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Using remote sensing techniques and analytical hierarchy process to select rainwater harvesting optimum sites: a case study in Ali Al-Garbi city, Iraq

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Abstract

The assignment of suitable sites for water harvesting techniques is a promoted strategy to be introduced to the community, for handling the water scarcity and risk due to floods. In the eastern part of Missan, water is always hampered due to the limited availability during the drought, while floods frequently and intensely occur in the wet season. This study aimed to choose the potential and suitable sites for applied water harvesting system using remote sensing techniques and analytic hierarchy process (AHP). Ali Al-Garbi city is divided into three watersheds (site1, site2, and site3), which have been characterized by flash floods that produce high quantities of runoff. The six parameters: slope, lineament density, drainage density, soil texture, rainfall, and runoff. These factors are selected based on previous studies to detect the potential zones of water harvesting system in the study area.Pairwise comparison method consistency index, consistency ratio, and parametersweight is evaluated. The result discovers that the highly probable zone is situated in the north and north-eastern portions in watershed no.1 and watershed no.2, while watershed no.3 located in the south portions. In contrast, the low to medium WH is situated in the center and south portion in watershed no.1 and watershed no.2, whereas in watershed no.3 located in the north.

Keywords: Water harvesting techniques, AHP, Ali Al-Garbi, remote sensing

استخدام تقنيات التحسس النائي وطريقه التحليل الهرمي لتعيين المناطق المناسبه لحصاد المياه, في مدينه علي الغربي, شمال ميسان,العراق

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الخلاصة

ان تقنيه تحديد او تعيين مناطق حصاد المياه هي استراتيجية مهمه وواعده تم تقديمها للمجتمع لمجابهه ازمة شحه المياه ودرء خطر الفيضان. الاجزاء الشرقية من محافظة ميسان تعاني من قله توفر المياه في فترات الجفاف, وفي الوقت ذاته تتعرض المنطقة لسيول وفيصانات. تهدف الدراسة الى اختيار مناطق مناسبة لتطبيق تقنية حصاد المياه بالاعتماد على تقنيات التحسس النائي وطريقة التحليل الهرمي. تم تقسيم منطقة

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علي الغربي الى ثلاث احواض ثانويه, تتميز المنطقة بحدوث الفيضانات المفاجاه التي تولد كميات كبيرة من الجريان السطحي. سته متغيرات تم اختيارها وهي: الميل, كثافة العناصر الخطيه, كثافة التصريف, نسيج التربة, الجريان السطحي , والساقط المطري تم اختيارها بالاعتماد على الدراسات السابقة لتحديد المناطق المناسبة لاقامه نظام حصاد المياه في منطقة الدراسة. وفقاً لطريقة المقارنه بين الازواج تم حساب معامل CI ومعامل CR بالاضافة الى وزن كل صنف ضمن المتغير الواحد. تظهر نتائج البحث أن المناطق المحتملة لحصاد المياه بنسبة عاليه تتواجد بالاجزاء الشمالية والشمالية الشرقية في حوض 1 وحوض 2 بينما في حوض 3 فهي تقع بالاجزاء الجنوبية للحوض. على العكس نجد ان المناطق ذات النسب القليلة والمتوسطة تقع عند المنتصف والجنوب من حوض1 وحوض2 بينما تلاحظ في الجزء الشمالي بالنسبة لحوض3.

1. Introduction

Water is an essential element for life on the planet. Water scarcity one of serious problems the world has suffered for decades. About 33% of developing countries have suffered from water scarcity for decades [1]. Iraq was an example of these countries, especially in dry areas by the influence of unplanned agriculture, industry, and human activities water resources continue to decline and deteriorate in quality. Therefore, a strategy for the sustainable management of water resources must be developed. [2] In the eastern part of Missan water is always hampered due to the limited availability during drought, while flood frequently and intensely occurs in the wet season .

To overcome the problem during collecting and storing water to cover all needs and minimize the pressure on our limited water resource.Water harvesting techniques are the chosen promoted strategy to be introduced to the community for handling the water scarcity and risk due to flood. The definition of a water harvesting system can be summarized as accumulating and managing rainwater and flooding for domestic and agricultural affairs and recharging groundwater [3] .

2. Study area

Ali Al-Garbi city is situated in the south-eastern of Iraq at a distance of 236 km from Baghdad. Its lies between longitude 647869.40 m E, 3632560.89 m N and latitude 670174.72 m E, 3615244.29 m N with total area extent about (577km) (Figure 1). The annual rainfall between the high altitude region (Hamrin Hill) and the low region. The study area was characterized by a high precipitation about 200mm or more [4]. In general, the climate of the study area is a part of Mesopotamian and classified as Mediterranean climate, dry summer, cold winter and a pleasant spring and fall. The data were taken from Al-Amara station records. The major climate parameters in this station are precepitation (200mm), monthly average relative humidity (50%), wind direction (NW), and mean temperature (50 C).

3. Geology and hydrogeology of the area

The study area is covered by Quaternary deposits that consist of alluvial fan, aeolian deposits, and flood plain. It's a fine grained-sediments compared to Mukdadya and Bai Hassan formations . The major thickness of alluvial fan is about 15m of coarse and poorly sorted deposits of boulder and gravel, in addition to layers of fluvial sediments. Silty clay and clay sediments of floodplain in the study area with a depth of 1m or less. In tectonic aspect, the study area is located in the Mesopotamian Zone [5]. The Mesopotamian Zone is the eastern most unit of the stable shelf. It is bounded north by Hemrin and Makhul in the zone was probably uplifted during the Hercynian, but it subsided from Late Permian period onwards. The study area contains a buried faulted structure below the Quaternary cover, separated by broad synclines [6].

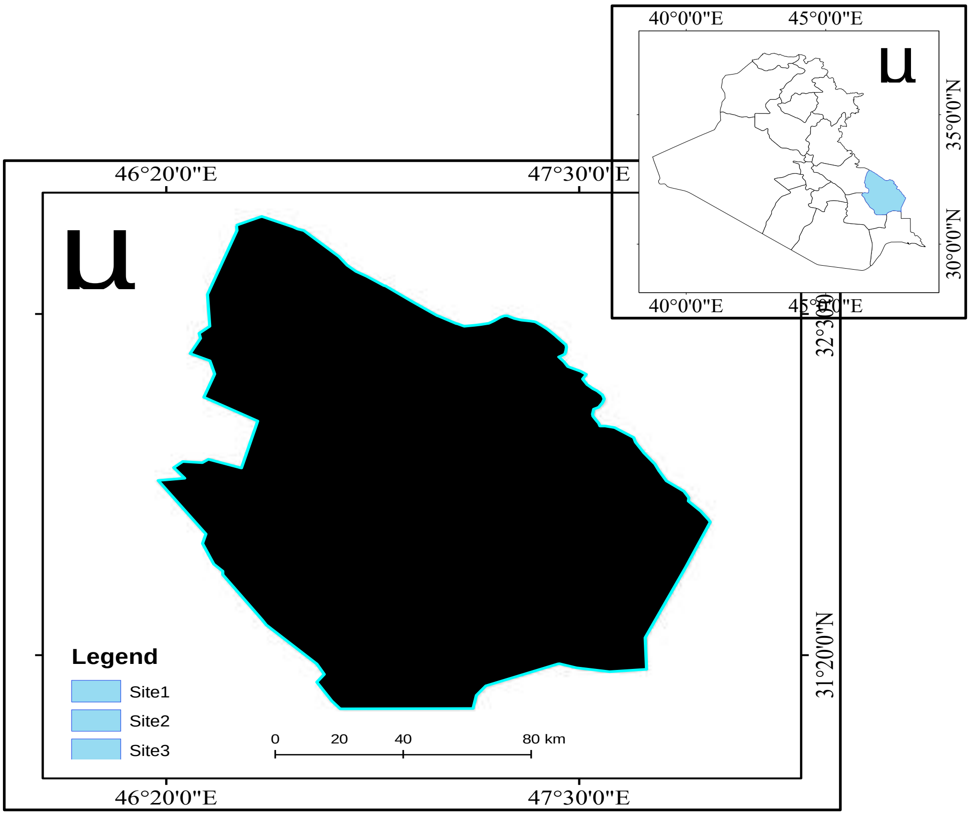

Figure 1-location of study area

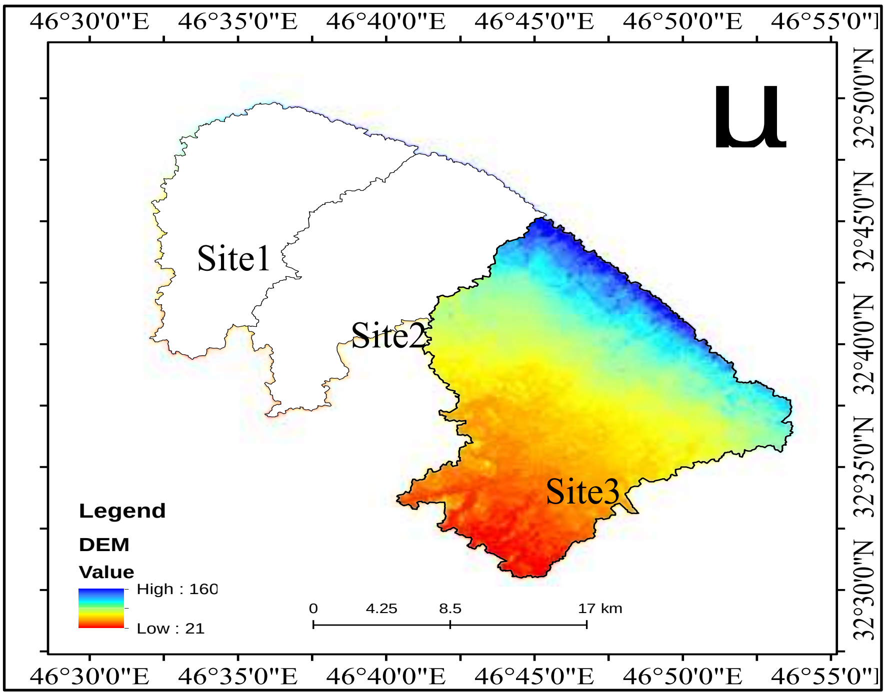

Figure 2-River network of study area

4 . The analytical hierarchy process (AHP)

The Analytic Process Hierarchy (AHP) /is a statistical analytical method has been evolved in the 1970s and is used to simplify and organize difficult and complex outputs [7]. The AHP is a delicate procedure to compute the weight of the criteria via evaluating the relative magnitude of the criteria by comparing a pairwise series [8] . The analytical hierarchy process is a widely used approach around the world in various domains likes: business, healthcare, industrial, and education [9].

4.1 The procedure of AHP applied in this study

Identify the adopted criteria:

In this study, five parameters have been achieved using previous studies and GIS and remote sensing strategies Figure 3.Under investigated area was divided into watersheds. To make it easy to apply AHP. All these factors have been weighted according to their significance in water harvesting results. The rainfall, slope, runoff, drainage density, and lineament density are the selection and adopted parameters in this study.

1. Rainfall

The mean annual precipitation in the study area range from 184.89 to 209. Since the area is classified as an arid area. Rainfall is the most influential parameter in the study area that is mainly related to the runoff factor [10]. Based on the rainfall raster of the area (Figures 7, 15, and21), maximum values were recorded 209.99 mm.

2. Slope

The digital elevation model with 12.5m was used to produce a slope map. The general raster of the study area was categorized into five classes (Figures 5, 11, and 17), range from 0 to 44.5 m. The landscape slope control on accumulation and movement of water. High slope areas make water moves quickly. In contrast, gentle slope areas make water moves slowly [11].

3. Runoff

The runoff coefficient map of the study area has been extracted by digitizing using the runoff of Iraq. The highest value of runoff is in the same position when the rainfall has the highest value. The runoff raster has been classified and weighted according to the effect of class value (Figures 8, 16, and 22).

4. Drainage density

Can be defined as the ratio between lengths of stream orders to the basin area. Drainage density reflects differences in soil and represents a significant topographic aspect [12]. The high rate of drainage density refers to the high amount of water runoff, whereas the low rate reflects high infiltration, high groundwater storage, and low overflow land [13] (Figures (9, 13, and 19).

5. Lineament density.

The term lineament refers to linear features on the surface that demonstrate geological structures through a weakness in landscape and can be distinguished using remote sensing data (aerial photos, Digital elevation models, and satellite images) [14]. In current study hillshade option in spatial analysis tool has been used to produce lineament density raster, according to DEM raster. Figures (6, 12, and 18).

6. Soil texture

Soil texture is one of the adopted criteria in this study, which reflect soil storage and infiltration rate. The soil texture map is categorized into coarse, medium, and fine texture. The soil texture layer has been derived using spectral indices NDTeI. Satellite imagery landate8 OLI was creating a normalized difference texture index (Figures 10, 14, and 20).

3. Materials and methods

The methodology adopted in the current study integrated the benefit of remote sensing technique (Landsat imagery) and AHP in estimation of the potential sites water harvesting system. Procedure and steps are explained in Figure 4. To select potential water harvesting sites, several datasets have been utilized: satellite imagery, previous studies, and DEM with 30m resolution. Landsat imagery (OLI) was used to create a soil texture layer by producing spectral index NDTeI. Normalized difference texture index (NDTeI) is a major spectral index applied in the soil. NDTeI can be calculated by the difference between SWIR1 and SWIR2, which is significant to characterize the texture of tropical soils. Also used to distinguish specific minerals in soils. For instance, gibbsite and kaolinite. NDTeI has been applied to recognize soil of tropical regions as clay or sandy soil. The thematic layers of slope, lineament density, and drainage density are generated via a spatial analyst tool in Arc Toolbox, based on DEM. The rainfall and runoff layers were prepared by digitizing general map of iraq. The AHP way is applied for simplifying and organizing difficult and complex results. The chosen criteria were evaluated according to their relative importance in selecting water harvesting sites table 1. The weight eveluated of thematic layers was applied to explain importance of these layers in selection water harvesting potential sites.

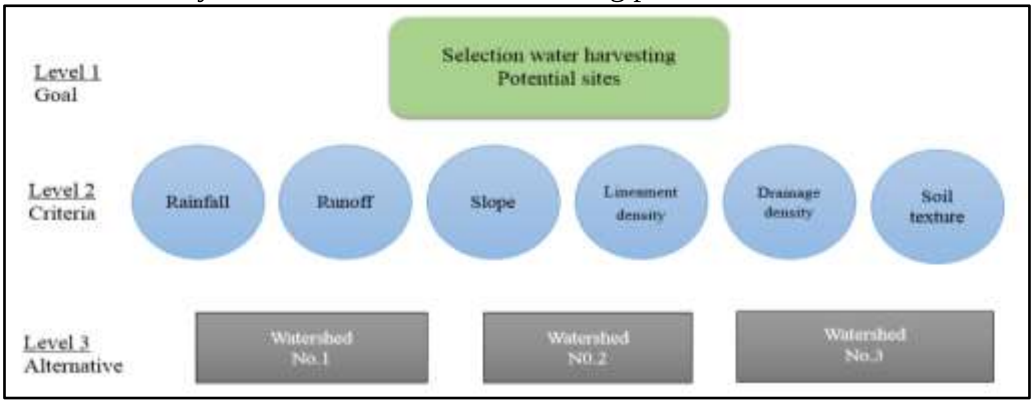

Figure 3-The components of Analytic Process Hierarchy

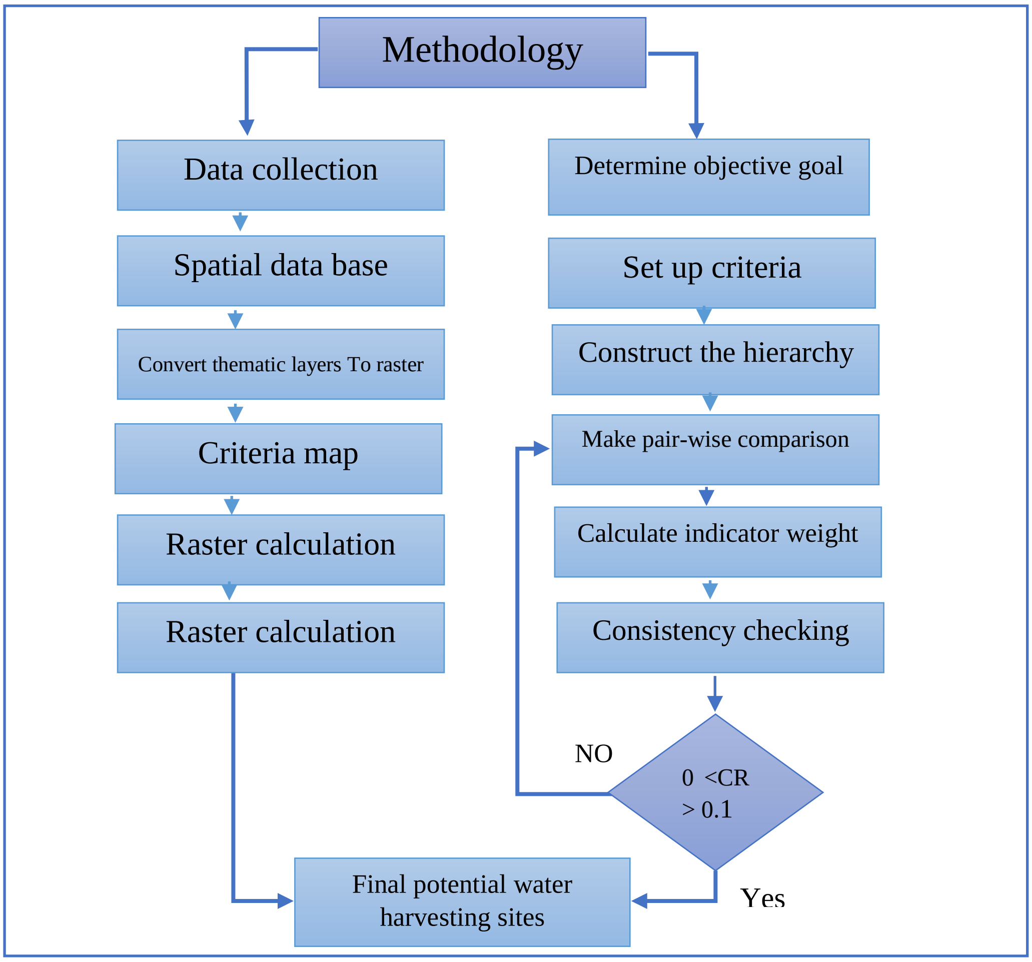

Figure 4-Flow chart showing water harvesting potential mapping methodology

The main stages of AHP are [3]:

I. Assignment the significant criteria (research problem).
II. Determination of the relative significance of each used criteria.
III. Using pairwise comparison to assess the value of consistency ratio.

The assessment process of consistency ratio involves:

1. Evaluate the priority of each criterion.
2. Calculation of λ_{max}.
3. Finding consistency index (C.I).
4. Estimate random consistency ratio (RI).
5. Comparison between calculated CR and the standard CR.

In the calculation (Tables 1 and 2) of thematic layers, the final maps were reclassified based on their weights (Table:3).

B. Set up The pairwise comparison matrix.

Table 1-show pairwise comparison matrix

Criteria	Rainfall	Runoff	Slope	Soil texture	Drainage density	Lineament density
Rainfall	1	2	3	4	5	6
Runoff	0.5	1	1.5	2	2.5	3
Slope	0.333	0.66	1	1.3	1.6	2
Soil texture	0.25	0.5	0.7	1	1.25	1.5
Drainage density	0.2	0.4	0.6	0.8	1	1.2
*Lineament density	0.2	0.4	0.6	0.8	1	1

4. Results

According to the matrix of pairwise comparison (Table1) and final weight of each subclass in selected parameters (table4). In addtion to thematic layers below the final WH map has been created (Figures 23, 24, and 25).

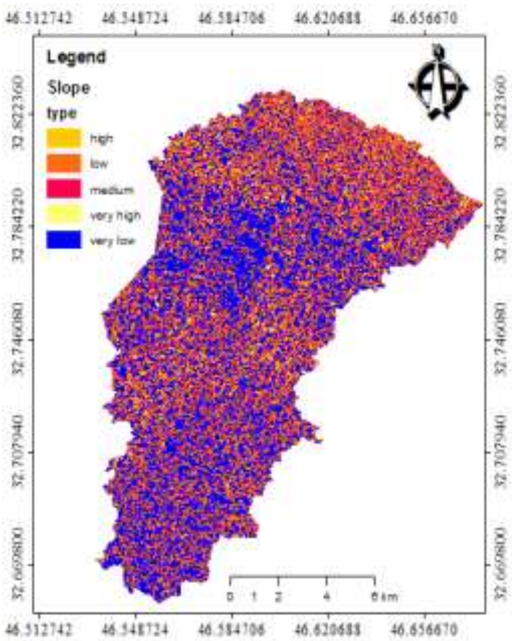

Figure 5-Slope values in site1

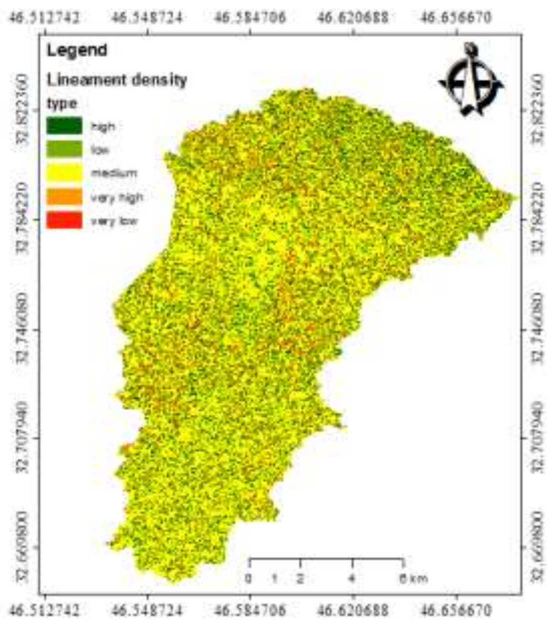

Figure 6-Lineament density in site1

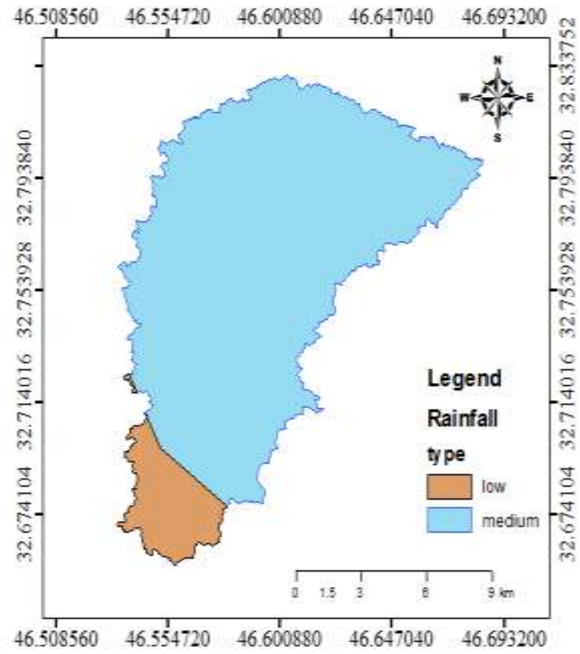

Figure 7-Rainfall in **site1**

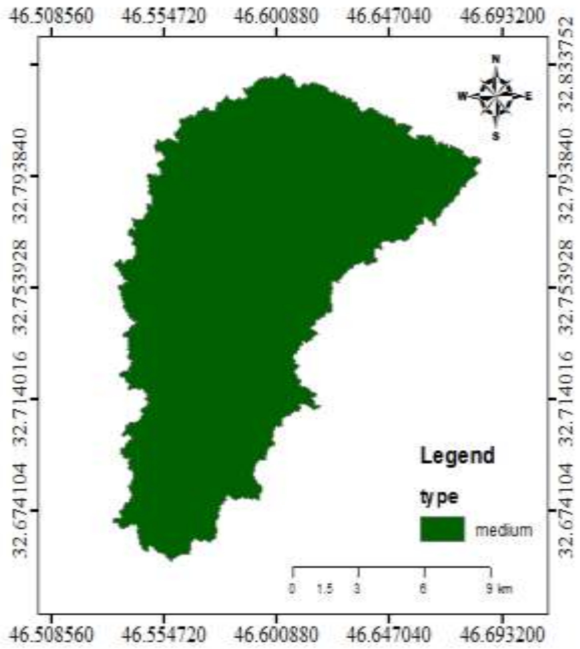

Figure 8-Runoff in site1

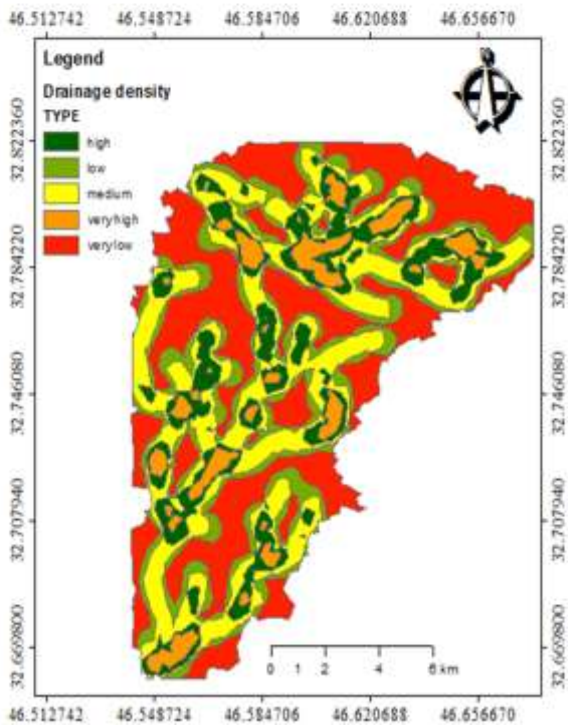

Figure 9- Drainage density in site1

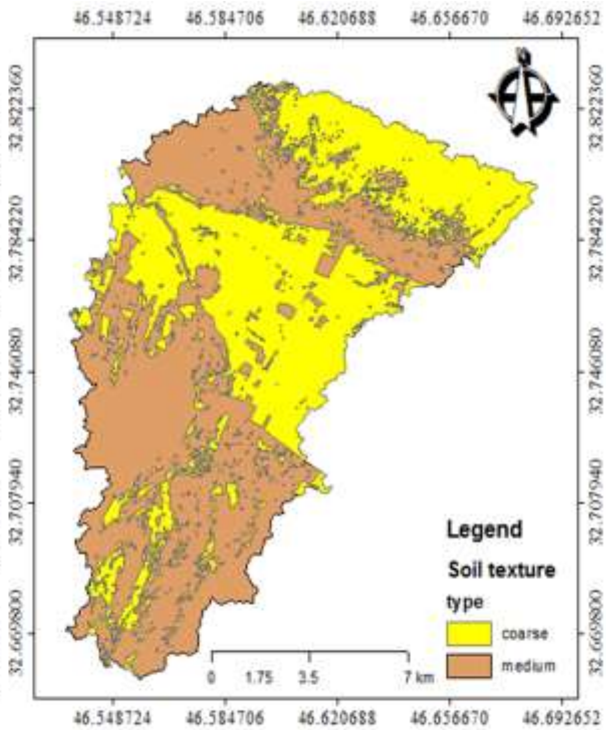

Figure 10-Soil texture in site1

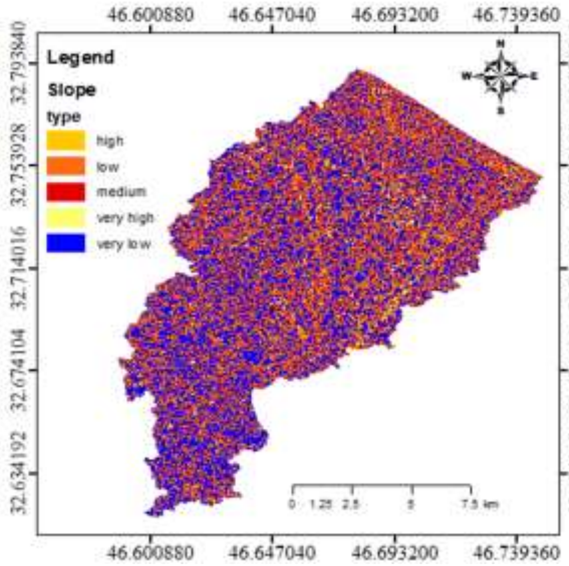

Figure 11 Slope values in site 2

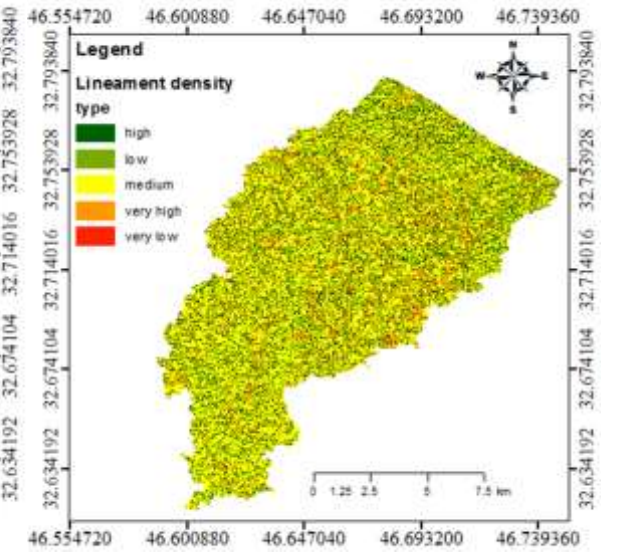

Figure12 Lineament density in site 2

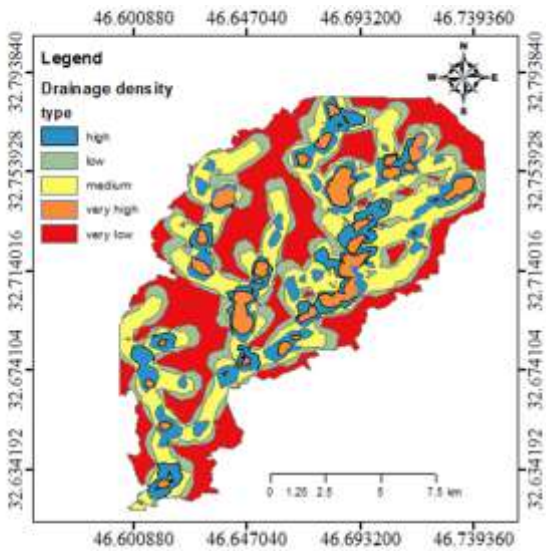

Figure13-Drainage density in site **2**

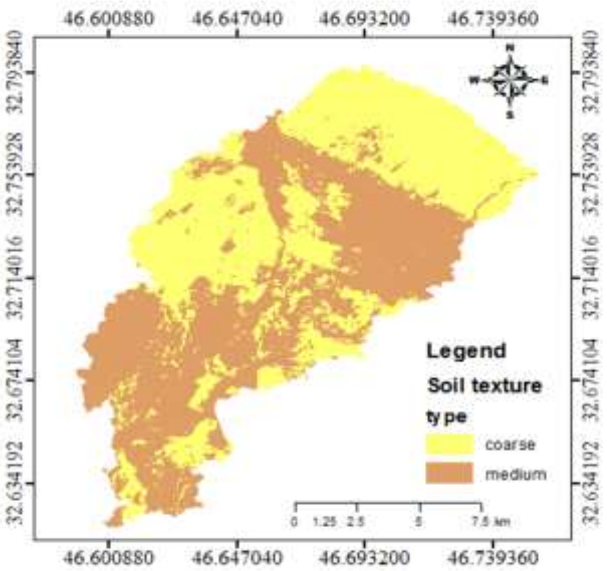

Figure14-Soil texture in site 2

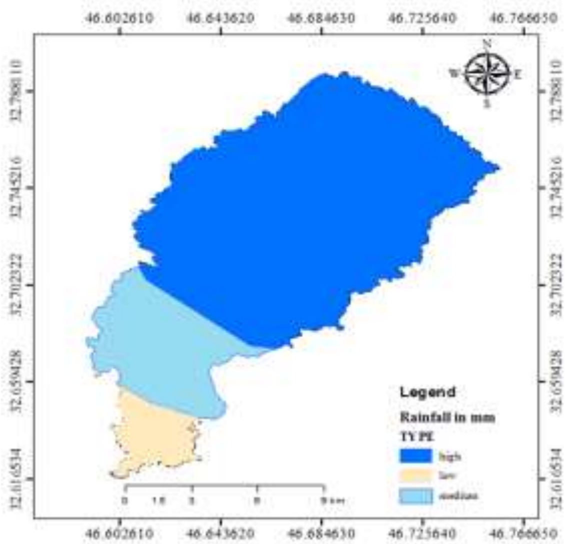

Figure15-Rainfall in site **2**

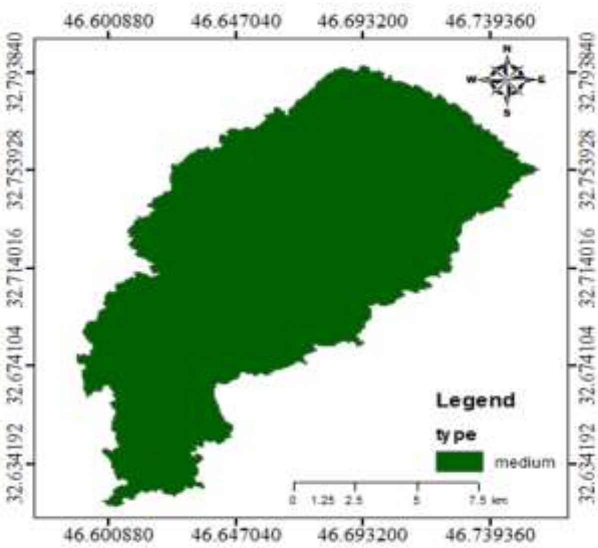

Figure 16-Runoff in site 2

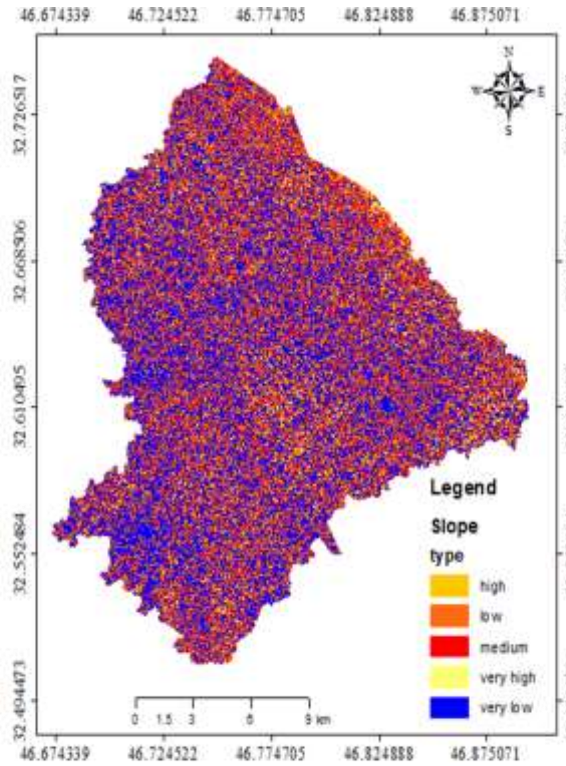

Figure17-Slope values in site 3

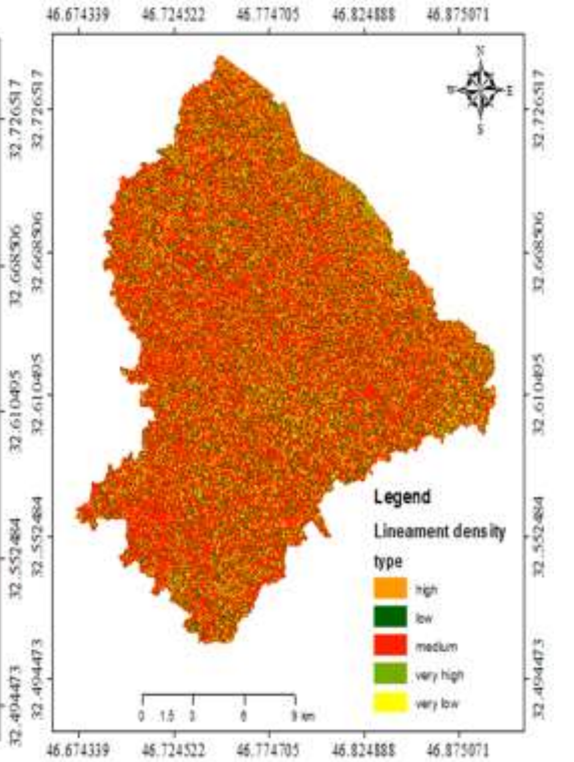

Figure18-Lineament density in site 3

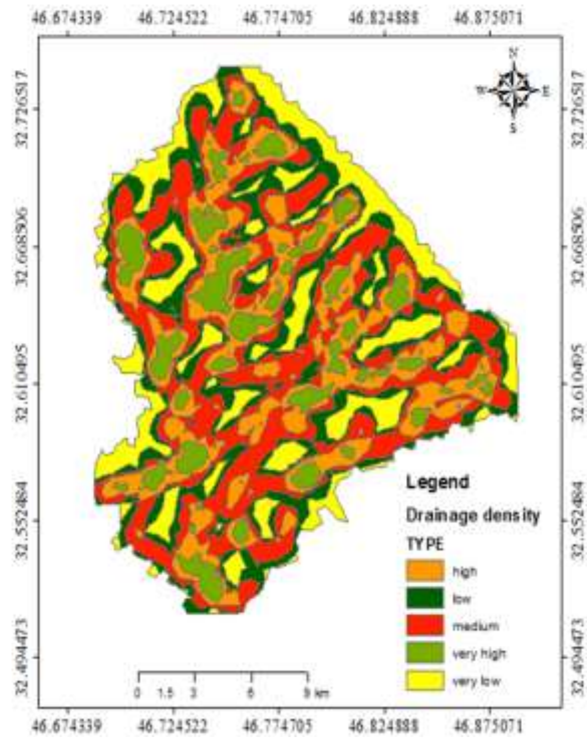

Figure 19-Drainage density in site **2**

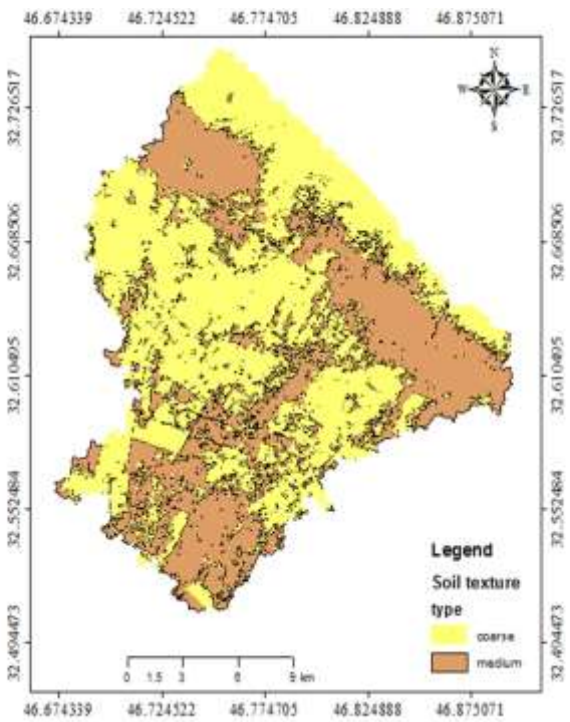

Figure 20-Soil texture in site 2

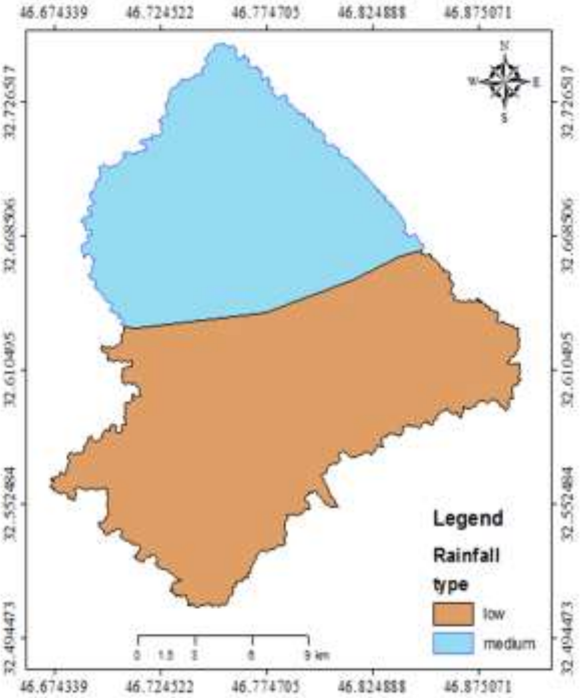

Figure -21 Rainfall in site 3

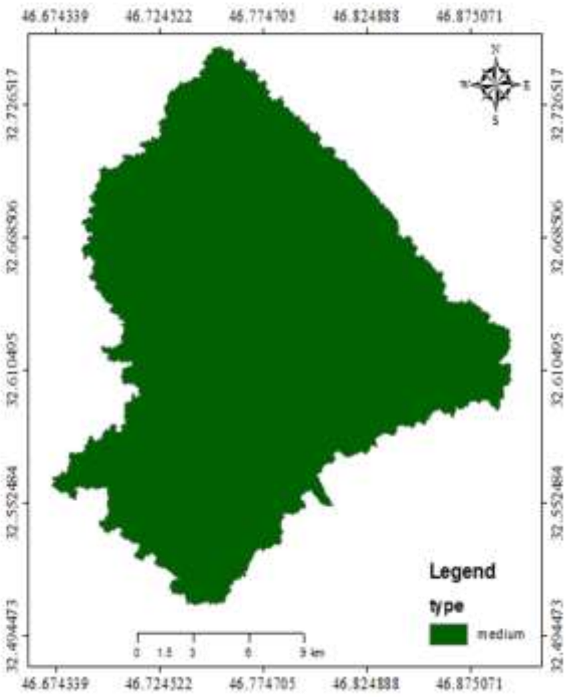

Figure 22-Runoff in site 3

The matrix of pairwise comparison comprises of pairs of factor that are compared with each other so as to determine the most important factor (Table2).

Criteria	Rainfall	Runoff	Slope	Soil texture	Drainage density	Lineament density
Rainfall	1	2	3	4	5	6
Runoff	0.5	1	1.5	2	2.5	3
Slope	0.333	0.66	1	1.3	1.6	2
Soil texture	0.25	0.5	0.7	1	1.25	1.5
Drainage density	0.2	0.4	0.6	0.8	1	1.2
Lineament density	0.2	0.4	0.6	0.8	1	1

Table 3-The summery of AHP results

Criteria	Weightage	λ_{max}	CI	RI	CR
Rainfall	41 %	6.13	0.02	1.24	0.02
Runoff	20 %				
Slope	13 %				
Soil texture	10 %				
Drainage density	8 %				
Lineament density	8 %				

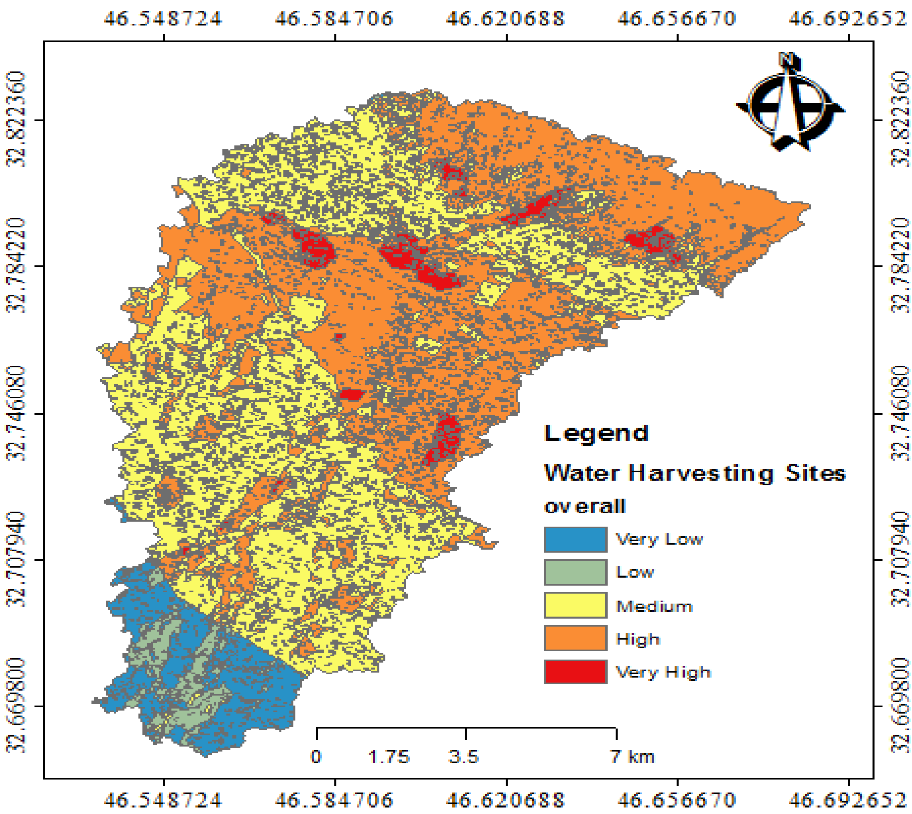

Figure 23-WH potential sites

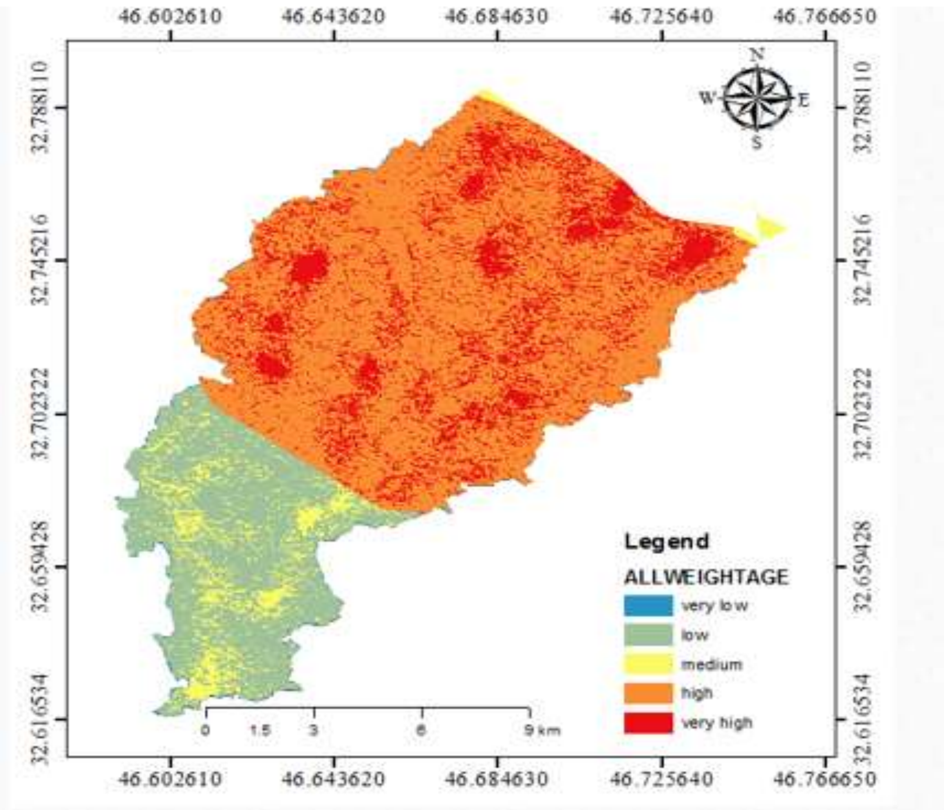

Figure 24-WH potential sites

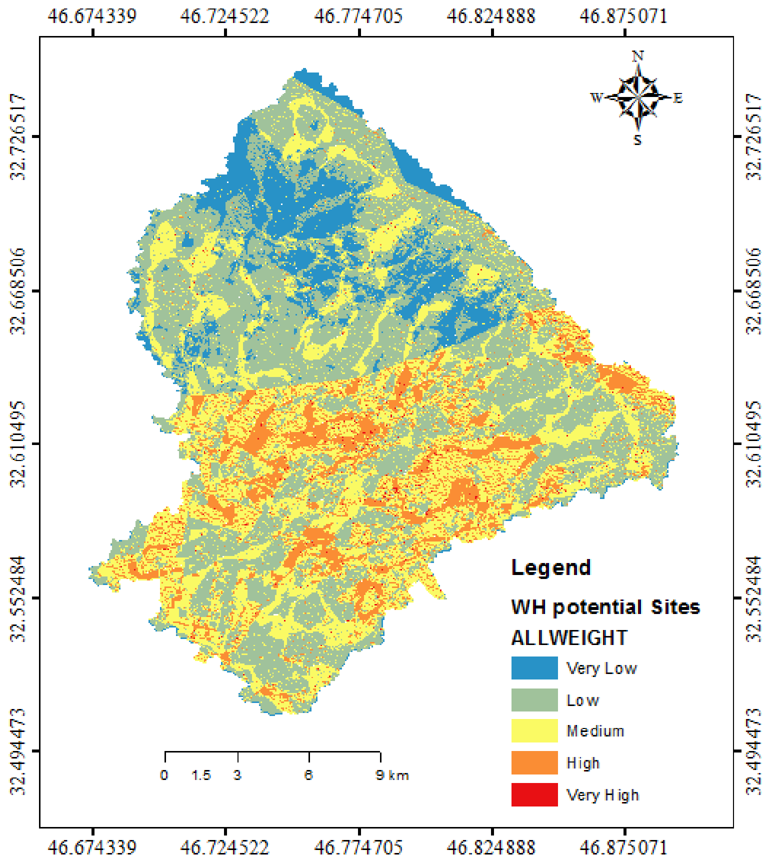

Figure 25-WH potential sites

Evaluate weight for each parameter

The six factors have been evaluated in detail in Table 4. According to percentage weight (criteria weight), subclasses rank is estimated based on its influence and multiple by criteria weight to calculate the final weightage of classes.

Table 4-Rating of used criteria which used is AHP

Criteria	weight	rank	Over all
rainfall			
high	41	3	123
medium		2	82
low		1	41
Runoff			
moderate	20	3	60
low		2	40
		1	20
Slope			
Very high	10	5	50
high		4	40
moderate		3	30
low		2	20
Very low		1	10
Soil texture			
Very high	13	3	39
high		2	26
moderate		1	13
Lineament d.			
Very high	8	5	40
high		4	32
moderate		3	24
low		2	16
Very low		1	8
Drainage density			
Very high	8	5	40
high		4	32
moderate		3	24
low		2	16
Very low		1	8

6. Discussion and Conclusion

In this paper, remote sensing techniques and analytic hierarchy process have been applied to assign and delineate probable WH suitable sites. The AHP has achieved the study based on several steps like thematic layer development, evaluation of weight, the relative weightage of each class, harvesting mapping, and finally overlay analysis of thematic layers. The WH potential zones in the three watersheds were divided into five subclasses: very low, low, medium, high, and very high. The result discovers that the highly probable zone is in the north and north-eastern portions in watersheds 1 and 2, whereas watershed 3 is located in the south. The low to medium WH is founded in the center and south portions of watersheds 1 and 2, whereas watershed 3 located in the north. The final water harvesting map was derived from the integrated operation of several parameters: rainfall, runoff, drainage density, lineament density, soil texture, and slope. The research results show that the application of AHP and RS is powerful in delineating water harvesting zones in the sites. In addition, The study can be adopted as a guide for exploiting rainwater and torrential water by constructing dams in Ali-Al-Garbi city.

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