IDENTIFYING SUITABLE SITES FOR RAINWATER HARVESTING USING RUNOFF MODEL (SCS-CN), REMOTE SENSING AND GIS BASED FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP) IN KENITRA PROVINCE, NW MOROCCO

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ABSTRACT:
The rising need for water coupled with an increasing scarcity in many parts across the world especially in the middle east and north african countries (MENA) requires more sustainable solutions for effective water conservation. In Morocco, water ressource is characterized by significant spatio-temporal variability. So, to ensure the availability of water for domestic and agro-industrial uses, it is advised to develop some alternatives that improve the local water resources management throughout the country. Rainwater harvesting (RWH) has been proven to be a very promising alternative to water shortage problem. However, identifying appropriate sites for RWH remains a complex task in the management of rainwater. The present study aims to identify optimal sites for RWH using GIS based Fuzzy Analytical Hierarchy Process (FAHP) method in the Kenitra province, NW Morocco. For preparing thematic layers, several data sources were used including remote sensing data (RS), digital elevation model (DEM), the soil and precipitation data were used to create the necessary database using ArcGIS software. Next, the model of the soil conservation service-curve number (SCS-CN) was adopted to generate the map of the annual potential runoff. Then, five thematic layers including runoff, slope, soil texture, land use/land cover (LULC) and drainage density were assigned apropriate weights for generating the RWH suitability map. The resultant map of runoff depth revealed that it ranges from 137 to 738 mm. Moreover, the RWH suitability map showed that Kenitra province can be classed into five RWH candidate areas: (i) unsuitable (12.7%), (ii) less suitable (10.9%), (iii) suitable (20.3%), (iv) very suitable (36%) and (v) extremely suitable (19.9%). The extremely suitable areas for RWH are distributed in the central and northeastern parts. Based on the area under curve (AUC) of the receiver operating caracteristics (ROC), the success rate for predicting suitable RWH sites was 51%.

Key-words: RWH Suitability, SCS-CN, FAHP, RS, GIS, Kenitra province.

1. INTRODUCTION

In Morocco, precipitation varies greatly in space and time (Tramblay et al., 2013). Morocco's climate varies from sub-humid in the northwest to arid in the south (Born et al., 2008). Average annual rainfall reaches 800 mm. yr^{-1} in the north, whereas the southern parts receives 100 mm. yr^{-1} (El Moçayd et al., 2020).

The water shortage problems in the south has led the Moroccan government to develop a strategic policy to improve the local management of water resources throughout the country by installation of some great hydraulic infrastructures such as El Wahda dam's in the north. The late sixties, King

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Hassan II launched a strategic project to increase the irrigated area to reach 1 Million ha by 2000. Nowadays, the situation is worsened due to the population growth and the associated expansion of agricultural activities, imposing a remarkable burden on the limited available and uncertain water supply. Moreover, several studies (Doukkali, 2005) have reported that although these efforts resulted in the significant optimization of water resource management in Morocco, they remain insufficient to ensure water and food security. A new policy is needed to complement these efforts.

In 2020, only the northern watersheds have registered a water excess compared with the demand. Then, it was proposed a water transfer project from the north to south (Water Highway) which aims to supply water to the arid southern regions from the northern watersheds. Other studies have suggested that Moroccan arid and semiarid regions should develop new policy in order to adapt to climate change (Kahil et al., 2015). As reported by man researchers (Greve et al., 2018), different policies could be adopted, including investments in structures for transferring water from one basin to another.

On the other hand, many countries across the world have been used some alternative measures such as Rainwater Harvesting (RWH) to ensure water availability for domestic, agricultural and industrial uses. This strategic alternative has been widely adopted for water shortage problem and has led to decrease groundwater extraction. In arid and semi-arid areas, RWH term has been employed by researchers to describe the various methods aimed at the use of, collection, and storage of rain runoff for increasing the availability of water for drinking and irrigation (Agarwal et al., 2001). Accordingly, RWH has been used to safeguard water by satisfying the increasing water supply–demand gap for both domestic and agricultural uses to enhance the quality of life by improving the social, environmental, and economic development in these areas.

In the last decades, Kenitra province has experienced a series of changes including significant population growth, expansion of agricultural activities, rapid urbanization and strong industrialization which have resulted in an increasing demand for water. This situation creates the need for continued economic development and places pressure on existing water resources. According to this water demand increase in Kenitra province, RWH can be used as a water source for additional irrigation in case of agricultural water supply shortage (e.g. use of small dams for collecting runoff). However, the rainwater harvesting suitability study is a complex and delicate task as identifying potential and effective locations is not always easy. Thus, RWH sites should be sitting scientifically by using efficient techniques.

The use of GIS coupled with fuzzy multi-criteria decision analysis (MCDA) method has been used widely as an efficient approach. Since, the GIS software toolbox includes many spatial analysis tools that facilitate the management of big geo-spatial data. Therefore, the present study aims to suggest optimal RWH sites in Kenitra province using the fuzzy multi-criteria decision making coupled with the geographic information system. This proposed approach combines the FAHP method, SCS-CN model and GIS techniques in order to increase the successful implementation of RWH. The findings of this research will be of interest to water managers and other potential stakeholders to identify areas where RWH can be most effective for increasing sustainable agricultural development and water accessibility in Kenitra province, NW Morocco.


2. MATERIELS AND METHODS

2.1. Study area

Kenitra Province is one of the northwest regions of Morocco bordered by Larache province on the north, Ouezzane province on the northwest, Salé and Khemisset provinces on the south, Atlantic Ocean on the west and the two provinces of Sidi Kacem and Sidi Sliman to the east and northeast, respectively. It consists of 3 urban communes and 20 rural communes. The administrative center is Kenitra city located 40 km northwest of Rabat, the capital of Morocco. Mehdia, Souk Tlet, Souk El Arba, Mograne, Lalla Mimouna, Sidi Allal Tazi, Moulay Bousselham, Sidi Taybi, Ameur Saflia, Sidi Mohamed Ben Mansour, Mnasra, Haddada, Oulad Slama and Arbaoua are other major towns in this province.

Covering a total area of 3,052 km^2 (**Fig.1**), Kenitra province is limited by latitudes 7°10′34 ′'- 8° 42′ 46″N and longitudes 38° 41′ 14 ′'- 40° 43′58″W. The Kenitra province's altitudes range from 6 to 606 m a.s.l. According to the last national census report (HCP, 2014), there were 1,061,435 people in this province with a population density of 224 km^2.

During the period from 2000 to 2019, Kenitra province recorded a minimum average T of 13.1 ° C and a maximum average T of 20.1 ° C. The rainfall in Kenitra province falls between mid-October to mid-April and the annual average is 450 mm (HCP, 2014). The LULC types in the study area are classified into seven major classes such as matorral or scrub, forest, agricultural fields, covered plantations, lagoons, settlements and water bodies with both types of matorral and forest have larger proportions.
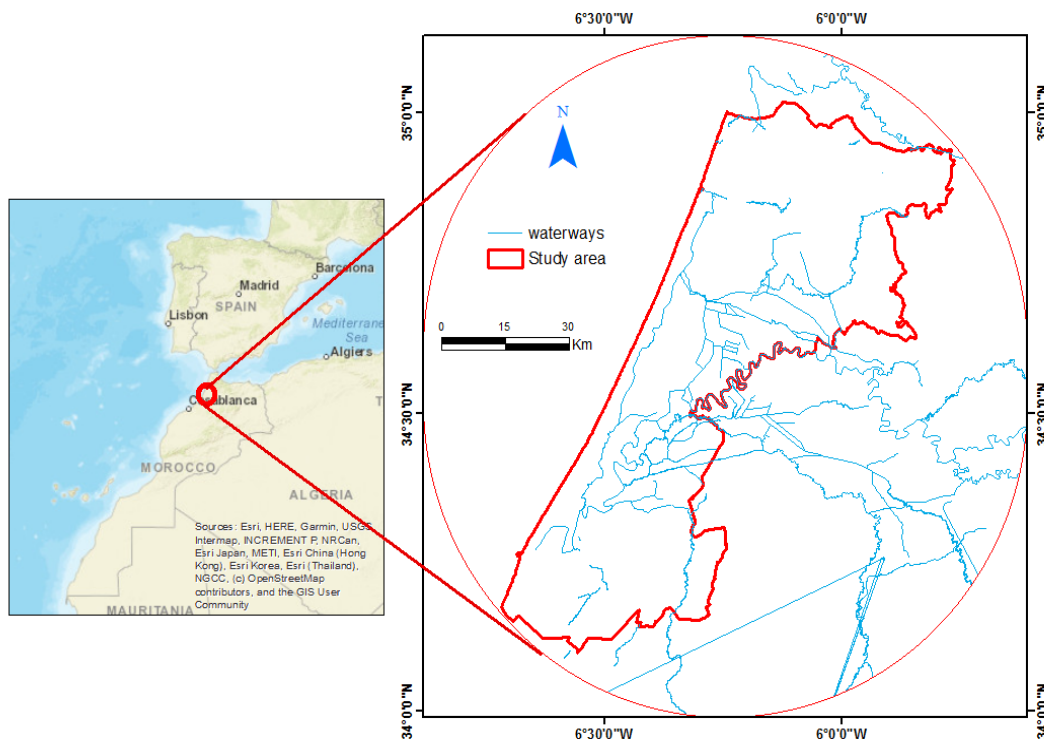
Fig. 1. Location of the Kenitra province on a map of Morocco.

2. 2. Data sources and adopted methodology

For the purpose of this study, a set of data was collected from different sources such as LULC from RS, DEM from SRTM, soil texture from previous studies, precipitation from the Sebou watershed agency (ABHS). Then, this database was processed in ArcGIS 10.5 software. The DEM-SRTM downloaded freely from the United States Geological Survey (USGS) site with a resolution of 30 m and used to delineate the Kenitra province watershed. The LULC map was compiled using Landsat 8 OLI satellite imagery, acquired on February 3, 2021, with a resolution of 30 m.

Rainfall data from the climate research unit of ABHS (ABHS, 2021) extending from 2000 to 2019. The geological map was obtained from the geological service of Morocco (SGM, 1985). The following figure (**Fig. 2**) presents a flow chart of the methodology adopted to produce the potential RWH map.
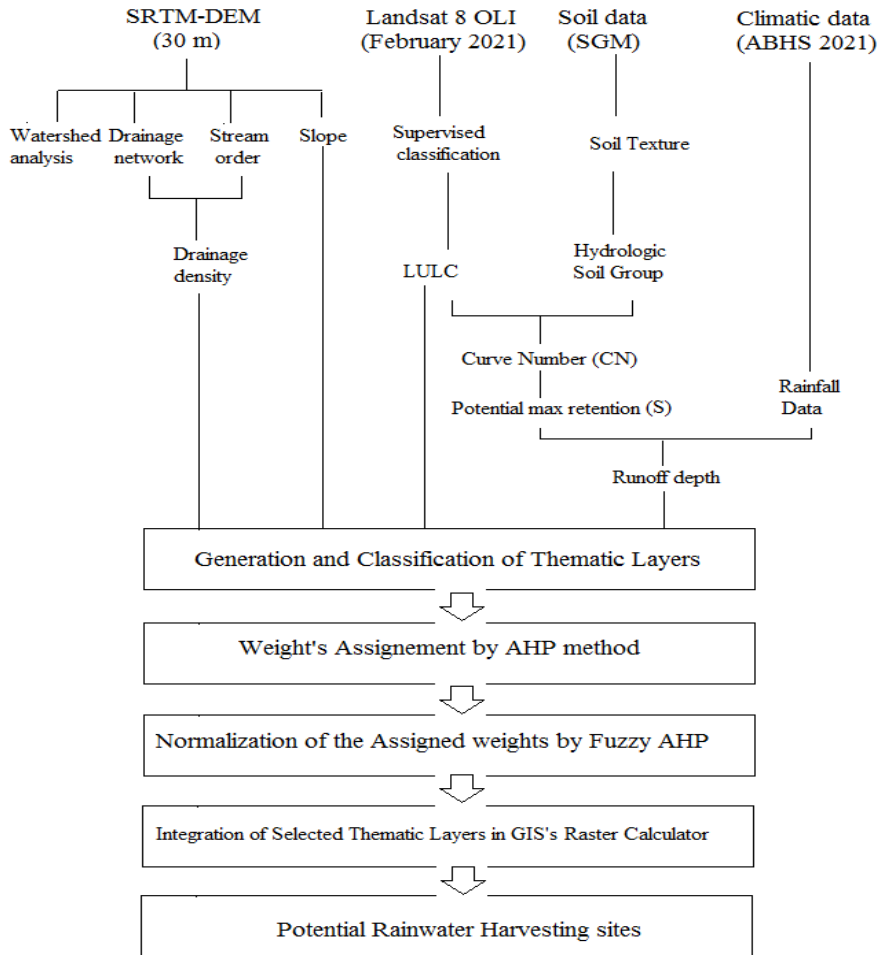
Fig. 2. Flow chart of the methodology used.

2.3. SCS-CN Model

The study area's potential runoff was estimated by the Soil Conservation Service-Curve Number (SCS-CN) model developed by the United States Department of Agriculture (SCS-CN USDA, 1956) which later became Natural Resources Conservation Service (NRCS). This SCS-CN model is a largely used approach for estimating the surface runoff (Ramakrishnan et al., 2009). CN value is the function of Hydrologic Soil Groups (HSGs), LULC and Antecedent Moisture Conditions (AMC). CN values for various Hydrologic Soil-LULC can be obtained for Kenitra province using NRCS (2004) data. To estimate the depth of runoff according to the SCS-CN method (Ramakrishnan et al., 2009), the following formula is used:

$$Q = \begin{cases} \frac{(P-\lambda S)^2}{P+(1-\lambda)S} & (P < S) \\ Q = 0 & (P > \lambda S) \end{cases} \tag{1}$$

$$S = \frac{25400}{CN} - 254 \tag{2}$$

where:

Q	-height of runoff (mm);
P	-annual precipitation (mm);
S	-maximum potential retention after the onset of runoff (mm);
λ	-abstraction of surface runoff (dimensionless);
CN	-value of the curve number which is between 0 and 100, reflecting the % of runoff.

A standard condition for the SCS value considers the parameter λ to be equal to 0.2 (SCS, 1985) and for CN, large values mean most precipitation is transformed into surface runoff and vice versa.

2.4. Thematic criteria layers preparation

Analysis of previous studies shows that six main factors which have been listed by the Food and Agriculture Organization (FAO) are widely used for selecting potential RWH areas including climatic data, hydrologic conditions, topography, agronomy, soils, and socio-economics data (FAO, 2003; Kahinda, 2008). Accordingly, the basic thematic layers in this study were rainfall, soil texture, LULC, slope, and drainage network. The choice of layers was intended to satisfy the rainfall-runoff model's requirements. However, socio-economic factors were not considered due to the lack of data and to make the interpretation of the results easier.

2.5. Fuzzy set theory

In classical set theories, an element is a full member of a set or not a member of a set. From 1965, Zadeh (Zadeh, 1965) has proposed a "Fuzzy set theory" as a simple new method for precise decisions from unclear situations (Balezentiene, 2013). It consists of assigning a membership value between 0 and 1 to each element (Zadeh, 1965). This approach has been widely used to model decision-making processes based on imprecise data such as decision-maker preferences. In geo-spatial sciences, fuzzy logic can be used for making choices to perform a spatial object on a map as a member. "Since a feature object can be used as membership values between 0 and 1 by fuzzy set theory, this represents the degree of membership function (Zadeh, 1965)".

More details on the principle of the fuzzy set is illustrated by the following equation (McBratney and Odeh, 1997):

$$A = \{x, \mu A(x) \text{ for each } x\} \tag{3}$$

where, μA is the MF (membership function of an element x in fuzzy set A) so that:

If x is not a member of A then μA = 0.
If x is a full member of A then μA = 1.
If x belongs in a certain level to A then:

$$0 < \mu A(x) < 1 \tag{4}$$

As displayed in the equation above, linear MF was used for runoff, hydrologic soil group, drainage density and LULC (Feizizadeh and Blaschke, 2013).

$$\mu A(x) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a < x < b \\ 1 & x \geq b \end{cases} \tag{5}$$

where:

x	-the considered parameter;
a	-the minimum value of the parameter x;
b	-the maximum value of the parameter x.

To estimate the effect of the slope on the suitability for RWH, the linear MF was used according to this equation (Feizizadeh and Blaschke, 2013):

$$\mu A(x) = \begin{cases} 0 & x \le a \\ \frac{b-x}{b-a} & a < x < b \\ 1 & x \ge b \end{cases} \tag{6}$$

where:

x	- the slope's value;
a	- the maximum value of the slope;
b	- the minimum value of the slope.

In the present study, five criteria for identifying the suitable sites for harvesting water were considered including runoff, slope, drainage density, soil texture and LULC (**Tab. 1**). In the fuzzy map of each criterion, each pixel's value ranges between the minimum 0 and the maximum 1. The value 0 means that the pixel is not a member of a set "not suitable" and the value 1 means that the pixel is a full member of a set "very suitable".

Table 1.

Fuzzy set memberships and control points used for identifying suitable RWH sites.

Criteria	Fuzzy / Membership Function	Control points (a=min & b=max)
Runoff (mm)	Linear, increasing	**a=257.7 & b=561.4**
Slope (%)	Linear, decreasing	**a=28.3 & b=3.8**
Drainage density (km/km2)	Linear, increasing	**a=0.28 & b=1.85**
Soil Texture	Categorical	**-**
LULC	Categorical	**-**

2.6. Analytic Hierarchy Process (AHP) method

For investigating the weight of the criteria or factors, the Saaty's AHP is the most used among MCDM methods. The fundamental concept of AHP is based on the simple binary comparison matrix to compute the criteria weights. The comparison is very important for determining the degree at which one criterion is more important than another is. The AHP method generally consists of three steps: determining the hierarchy, creating the pairwise comparison matrix, and calculating the weights (Saaty, 2008). After the hierarchy is established, **Tab. 2** is used to determine the level of importance among them for pairwise comparison. Then, the comparison's results are acceptable if the consistency ratio (CR) value is below 10% (Saaty, 2008).

Table 2.

AHP criteria pairwise comparison.

	Runoff depth	Slope	Dd	ST/HSG	LULC	Weight
Runoff depth	1	2	3	4	5	0.41
Slope	0.5	1	2	3	4	0.26
Dd	0.33	0.5	1	2	3	0.16
ST/HSG	0.25	0.33	0.5	1	2	0.09
LULC	0.2	0.25	0.33	0.5	1	0.06
Consistency ratio (CR= 0.02); Random index (RI=1.12) and Consistency index (CI=0.226).						

*The value 0.02 of CR means that the judgments derived from the pairwise matrix of **Tab.2** are consistent.*

3. RESULTS AND DISCUSSIONS

3.1. Rainfall

Precipitation in Kenitra province is highly variable in terms of amount, time and space. Their regime is bimodal (two periods of precipitation occur separated by a dry period). About 90 percent of annual precipitation occurs from mid-October to mid-April (HCP, 2015). The precipitation map was developed using data from meteorological stations and the inverse weighted distance interpolation (IDW) method, which allows to estimate the values of any point in the study area. Average annual rainfall value ranges from 467 to 740 mm. yr^{-1}. Low values occupy the central eastern parts. However, high values are observed in the northwestern borders (**Fig. 3**).
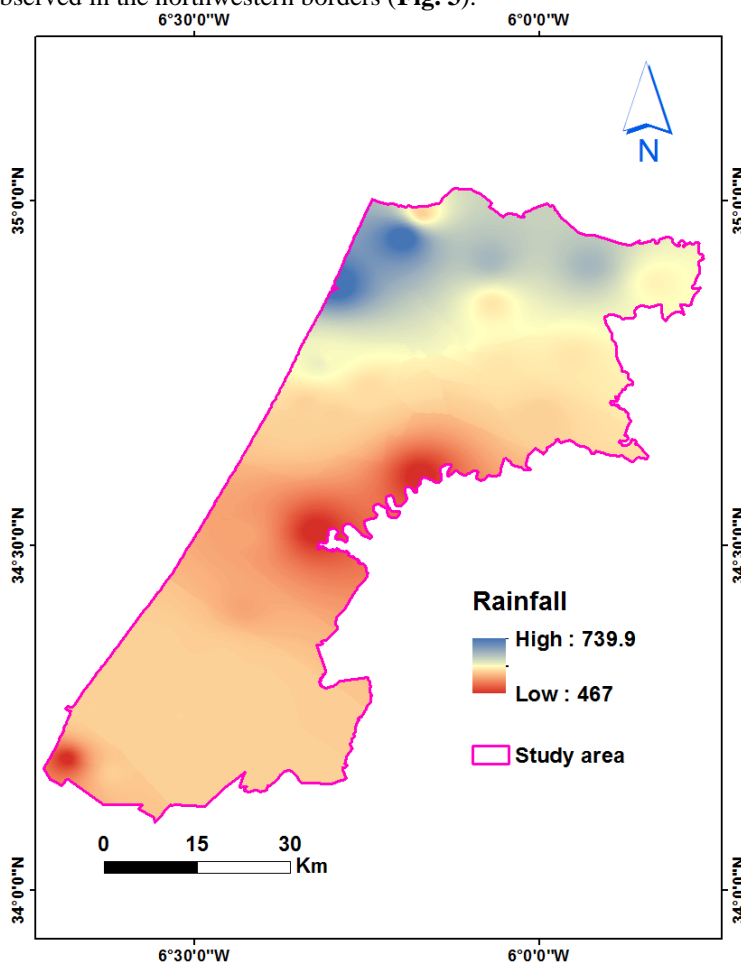

Fig. 3. Annual precipitation (in mm) in Kenitra province using ABHS data.

3.2. LULC

Kenitra province's LULC map was derived from Landsat 8 OLI images taken in February, 2021 with spatial resolution 30m. Then, the supervised classification was used to classify the study area into six categories: Matorral or scrub land, forest, agricultural fields, covered plantations and water bodies (**Fig. 4**). The studied area is largely covered by matorral, agricultural fields and forest covering 56.2%, 25.6% and 16.5%, respectively (**Tab. 3**). The covered plating takes up 1% of the total area. Conversely, water bodies and settlements occupy about 1% are considered unsuitable for harvesting rainwater. Thus, it is apparent that both matorral and forest which take up 72% of the study region are the most favorable areas for collecting runoff rainwater.
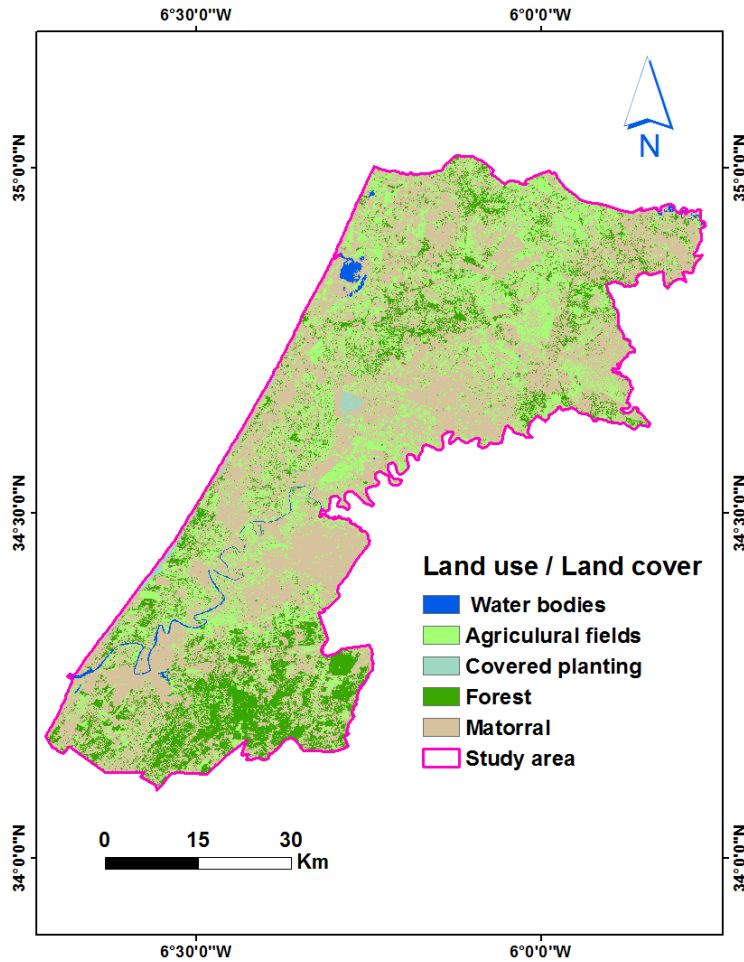
Fig. 4. LULC map of the study area.

<div align="right">**Table 3.**</div>

<div align="center">**LULC suitability class.**</div>

Factor	Type	Rate	Classification	Coverage (%)
LULC	Covered plantations	1	Unsuitable	1
	Agricultural fields	2	Less suitable	25.6
	Water	3	Suitable	0.7
	Forest	4	Very suitable	16.5
	Matorral or scrub	5	Extremely suitable	56.2

3.3. Soil Texture

Soil texture of in Kenitra province can be split into four classes based on previous studies (Batchi et al., 2017): fine, fine-medium, medium and coarse. Using the infiltration rates and soil classification data, this area contains the four types of HSG: A, B, C and D (**Fig. 5**). The parts extending to the center, northeast and west of the study area are covered by HSG-D occupying 35.2%. While, HSG-A and HSG-C cover 28.4% and 23.8% of the total area, respectively. Finally, HSG-B is spreading in small patches in the south-east (**Tab. 4**).
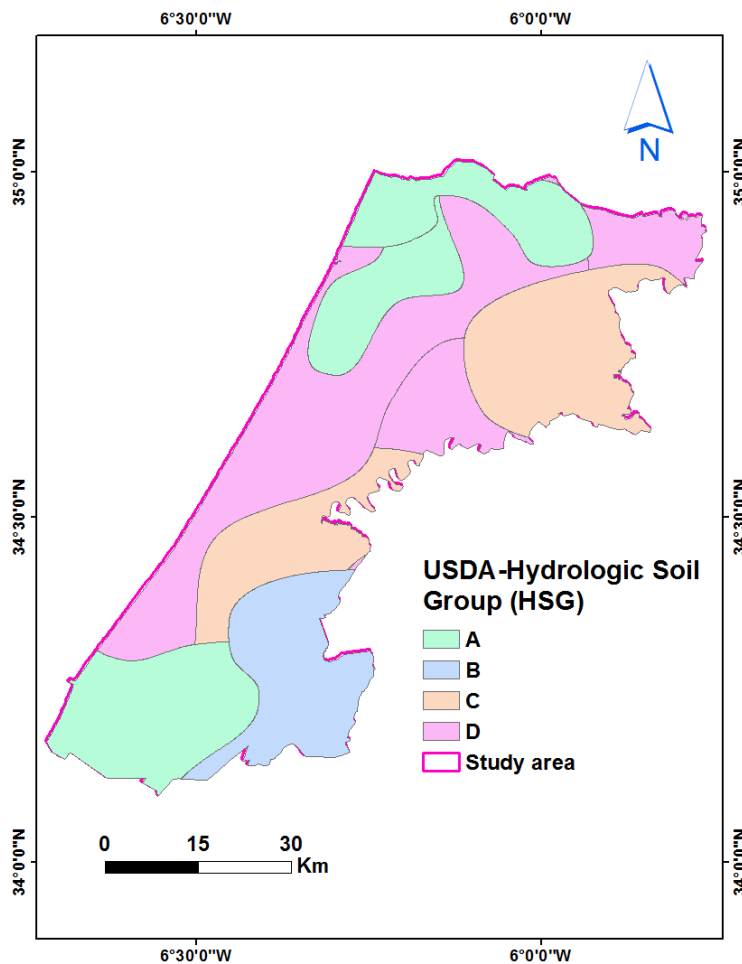
Fig. 5. Soil Texture Suitability Class.

Table 4.

Soil texture and HSGs suitability class.

Factor	Texture	Class	Rate	Classification	Coverage (%)
Soil Texture / HSGs	Fine	A	1	Unsuitable	28.4
	Fine-medium	B	2	Less suitable	12.6
	Medium	C	3	Suitable	23.8
	Coarse	D	4	Very suitable	35.2

3.4. Slope

The developed slope map (**Fig. 6**) was classified into five intervals: (I) almost flat (<3%), (II) gentle (from 3 to 8%), (III) moderate (from 8 to16%), (IV) steep (from 16 to 28%) and (V) very steep (> 28%). The almost flat and gentle slope categories, together occupying almost 86%, these areas are considerably suitable for RWH. The moderate slope class is distributed over small plots in the northeast and occupying about 10%. The steep and very steep classes occupy 4.2%, are considered unsuitable areas for the RWH (**Tab. 5**).
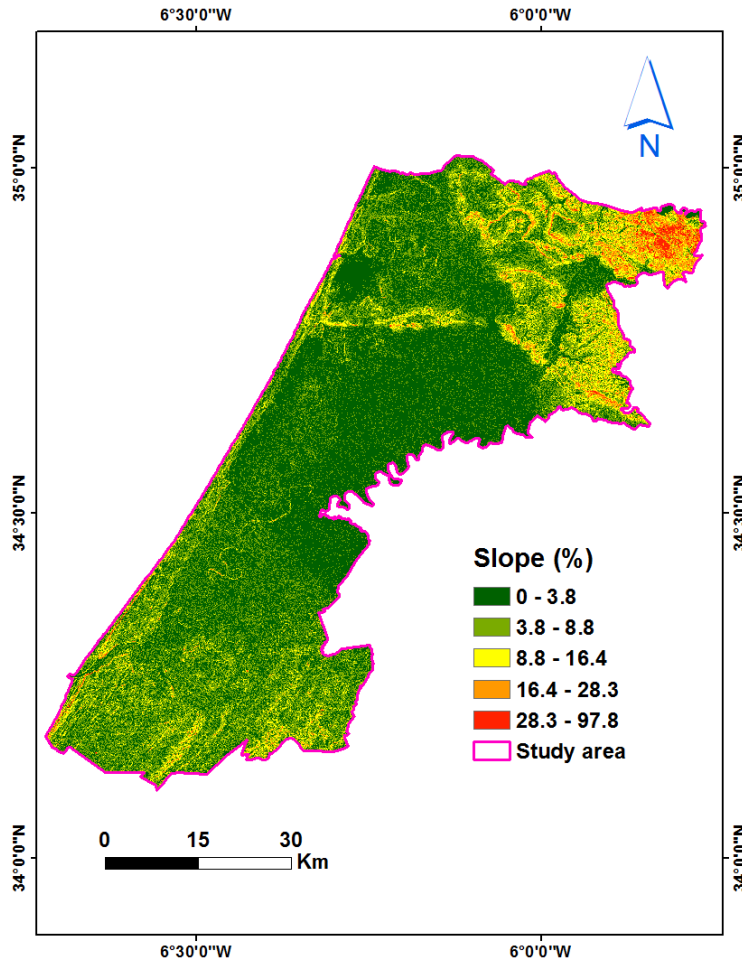
**Fig. 6.** Slope suitability map.

Table 5.

Slope suitability class.

Factor	Interval	Rate	Classification	Coverage (%)
Slope (%)	>28	1	Unsuitable	0.8
	16-28	2	Less suitable	3.4
	8-16	3	Suitable	10.2
	3-8	4	Very suitable	31.5
	<3	5	Extremely suitable	54.1

3.5. Runoff

The produced map of hydrologic soil group based on Kenitra province's soil texture and the LULC map were selected for intersection. Then, a resultant map with new polygons representing the merged hydrologic soil group and LULC (HSGs-LULC map) was generated using ArcGIS software. After this process and using the standard table given by SCS (SCS, 1985), the appropriate CN value was assigned for each polygon (**Tab.6**) in the new HSGs-LULC map to generate the CN map. The CN values range from 30 (HSG$_A$-Forest) to 100 (Water bodies and covered plantings), implying different runoff ability within the study area (**Tab.6**). Based on the CN map, the maximum potential retention map (S) was calculated by **Eq. (2)**. The runoff potential map was calculated using **Eq. (1)**.

Fig. 7 illustrates the spatial distribution of the runoff values in mm. These values ranging from 137 to 738 mm. yr^{-1} and depend on the climate, topography and environment of the study area.

Then, the prepared runoff depth map was classified into five categories (**Tab. 7**): unsuitable (<257 mm. yr^{-1}), less suitable (257-377), suitable (377-497), very suitable (497-561) and extremely suitable (>561 mm. yr^{-1}). Areas where the runoff depth is high is considered extremely suitable for RWH while those where this depth is low is considered unsuitable. About 46% of the study area is occupied by the "very suitable" class. While the "extremely suitable" class occupies 12.6% and the "suitable" and "less suitable" runoff classes occupy 19.6% and 7.7% of the total area, respectively. inappropriate areas occupy only 13.7%.
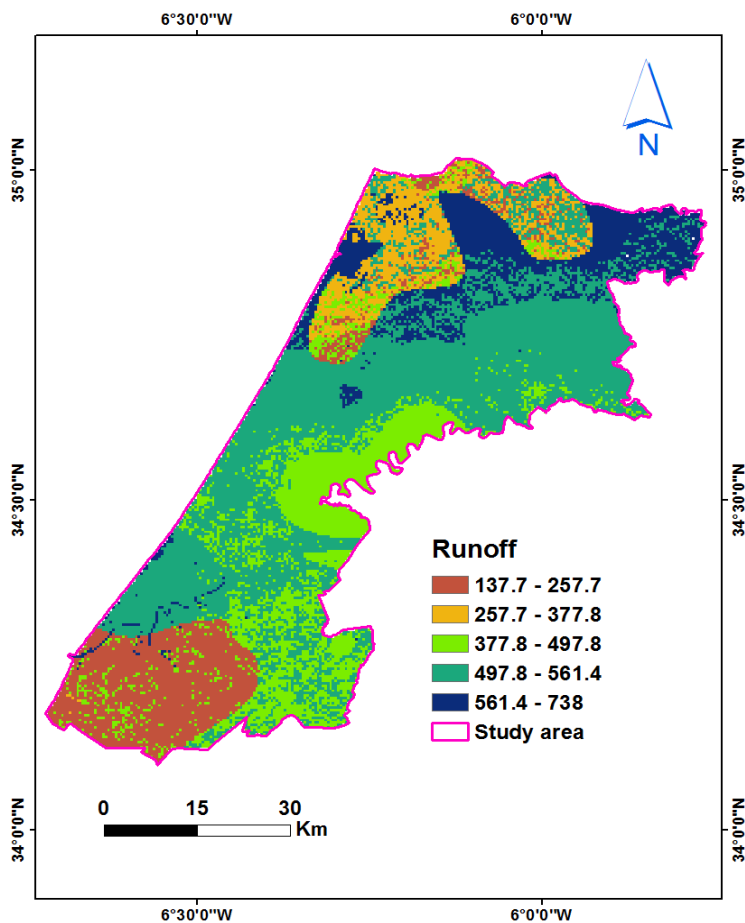
Fig. 7. Runoff depth suitability class.

Table 6.

CN as a function of LULC and HSGs. (USDA-SCS, 1985).

LULC types	CN-II			
	HSG$_A$	HSG$_B$	HSG$_C$	HSG$_D$
Agricultural field	67	77	83	87
Surface water	100	100	100	100
Forest land	30	67	77	83
Matorral or scrub	35	86	91	94
Covered plantations	100	100	100	100

Runoff depth suitability class.

Factor	Class	Rate	Classification	Coverage (%)
Runoff depth (mm)	I	1	Unsuitable	13.7
	II	2	Less suitable	7.7
	III	3	Suitable	19.6
	IV	4	Very suitable	46.3
	V	5	Extremely suitable	12.6

3.6. Drainage density

The developed drainage density map was grouped into five groups according to their importance to RWH suitability. These groups are: (I) Unsuitable (0-0.28 km. km^{-2}), (II) Less suitable (0.28-0.7), (III) Adapted (0.7-1.17), (IV) very suitable (1.17-1.85), (V) extremely suitable (1.85-3.06 km. km^{-2}) (**Fig. 8**). The spatial distribution of these categories shows that I covers 42%, and II covers 23.4% of the study region. However, III, IV and V cover 19.9% 9.8% and 5% respectively. The extremely appropriate category V is distributed in the central parts (in spots) of the study area (**Tab. 8**).
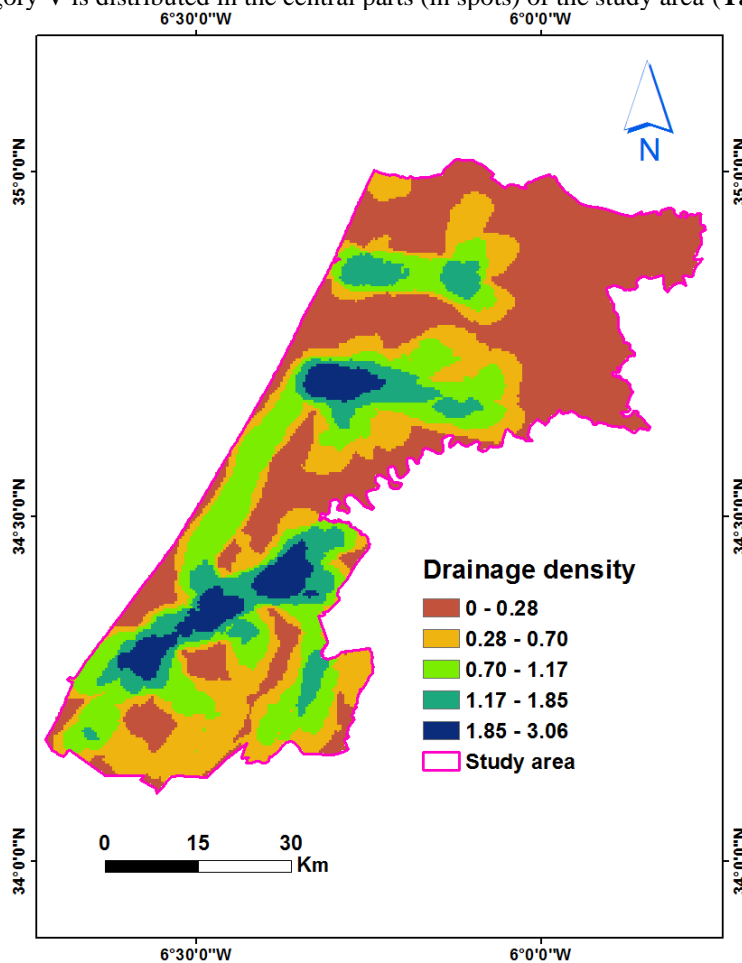

Fig. 8. Drainage density map.

Table 8.

Drainage density suitability class.

Factor	Interval	Rate	Classification	Coverage (%)
Drainage density (km. km-2)	<0.28	1	Unsuitable	42
	0.28-0.7	2	Less suitable	23.4
	0.7-1.17	3	Suitable	19.9
	1.17-1.85	4	Very suitable	9.8
	>1.85	5	Extremely suitable	4.9

3.7. Fuzzy thematic layers

Using "Fuzzy Membership Function" tool of the ArcGIS 10.5 software, all the selected thematic layers used in this study were transformed into fuzzy raster maps with values ranging from 0 to 1. In each fuzzy raster map, pixels with a value of zero means that they are not suitable and those with a value of one means that they are extremely suitable. In these fuzzy raster maps shown in **Fig. 9**, the blue colored areas indicate suitable sites for RWH.
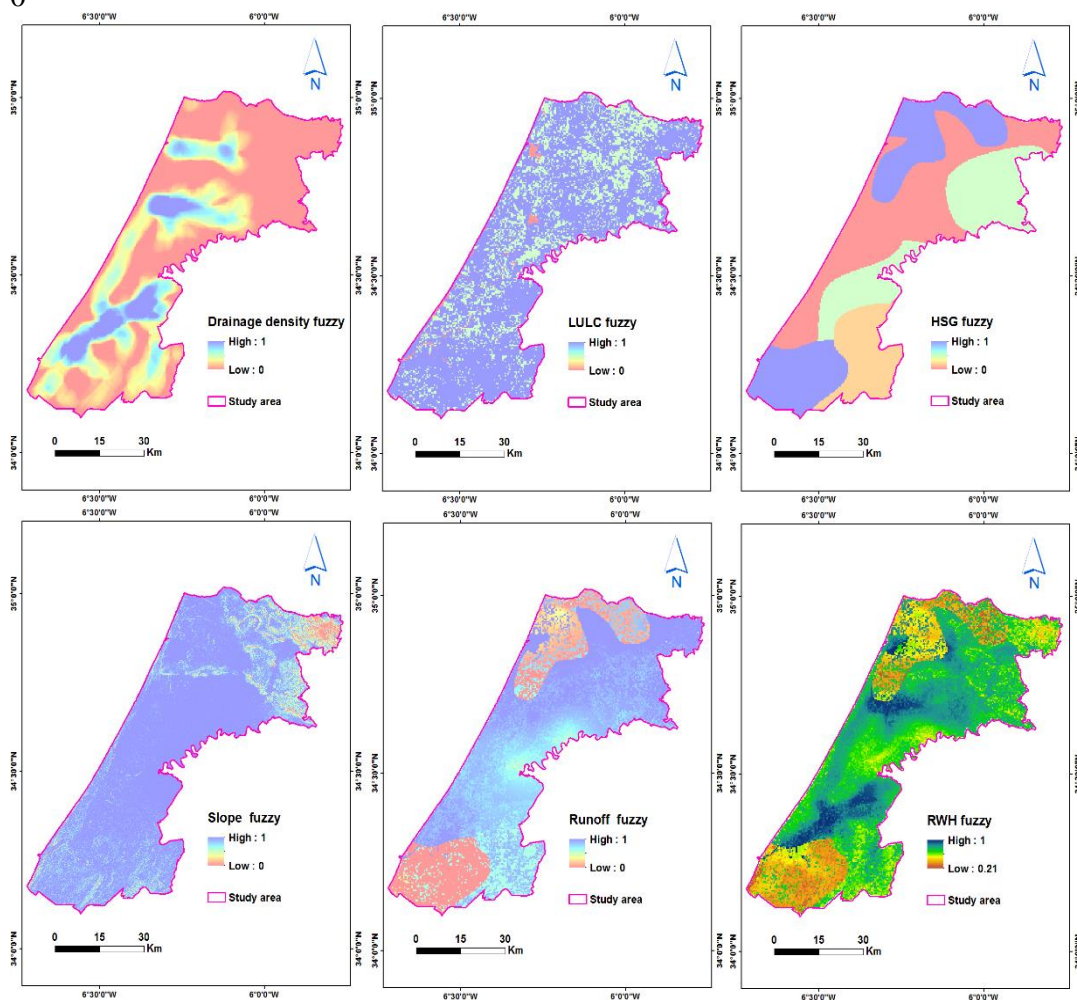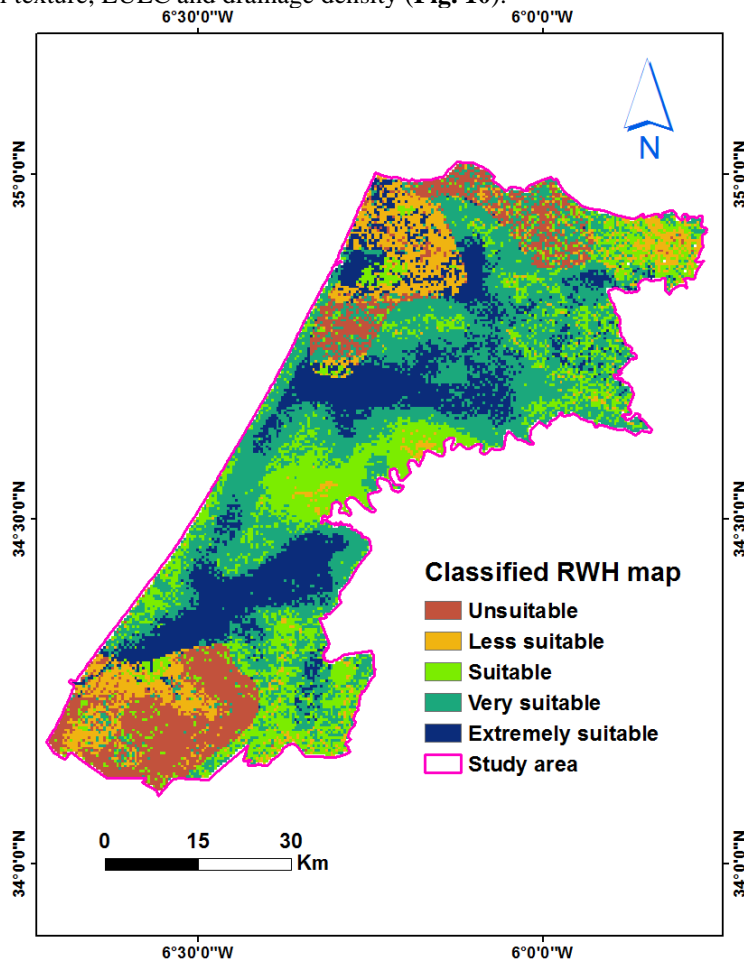
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Fig. 9. Fuzzy maps of the parameters used for the RWH suitability study.

3.8. RWH Potential Map

After a consistent weighting (CR <0.1) of the factors which influence the identification of suitable RWH sites, the RWH potential map was developed by integrating the weighted thematic layers of runoff, slope, soil texture, LULC and drainage density (**Fig. 10**).

Fig. 10. Classified RWH suitability map.
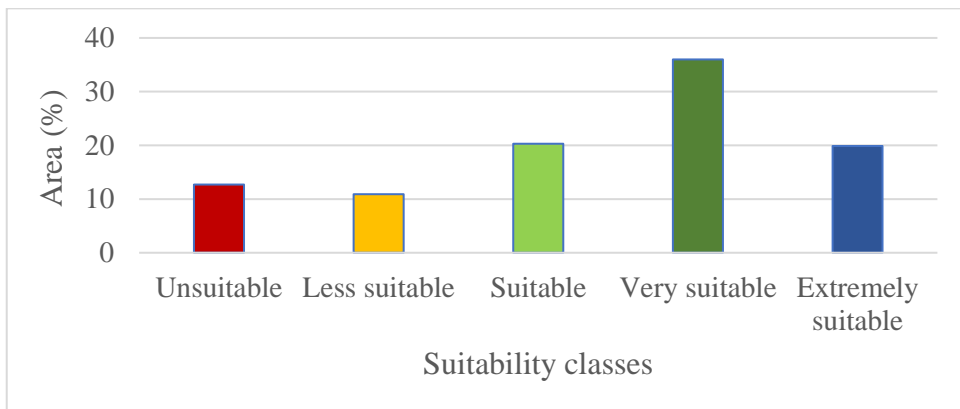
Fig. 11. Distribution of areas covered by the RWH suitability classes.

Then, this map was classified into five main groups: (I) unsuitable, (II) less suitable, (III) suitable, (IV) very suitable and (V) extremely suitable (**Fig. 11**). Group IV is the most dominant, accounting for 35%. Groups III, II and I occupy 20%, 10% and 12% respectively. While group V is distributed in the center and northeast, representing 19% of the study area. Thus, we conclude that a significant part of the study area is optimal for the RWH (**Fig. 12**).

3.9. Validation of the predicted RWH sites with existing ponds or merja

Using an inventory of certain natural ponds and lakes also locally called merjas (In Kenitra province and the Gharb plain in general, the term "merja" designates the lowlands liable to temporarily retain runoff, flood and rainwater) for checking the accuracy of the predicted results by Fuzzy-AHP model. Then, the predicted suitable sites by this model were compared with the existing natural ponds and lakes in the study area and which have been considered as really suitable sites.
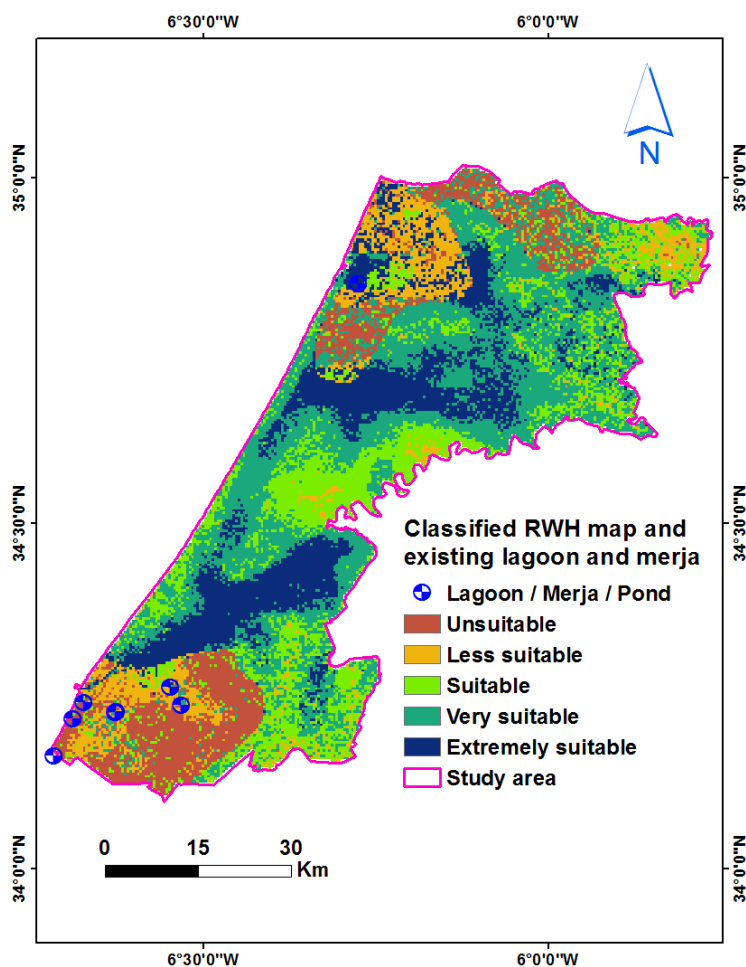

Fig. 12. Classified RWH suitability map and existing natural ponds, lagoons and merjas.

For the validation process, the receiver operating characteristics (ROC) curve was drawn, and the area under curve (AUC) value was calculated by using the ArcSDM software package. The AUC represents the quality of the model to reliably predict the suitability of RWH sites. A good fit model has AUC values that range from 0.5 to 1, while values below 0.5 represent a random fit.

In this work, a success rate curve has been used for validation, as shown in **Fig. 13**. The success rate curve is obtained by plotting the cumulative percentage of existing ponds and merjas against the areal cumulative percentage in decreasing RWH suitability values. The area under the curve can be used to assess the prediction accuracy qualitatively (Lee, 2005). The AUC for the RWH suitability map produced using the FAHP model is 0.51, which means that the overall success rate of the RWH suitability map is 51%. The results obtained from success rate graph indicate that the FAHP model look to be less accurate in terms of the performance of RWH suitability mapping and has acceptable prediction accuracy in the study area.
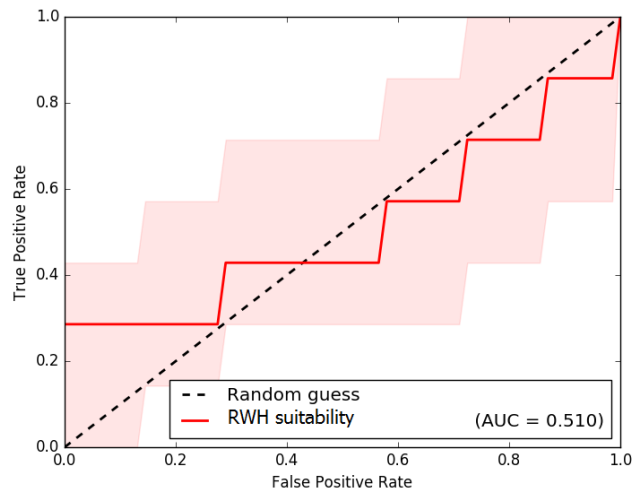
Fig. 13. Success rate curve of the predicted RWH suitability model.

4. CONCLUSIONS

RWH is a strategic alternative source of water in many regions around the world. We selected the Kenitra province in NW Morocco as a representative area experiencing significant demographic growth with rapid expansion of agricultural and industrial activities. We developed and assessed a methodology that integrates a procedure of continuous runoff accounting based on the SCS-CN model with GIS based FAHP method to identify potential sites for harvesting rainwater.

In the present study, the RWH suitability analysis process is due to the ability to integrate into GIS environment a multilayer of relevant parameters such as runoff, slope, soil texture, LULC and drainage density, which give smaller units of suitability as a composite layer. This methodology does not require a lot of time and resources so it is advantageous and profitable for the identification of potential RWH sites.

The runoff depth was estimated by the SCS-CN approach, which was employed using the mean annual rainfall data for the period of 2000–2019 and land use/land cover superimposed by the Kenitra province's soil data. The generated map of runoff showed that the quantity of water runoff is low in the southwest of the study area while it is high in the northeast.

For the RWH potential areas, the results showed that 19.9% of the study area is extremely suitable and 36% is very suitable. On the other hand, 44% remaining distributed in the south-west, center and north-west is moderately adapted or totally useless to the collection of rainwater.

The results of this study are very interesting for water resource managers in the Kenitra province, especially for water supply studies. However, additional fieldwork needs to be carried out in areas considered so suitable for RWH to confirm the results of this study. The techniques used in this work are simple and applicable so they can be used in other parts of the world with water scarcity problems.

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