polygon feature. Then this polygon was changed to distance layer. The urban layer value was between 0-63280.8 m and the criteria of urban were greater than 200 m. The sigmoidal decreasing equation was used to standardise urban layer, and the maximum distance was 200 m and the minimum distance was 63280.8m (Figure 2).

### Slope Layer Standardisation

The slope layer was generated from DEM image. The slope layer value was between 0-66.87 and the criteria of slope were between 0-5%. The sigmoidal decreasing was used to standardise the slope layer, the maximum slope was 0 and the minimum slope was 5% (Figure 2).

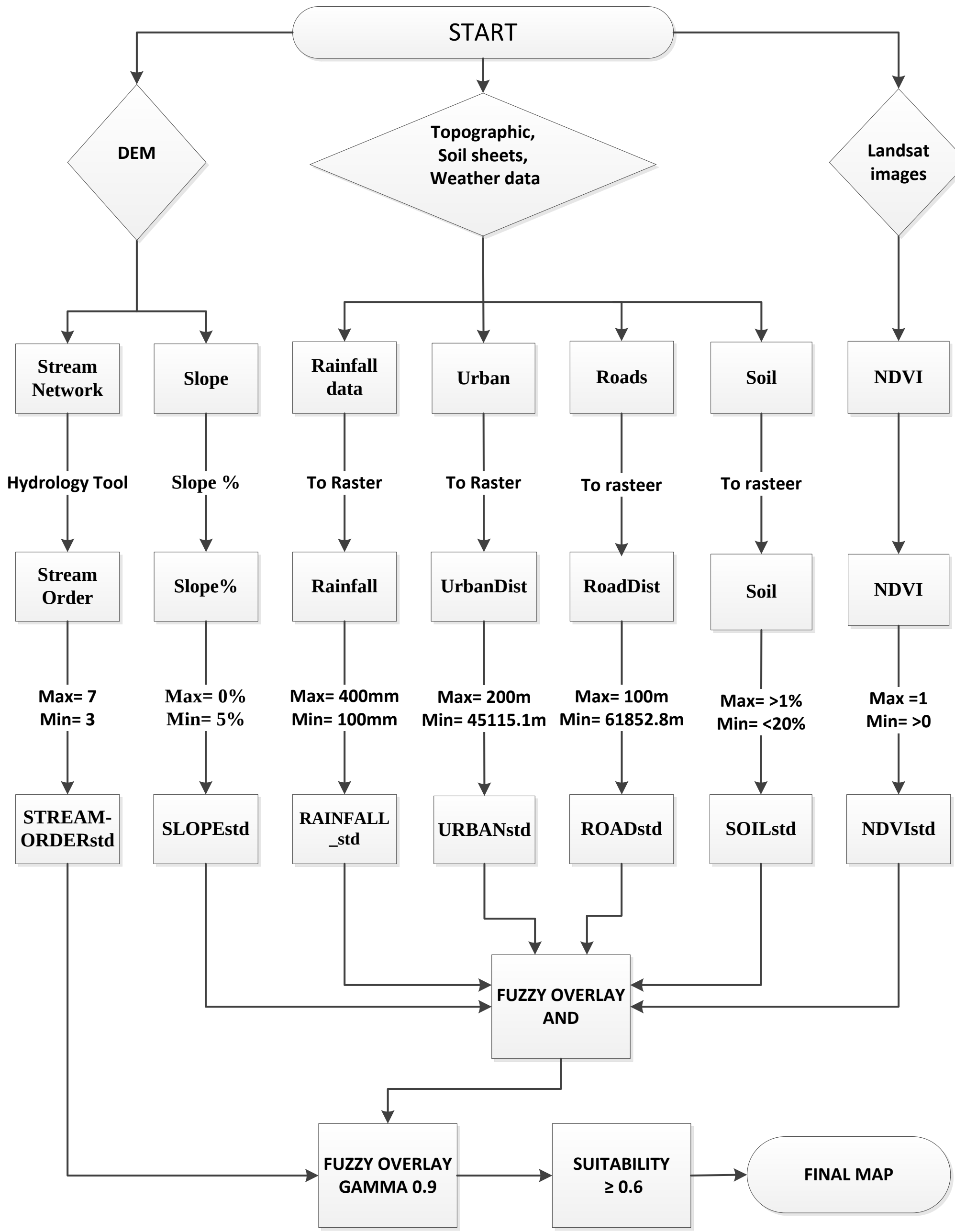


**Figure 2 Flowchart of methodology**

**Soil Layer Standardisation**

The soil layer was generated from soil sheet as polygon feature. This feature was converted to raster layer. The soil layer value was between 0 To 60% (gypsum) (each percentage represents different type of soil) and the criteria of soil was less than 20% to avoid high ratio of gypsum. The sigmoidal decreasing equation was used to standardise soil layer (Figure 2).

**NDVI Layer Standardisation**

NDVI layer was obtained from analyses Landsat 8 image using equation (3). The NDVI layer value was between -0.097258776- 1. The sigmoidal increasing equation was used to standardise NDVI layer and the criteria of NDVI was greater than 0.0 (Figure 2).

**Stream Order Layer Standardisation**

The stream network layer was generated from DEM image and then used Strahler method to create stream order from stream network. The sigmoidal increasing equation was used to standardise stream order layer. The stream order layer value was between 1-7 and the criteria of stream order were > 3(Figure 2).

**Rainfall Layer Standardisation**

The rainfall layer was created from weather station data. The Rainfall layer value was between 0-350 mm and the criteria of rainfall were greater than 100mm. The sigmoidal increasing equation was used to standardise rainfall layer (Figure 2).

Site selection

To select the most suitable sites of water harvesting in Al-Therthar valley and to produce the final map, two steps were used:

**Using AND operation**

Fuzzy overlay method was used to combine these entire layers together and then obtained the final map. Slope, soil, NDVI, road, rainfall, and urban were multiplied using AND operator. The AND operation was used to combine them together (Figure 2).

**Using Gamma operation 0.9**

The result layer above was combined with stream order layer using Gamma 0.9 operator (Figure 2).

**Check dam**

To reduce the number of sites, this study adopted just the greater than 0.6 value suitability and then produce final map that represents the suitable sites of water harvesting in the study area (Figure 2).

## Results

All layers were used in this study were standardized using fuzzy logic modelling method. The Sigmoidal FMF standardised all of the layers according to the high important (maximum) and lower important values (minimum) within the most potential areas. Two equations were used to standardise the layers:

The Sigmoidal FMF increasing was used to standardise NDVI (Figure 7), stream order (Figure 8), and rainfall layers (Figure 9). While, Sigmoidal FMF decreasing was used to standardise roads (Figure 3), urban (Figure 4), slope (Figure 5) and soil (Figure 6) layers. The values of all layers were between 0 - 1. The value 1 refers to the highest potential area. However, the value 0 represents the lowest potential area within the study area.

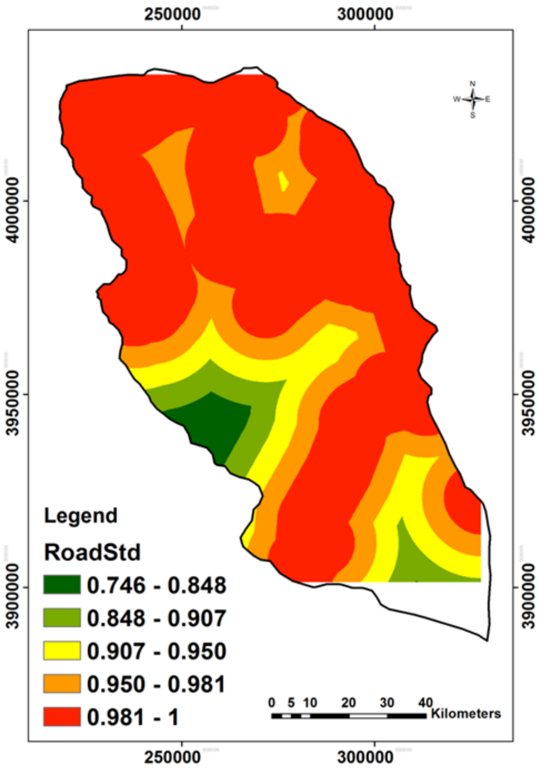


**Figure 3. Roads layer standardization**

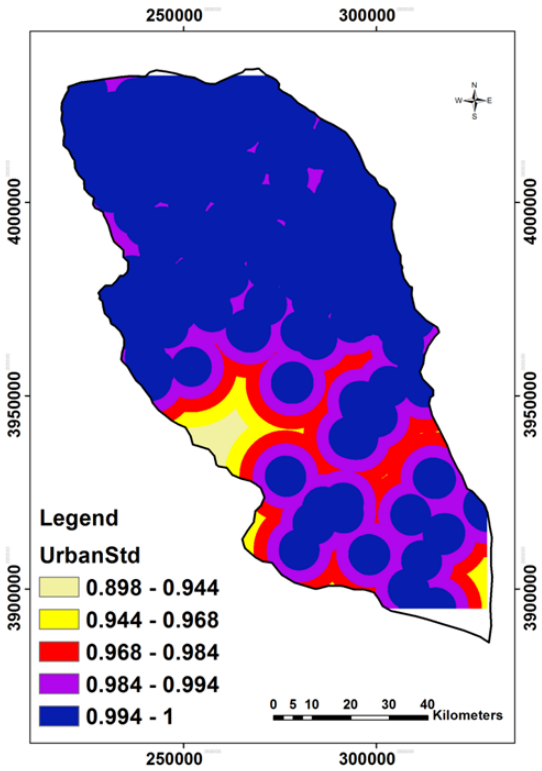


**Figure 4 Urban layer standardization**

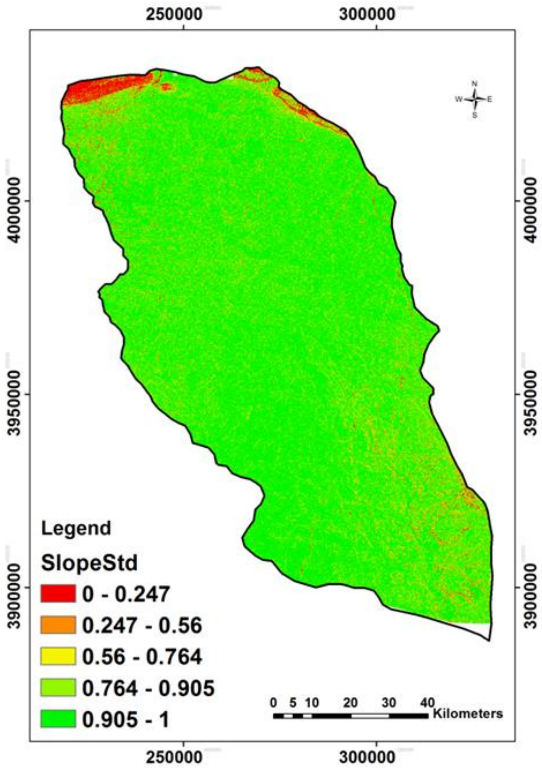


**Figure 5 Slope layer standardization**

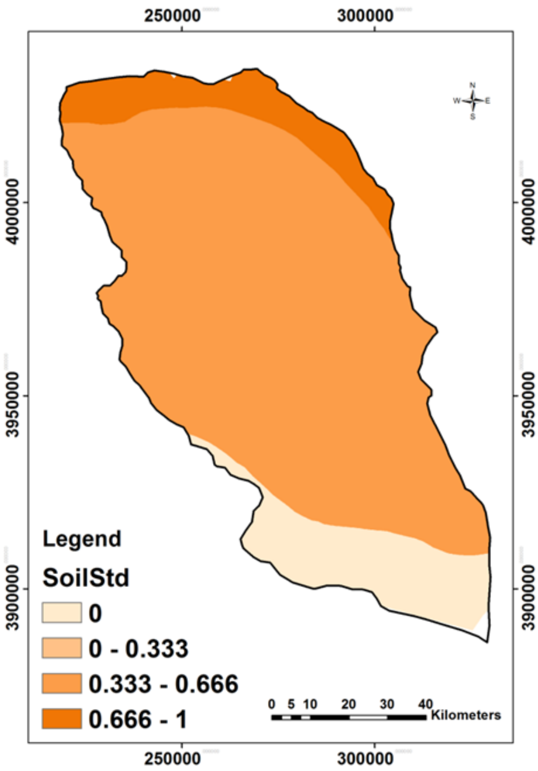


**Figure 6 Soil layer standardization**

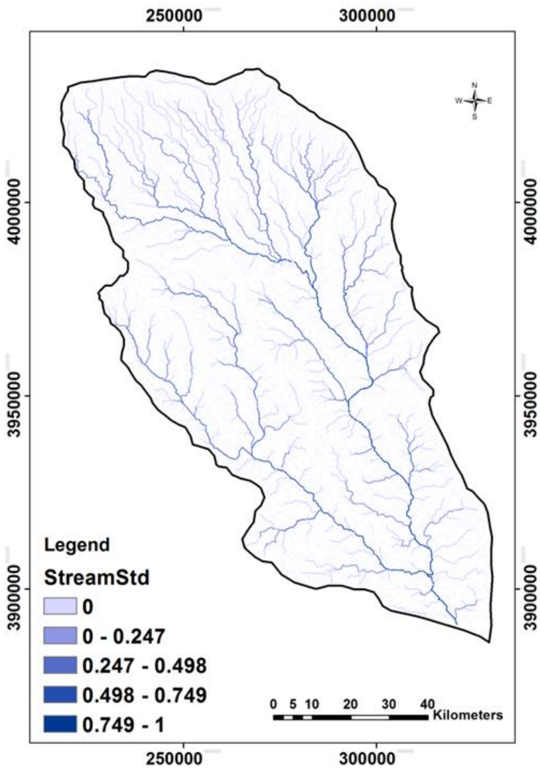


**Figure 8 Stream layer standardization**

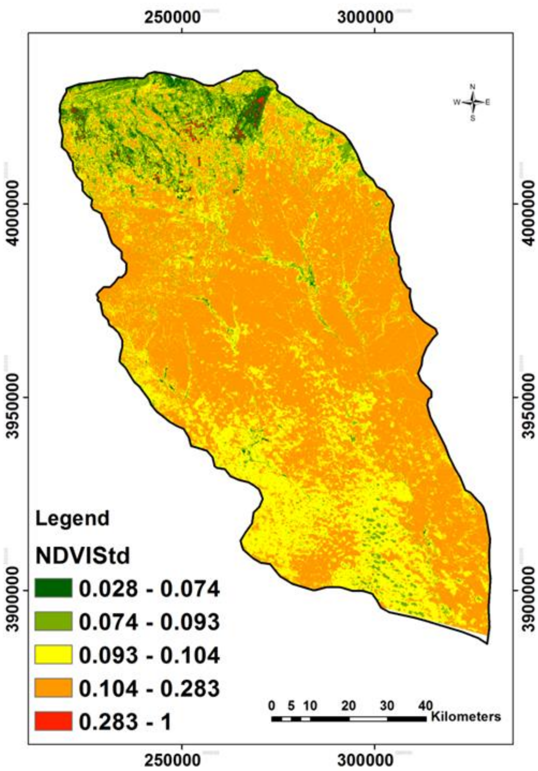


**Figure 7 NDVI layer standardisation.**

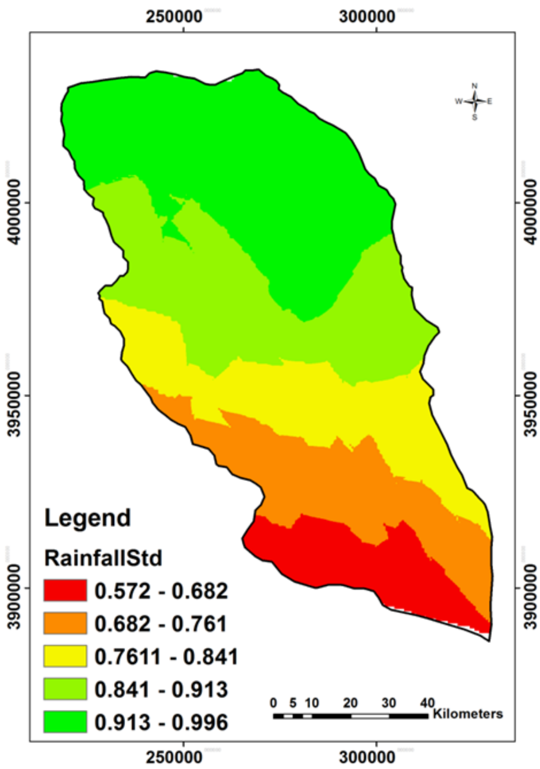


**Figure 9 Rainfall layer satandardisation**

**Sites Selection**

The slope, urban, soil, roads, NDVI, and rainfall were combined together after standardised using the AND Fuzzy overlay method to find the most suitable sites of water harvesting in the study area (Figure 10). This result was combined with stream order layer using Gamma 0.9. The result was new layer represents wide range (0 To 79.9%) of degree of suitability of water harvesting sites within the study area (Figure 11).

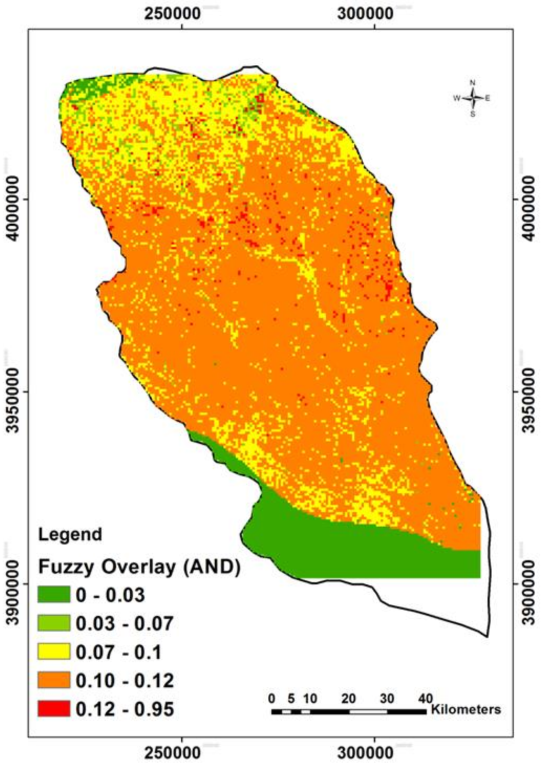


**Figure 10 Combine layers using AND.**

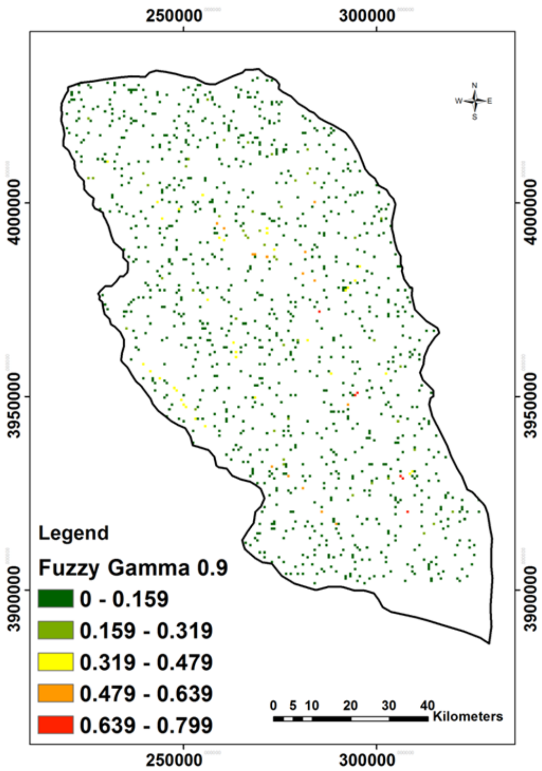


**Figure 11 Combine layers using Gamma 0.9**

**Check dam**

To improve this result and to select the most suitable sites of water harvesting in Al-Tharthar valley area, this study adopted just the greater than 0.6 value suitability. The result was 16 potential sites are distribution within the study area (Figure 12). Ultimately, produce final map that represents the most suitable sites of water harvesting in the study area.

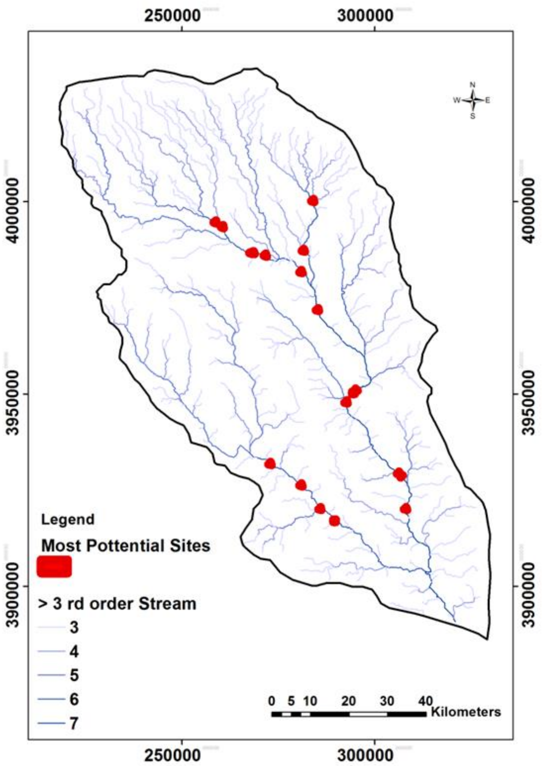


**Figure 12 Final potential sites in the study area.**

## Discussions

This study adopted the fuzzy logic modelling method to standardise all layers: soil, slope, NDVI, roads, stream network, rainfall and urban centres. Standardisation of these layers require using specific criteria (Table 2). The results were wide range [0 to 1] values of potential sites. To make the results logical and to limit the number of potential sites within the study area, this study adopted using ≥ 0.6 value suitability. The final result was 19 potential sites of water harvesting were distribution within the study area. These sites were fallen on the stream network within Al-Tharthar valley.

## Conclusion

This research demonstrated the powerful capabilities of GIS technique by using fuzzy logic modelling with RS data to study the possibility of selecting the most suitable sites of water harvesting in Al-Tharthar valley, West Nineveh. This research found that using fuzzy logic modelling was valid and useful to select the water harvesting sites in the study area.


## Acknowledgements

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# اختيار مواقع محتملة لحصاد المياه باستخدام نظم المعلومات الجغرافية والتحسس النائي في وادي الثرثار، غرب نينوى، العراق

**محمود احمد حسن الارديني**

*قسم العلوم المكانية ، كلية العلوم والهندسة ، جامعة كيرتن*

**الملخص**

الهدف الرئيسي لهذا البحث هو لاستخدام تقنية نظم العلومات الجغرافية مع بيانات التحسس النائي لتوليد خرائط لاختيار افضل المواقع المحتملة لحصاد المياه في منطقة الدراسة. هذه التقنيات سوف تساعد في اكتشاف مواقع لحصاد المياه في اماكن مناسبة فضلا عن تحسين ادارة مصادر المياه في منطقة الدراسة. المنهجية التي تم تبنيها في هذه الدراسة كانت باستخدام ما يعرف اصطلاحا بالفزي موديل (Fuzzy logic modelling). هذا الموديل يستخدم لتوحيد الطبقات وجعلها جميعا في نفس الوحدة، اما طريقة (Fuzzy Overlay) فتستخدم لدمج ومعالجة الطبقات معا. استخدمت معايير خاصة لتوحيد وحدات الطبقات، حيث استخدمت سبعة انواع مختلفة من المعايير في هذه الدراسة لاختيار بموجبها مواقع محتملة لحصاد المياه مثل معيار الميل (%)، وشبكات الاودية (Order)، والامطار (mm)، والترب (النوع)، والمسافة عن الطرق، والمسافة عن مراكز الاستيطان، ونسبة وجود الغطاء النباتي. نتائج هذه الدراسة سوف تكون مواقع لحصاد المياه والتي سوف تساعد في عدد من الجوانب الحيوة في الحياة مثل جانب زيادة الانتاج الزراعي، تربية الماشية، تحسين البيئة، خصوبة التربة، تحسين ادارة المياه، تحسين حياة الناس وتحسين الصناعات الزراعية. النتائج المباشرة من هذه الدراسة هو انتاج خارطة للمواقع المحتملة لحصاد المياه على وادي الثرثار الذي يقع في غرب نينوى. هذه الخارطة سوف تعطي فرصة لمعرفة افضل الاماكن لبناء سدود صغيرة لحصاد المياه والتي تقع ضمن المناطق الجافة وشبه الجافة. وجدت هذه الدراسة ان هناك 16 موقع محتمل لحصاد المياه ضمن منطقة الدراسة والتي تمثل افضل الاماكن لحصاد المياه علما ان تلك المواقع تم اختيارها وفقا لمعايير خاصة استخدمت لهذا الغرض.