Efficient rainwater harvesting planning using socio-environmental variables and data-driven geospatial techniques

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Abstract

Water scarcity is increasing worldwide due to population growth and climate variability/change. As a supplementary water resource, Rainwater harvesting (RWH) is a possible solution for dealing with water scarcity, particularly in arid and semi-arid regions with considerable water demand and high variability in precipitation and unexpected extreme events (floods and droughts). The success of RWH systems significantly depends on the location of RWH structures and usually selecting suitable sites is challenging for decision-makers and managers. This paper presents an approach for mapping suitable sites for RWH structures using socio-environmental variables and artificial intelligence algorithms (AIAs). Based on FAO recommendations, the most important conditioning variables for RWH systems are elevation, slope, aspect, precipitation, temperature, distance from the river, curve number (CN), land use, geology, soil type, population density, distance from road, and distance from lakes. An ensemble model was developed based on AIAs, socio-environmental variables, and existing RWH projects, and used for RWH suitability mapping in the large Maharloo-Bakhtegan basin, Iran. Model performance was evaluated using receiver operating characteristic (ROC) and Kappa index. Using the best-performing model, threshold values for conditioning variables were determined from probability curves (PC). The results showed that land use, precipitation, soil type, CN and slope were the most important variables for RHW sites, with the lowest correlation and autocorrelation. The suitability map indicated that 9.7% (3070 km^2) of Maharloo-Bakhtegan basin had very high suitability for RWH systems. Thus, in RWH suitability mapping for large area, climate, hydrological, geological, agricultural, topographical, human and socio-economic parameters should be considered to enable efficient RWH planning. Probability curves revealed that the optimum parameter range (α) in Maharloo-Bakhtegan basin was precipitation 357-428 mm, temperature 12.80-15.16 °C, slope 3-6%, elevation 1612-1975 m asl, distance from lake 32-45 km, distance from river 11.4-15.9 km, distance from road 2.59-4.80 km. The RWH suitability map presented can assist decision-makers, hydrologists, and natural resources planners in finding suitable locations for constructing RWH systems.

Keyword: Water scarcity; RWH planning; AIAs; probability curve (PC); optimum range

1. Introduction

Water is essential to human life and socio-economic development, particularly for agricultural, industrial and domestic consumption (Şahin and Manioğlu, 2019; Ali et al., 2020, Torabi Haghighi et al., 2020). During recent decades, increasing water shortages and climate change at local and global scale have led to more demand for effective alternative water resources, such as rainwater harvesting (RWH), in arid and semi-arid regions (Jha et al., 2014; Imteaz and Moniruzzaman, 2020; Alim et al., 2020b). Besides water scarcity, arid and semi-arid regions are experiencing unexpected flood events due to climate change. RWH systems can be used to collect and store rainwater during wet seasons (with intensive precipitation), for use during water shortages in dry seasons, which also increase soil moisture, recharge aquifers, and rise the capacity of small-holder farmers to irrigate with rainwater harvested, for more agricultural production (Gupta, 1994; Aladenola and Adeboye, 2010; Sepehri et al., 2018). The use of RWH systems to supply non-potable and potable water has been reported in many studies, by e.g. Lee et al. (2016) in Malaysia, Gómez and Teixeira (2017) in Brazil, Kisakye and Van der Brugge (2018) in Uganda, and Bashar et al. (2018) in Bangladesh. All those countries are suffering from water scarcity and all promote the use of rainwater for different purposes. RWH is a well-known approach to increase available water for agriculture and domestic use by recharging groundwater, thus improving small-scale agricultural production (Nachshon et al., 2016; Mucheru-Muna et al., 2017; De Souza and Ghisi, 2020). However, water consumption is increasing due to population growth, industrialisation, agricultural development, changes in human lifestyles, and climate change. Against this background, RWH systems can be considered important water resources for agriculture or even freshwater supply during water shortages (Glendenning et al., 2012; Sepehri et al., 2018; Rahaman et al., 2019). RWH structures can also provide flood control during heavy rain events (Rosmin et al., 2015; Zhang et al., 2018; Liu et al., 2020). For example, they can be used in settlements and cultivated areas to collect water from rooftop and non-rooftop areas, such as residential buildings, roads or cultivated areas (Campisano et al., 2017; Wei et al., 2018; Mugo and Odera, 2019).

Many global investigations applied various criteria and methodologies to study suitable sites of RWH. In Iraq, Ibrahim et al. (2019), and Hashim and Sayl (2020) determined suitable locations for RWH by the weighted linear combination (WLC) and some criteria including climatological, physical characteristics, and socio-economic parameters in GIS. Al-Ruzouq et al. (2019) applied hybrid GIS decision-making and machine learning techniques to identify the best location for RWH structures in the United Arab Emirates. In North-eastern Guatemala, Wu et al. (2018) have used an Analytical Hierarchy Process (AHP) and GIS to determine suitable sites for the implementation of RWH projects. They have employed six sub-criteria: distance from roads potential runoff; slope; land use; distance from agricultural land and soil texture. Also, in some studies, the potential sites for RWH were identified using remote sensing coupled with GIS techniques (Pareta and Pareta, 2020; Singh et al., 2021; Patel et al., 2021). In a research that was done by FAO (2003), some criteria including geographical suitability, technical and environmental suitability, socio-economic suitability and also, associated indicators including agro-ecological zones, storage capacity, soil quality, multiple uses of water, costs, management and maintenance capacity and gender were used in the multi-criteria analysis method. The selection of the suitable site for RWH was carried out by the weights of the criteria in GIS software. Also, Kahinda (2008) used model builder in ArcGIS to combine the physical, socio-economic, and ecological criteria maps to identify RWH sites in South Africa. They express that the acceptable assessment of RWH location cannot be achieved by ignoring socio-economic factors. In another research, Adham et al., (2018) used model builder in ArcGIS to recognize the best location to construct RWH in Iraq. In this study, some biophysical factors, including slope, land use, stream order, soil texture, and runoff depth, were considered for mapping RWH locations.

According to the literature, the possibility to construct RWH systems varies locally and relies on several factors, e.g. socio-environmental conditions, climate pattern, water treatment method, and even availability of construction materials (Domènech and Saurí, 2011; García Soler et al., 2018; Hofman-Caris et al., 2019; Al-Batsh et al., 2019; De Souza and Ghisi, 2020; Alim et al., 2020a; Rahman et al., 2020; Ali et al., 2020). Previous studies have shown that RWH can even be conducted on existing buildings, using small-scale structures. The RWH can efficiently diminish the water shortage due to increased demand for freshwater, climate change/variability, urbanization, population growth, and flooding conditions. An accurate site selection of the RWH is one of the requirements to have an efficient RWH. In this regard, considering the appropriate socio-environmental variables plays an important role in identifying suitable sites for RWH projects. In this study, land suitability for the construction of RWH structures was mapped for a large area (Maharloo-Bakhtegan basin in Iran) by considering different socio-environmental variables and using artificial intelligence algorithms (AIAs). To our knowledge, this is a novel application for AIAs as an efficient rainwater harvesting planning. Other data-driven geospatial techniques have been employed to identify suitable sites for RWH structures for domestic purposes in Maharloo-Bakhtegan basin. Existing RWH structures in the study area were considered in RWH location mapping. An inventory of these structures was conducted through field surveys and available local data. The structures identified included artificial recharge structures, flood spreading structures, crescent pools, bench terraces, farm and storage ponds, percolation tanks, contour ridges, and bunds.

The suitability of land for constructing new RWH structures was assessed by: i) comparing the outputs from three different AIAs (support vector machines (SVM), maximum entropy (MaxEnt), genetic algorithm for rule-set prediction (GARP)); ii) developing a spatial framework for RWH suitability mapping by applying new socio-environmental conditioning variables; iii) developing an ensemble model for RWH that exploited the advantages of the individual AIAs, to increase the accuracy of the results; and iv) developing probability curves, threshold values and optimum ranges for socio-environmental variables affecting the feasibility of RWH systems.

2. Materials and methods

2.1. Study area

The study area, Maharloo-Bakhtegan basin (31,511 km^2), lies in Fars province, southern Iran (29°1′-31°15′N, 51°41′-54°30′E) (Fig. 1). Mountainous areas and plains in the basin occupy

16,630 km^2 and 14,881 km^2, respectively (Hedayat et al., 2017; Abou Zaki et al., 2019). Precipitation in the region is influenced by the Mediterranean regime and changes at different altitudes, so that mean annual precipitation varies from 200 mm in low-lying areas in the southeast of the basin to over 700 mm in the northwest heights. The dominant climate in the region is arid and semi-arid, with cool winters and dry summers (Torabi Haghighi et al., 2020). For climate reasons, water supply in Maharloo-Bakhtegan basin has always been a challenge. In recent decades, consecutive droughts due to low annual precipitation and excessive exploitation of water resources have led to failure of water resources to meet water demand (Haghighi and Keshtkaran, 2008; Choubin et al., 2014). Decreasing vegetation cover has led to increased runoff and soil erosion, and associated damage to surface water quality. These negative changes in the quality and quantity of water resources have resulted in socio-economic problems such as migration and poverty (Tabrizi et al., 2010; Kiani et al., 2017; Torabi Haghighi et al., 2020). Over millennia, inhabitants of Maharloo-Bakhtegan basin used their traditional knowledge to deal with water scarcity by constructing local structures to collect and store rainwater (Shah and Abadi, 2006). The population of the study area is about 2912721 that the per capita water consumption in this area is about 270 liters per day. Also, the area of irrigated lands in the region is 6818.43 km^2 and due to the variety of crops in the region, the per capita consumption varies per hectare. However, considering that more than 90% of water consumption belongs to the agriculture sector, as a result, due to the lack of surface water resources in the Maharloo-Bakhtegan basin, the volume of groundwater withdrawal is more than allowed and this amount has a significant impact on surface water resources such as drying of the Kor River (main river of the Maharloo-Bakhtegan basin), subsidence in plains of the Maharloo-Bakhtegan basin, economic losses due to the reduction of cultivated lands in downstream of the Kor River and the drying of Mahraloo and Bakhtegan Lakes.

This means that in addition to surface and groundwater, special attention should be paid to rainwater harvesting methods as supplementary sources (Zehtabian et al., 2010; Ahmadi et al., 2018). Considering the arid and semi-arid climate of the Maharloo-Bakhtegan basin and high potential for intense flash flooding during the rainy season, identifying suitable areas for RWH structures can be a way forward for sustainable agriculture and water utilisation.

Fig. 1. SOMWHERE HERE

2.2. Materials

2.2.1. RWH systems

Since in this study, all selected RWH structures, which have been constructed over the Maharloo-Bakhtegan basin (as large area), the main purpose of this study was to map the suitability of the RWH structures for water supply based on collecting runoff from intensive precipitation. RWH at the large-scale over the basin (the area where the rainfall or water runoff is initially captured) can be suitable for farmers and even natural ecosystems. The collected water has an acceptable quality for irrigation purposes. Other benefits can briefly be summarized as increasing soil moisture levels, flood control, and increasing the groundwater level through artificial recharge. Rainwater harvesting can be led to achieving higher crop yields, encourage farmers to diversify their enterprises, increasing production, optimizing crop patterns and Livestock development (FAO, 2003; De Winnaar et al., 2007; Mbilinyi et al., 2007; Kahinda et al., 2008; Adham et al., 2018). In this study different types of RWH systems were considered in RWH suitability mapping, with historical RWH structures in Maharloo-Bakhtegan basin providing the most important information. A total of 167 existing RWH structures in the basin, including artificial recharge structures, flood spreading structures, pools, bench terraces, farm and storage ponds, percolation tanks, contour ridges and bunds, were considered (Fig. 2). Information on these structures was obtained in field surveys and in documents published by the Forest, Range and Watershed Management Organization of Fars province in recent years. The dataset on locations of RWH structures was divided 70:30 into two groups by the random split method in ArcGIS 10.5, with 70% of the data used for training (n=117) and 30% for testing (n=50).

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2.2.2. Relative environmental and human variables

Determining potential areas for RWH is important for making the best use of water availability and land productivity in semi-arid regions. However, selecting suitable sites for RWH structures on large-scale regions is challenging since the essential socio-environmental data are often lacking. This paper presents a geographic information system (GIS)-based and AIAs-based that uses socio-environmental data and some remote sensing (RS), limited field survey to identify potential sites for RWH structures. The Food and Agriculture Organization (FAO) has identified six main factors for soil and water conservation: climate, hydrology, topography, agriculture, soils, and socio-economic variables (FAO, 2003; Kahinda et al., 2008; Adham et al., 2018). Based on this, social and environmental conditioning variables were selected in this study: elevation, slope, and aspect (topographical factors); precipitation and temperature (climatological factors); distance from the river and curve number (CN) (hydrological factors); land use/land cover (LULC) (agricultural factor); geology and soil type (geological and pedological factors); and population density, distance from road and distance from lake (human or socio-economic factors). These variables were divided into two classes: i) continuous raster or non-discrete, where cell values show gradual changes (such as elevation, precipitation and temperature), and ii) categorical raster or discrete, which have different types of distinct themes in a given raster map (such as land use map). All factors and the method used for preparing variables are explained briefly below:

Elevation: A digital elevation model (DEM) with 30 m resolution showing the 1412-3922 m asl altitude variation in Maharloo-Bakhtegan basin was obtained from the Forest, Range and Watershed Management Organization of Fars province (Fig. 3a).

Slope: Slope plays an important role in generation of runoff by influencing the speed of overflow and consequently infiltration rate. For RWH systems, some researchers recommend avoiding areas with slope ≤5%, because of irregular runoff distribution and high erosion rates in those areas (De Winnaar et al., 2007; Ziadat et al., 2012). The DEM (30-m resolution) was used with the slope tool Spatial Analyst to generate a slope map for Maharloo-Bakhtegan basin. Slope was grouped into four classes: <0-5%, 5-12%, 12-25%, 25-40% and >40% (Fig. 3b).

Aspect: Maharloo-Bakhtegan is a mountainous basin and receives different amounts of solar radiation on different aspects of hillsides, which influences the rate of evapotranspiration by influencing the temperature and surface warming. As the basin is located in the northern hemisphere, its north-facing slopes are less exposed to sunlight than south-facing slopes, leading to differences in evapotranspiration rate (Fig. 3c).

Precipitation: Since the amount of rainfall in a particular year can not represent the climate of a region, so the long-term average of precipitation was used in the modeling. Data on mean annual precipitation 1989-2019 at 29 meteorological stations (Table 1), obtained from Iranian Meteorological Organization (IRIMO) and Fars Water Authority, were used to produce a spatial precipitation distribution map for the basin by applying the Kriging interpolation method in ArcGIS GIS 10.5. Mean annual precipitation varied from 201 mm in the southeast to 668 mm in the northwest of the basin (Fig. 3d).

Temperature: Since the amount of temperature in a particular year can not represent the climate of a region, so the long-term average of temperature was used in the modeling. Data on annual temperature 1989-2019 at 29 meteorological stations (Table 1), obtained from IRIMO and Fars Water Authority, were used to produce a spatial temperature distribution map for Maharloo-Bakhtegan basin by applying the Kriging interpolation method in ArcGIS GIS 10.5. Mean annual temperature varied from 8.45 °C in the northeast to 15.88 °C in the southeast of the basin (Fig. 3e).

Distance from river: In Maharloo-Bakhtegan basin, small structures play an important role for collecting surface runoff during the rainy season with its intensive rainfall events. Since part of the collected runoff is used for agricultural crops and tree plantations, the efficiency of RWH depends on appropriate site selection of farm and storage ponds. In this regard, analysis of distance from river is important, because at shorter distances soil permeability is higher and this leads to more infiltration and less potential for storing the collected surface runoff in RWH structures. Hence distance from river was considered as another variable in RWH suitability mapping (Fig. 3f). Moreover, dendritic drainage patterns due to the linking of streams have homogeneous soil texture and a lack of structural control.

Curve Number: CN can be used to identify areas with high potential for runoff generation and was thus selected as a hydrological factor for RWH mapping, using the Soil Conservation Service (SCS) method (Fig. 3g). Based on the LULC map and the Hydrologic Soil Groups (HSG), a lumped CN value for each pixel was generated using CN runoff extension in ArcGIS 10.5 software (Darabi et al., 2014). CN values range from 0 to 100, with higher values indicating greater potential of an area to produce runoff (more contribution of rainfall to runoff) (Krois and Schulte, 2014).

Land use land cover: LULC plays an important role in the runoff produced in each precipitation event in a watershed. Areas with a high density of vegetation have higher interception and infiltration rates, and thus lower potential to generate runoff (Fig. 2d) (Kahinda et al., 2008). A LULC map was prepared using Landsat 8 satellite/Operational Land Imager (OLI) images acquired from the USGS dataset for 4 June 2019. In a pre-processing step, atmospheric correction of Landsat-OLI data was carried out using QUick Atmospheric Correction (QUAC) in ENVI 5.5 software. Using the maximum likelihood method (supervised classification), a land use map was then prepared in the ENVI 5.3 software (Torabi Haghighi et al., 2018). Six types of land use and land cover were identified: Rain-fed area, irrigated area, residential area, water body, rangeland and bare soil, which occupied an area of 289.79 km^2 (0.92%), 6818.43 km^2 (21.06%), 272.18 km^2 (0.86%), 1497.97 km^2 (4.75%), 22573.59 km^2 (71.52%) and 109.52 km^2 (0.35%), respectively (Fig. 3h).

Fig. 3. SOMWHERE HERE

Table 1. SOMWHERE HERE

Population density: Inclusion of population density as a socio-economic criterion is highly recommended by FAO (2003), to ensure the success of RWH systems and to increase the adoption of RWH technology by local people and farmers. In this study, five classes of population density within Maharloo-Bakhtegan basin were considered: <18, 18-36, 36-66, 66-200 and >200 persons km^{-2} (Fig. 4a).

Distance from road: Distance from road was used as an indicator of infrastructure development to access RWH systems (Li et al., 2015). Data on distance from road were extracted using the distance module in Arc GIS 10.5 and a road map as a raster map (Fig. 4b).

Distance from lake: Since construction of RWH structures and collection of rainwater (surface runoff) upstream and near lakes reduces the inflow to lakes, distance from man-made reservoirs (e.g. Doroudzan and Mollasadra dams) and natural lakes (e.g. Maharloo and Bakhtegan lakes) was considered (Fig. 4c).

Geology: Geology of watershed can influence the quality of harvested rainwater, e.g. salt formation can create saline runoff, have a significant impact on the quality of collected water and increase water treatment costs. Therefore, choosing an appropriate location for rainwater harvesting structures in terms of geological formations is important (Ghimire et al., 2017). The geology of Maharloo-Bakhtegan basin was divided into four formations: Quaternary, limestone, granite-granodiorite and sandstone-shale (Fig. 4d).

Soil type: Soil type affects the rate of infiltration and consequently the amount of surface runoff. It is thus a critical conditioning variable for site selection for RWH structures, particularly if these structures are intended to store water for domestic and agricultural use (Mbilinyi et al., 2007). The soil types in Maharloo-Bakhtegan basin were divided into eight categories: Aridisols, Entisols/Aridisols, Entisols/Inceptisols, Inceptisols, Playa, Rock Outcrops/Entisols, Rock Outcrops/Inceptisols and Salty Plain (Fig. 4e).

Fig. 4. SOMWHERE HERE

2.3. Methods

Mapping of RWH suitability consisted of following steps: i) Considering existing RWH systems ii) using environmental and human conditioning variables; iii) applying AIAs, iv) performing geographic information system (GIS) analysis and generating suitability maps using AIAs, and v) developing a robust model and identifying important variables using performance criteria.

2.3.1. Artificial Intelligence Algorithms (AIAs)

Support vector machines (SVM)

The SVM algorithm, originally introduced by Vapnik (1963), is a supervised modelling algorithm based on strong generalisation capability with high strength and capacity to handle big data (Antonanzas et al., 2015; Choubin et al., 2018). SVM has been effectively used in different classification and regression environmental problems, mainly due to its high capacity to deal with large non-linear and high-dimensional datasets (Colkesen et al., 2016). Statistical learning theory is the theoretical basis of SVM, which assumes that each input variable has a separate dependency to each response (output) variable and that dependency of input variables on one another is sufficient to determine the rules which can be applied for spatial modelling of the response variable from independent input variables (Huang and Zhao, 2018). SVM thus follows the rule of structural error mineralisation (Wang et al., 2020).

The kernel mathematical function in SVM transforms data into two classes, based on the specific purpose and type of data. Based on the literature (Pranckevičius et al., 2017; Choubin et al., 2019), in this study the radial basis function (RBF) was used to data transformation in R software using ‘e1071’ package The RBF kernel is defined as (Vert et al., 2004; Cura, 2020):

$$K(x_1, x_2) = \exp\left(-\frac{\|x_1, -x_2\|^2}{2 \times \sigma^2}\right) \qquad (1)$$

where $K(x_1, x_2)$ is the RBF kernel, x_1 and x_2 are two features of the kernel, $x_1 - x_2$ is Euclidean distance of two features and σ is a free parameter. The RBF kernel value declines with distance and ranges between zero and one.

Genetic algorithm for rule-set prediction (GARP)

GARP, based on a genetic algorithm (Stockwell, 1999), is widely used in the environmental sciences (Moghaddam et al., 2020). GARP limits environmental conditions by a random set of mathematical rules, where each gene is considered a rule and the cluster of genes is combined in random behaviours (Moghaddam et al., 2020). Genetic evolution models by the iterative process for training and validation inspired the GARP model, which analyses the relationship between environmental variables and response variables (Boeckmann and Joyner, 2014; Darabi et al., 2019). For different outputs, GARP as a stochastic approach applies the best-subset method to select the best run and consequently best result. More detailed explanation of the GARP model is provided by Darabi et al. (2019). In this study, GARP was applied (using Open modeler) for the first time in RWH suitability mapping in Maharloo-Bakhtegan basin.

Maximum Entropy (MaxEnt)

The popular MaxEnt model estimates uncertainty of all conditioning variables, probability of the occurrence of a variable and estimation error variations (Phillips et al., 2006). MaxEnt is useful for geographical distribution modelling based on the most significant environmental conditions (Moreno et al., 2011). It uses the occurrence locations of RWH and a set of environmental conditioning variables to predict RWH suitability. MaxEnt also uses the uniform probability distribution function, where the spatial probability of RWH practice is equal at all pixels (Moreno et al., 2011; Mamun et al., 2018; Kariminejad et al., 2020; Fernandez-Manso et al., 2019). The output of MaxEnt, which generally varies from 0 (lowest) to 1 (highest), was used here to determine the geographical distribution of RWH suitability in Maharloo-Bakhtegan basin.

Ensemble model

An ensemble model was built from the two best AIAs in terms of model performance. The ensemble model was constructed by the following steps: *i)* choosing the best two AIAs based on performance criteria, *ii)* combining these models using R program, to gain all their advantages and avoid disadvantages, and *iii)* evaluating the created ensemble model using performance criteria and selecting the most important socio-environmental variables in the RWH suitability map.

2.3.2 Predictive performance of the models

Model performance was assessed using receiver operator characteristic-area under the curve (ROC-AUC) and Kappa value. The ROC-AUC value is commonly used to evaluate models in distributional modelling and represents the trade-off between two rates as the false-positive and true-positive rates on the X and Y axes (Darabi et al., 2019). On plotting the false-positive fraction against the true-positive fraction for all training and testing points for all possible thresholds, any model that creates a curve with a low number of false-positive at high true-positives is considered a good model, commonly quantified by calculating AUC. The AUC value varies from 0 to 1, where 1 shows the model can distinguish faultlessly between presence and absence data and 0.5 indicates that the model is no better than random prediction. AUC values of 0.51-0.60 indicate weak performance, 0.61-0.70 average, 0.71-0.80 good, 0.81-0.90 very good and 0.90-1.00 excellent accuracy of the model (Pourghasemi et al., 2017). The Kappa statistic was applied to calculate the likelihood of agreement by chance based on null hypothesis assessment. According to Monserud and Leemans (1992), Kappa value is classified into five class: $K < 0.4$ poor, $0.4 < K < 0.55$

moderate, $0.55 < K < 0.85$ good, $0.85 < K < 0.99$ excellent, and $0.99 < K < 1.00$ perfect (Darabi et al., 2019).

2.4. Determining threshold values for conditioning variables

Probability curves (PC) for socio-environmental variables were created based on the constructed RWH systems. The PC represents the probability of establishment (P1) and the probability of non-establishment (P0) for different RWH systems. Based on the probability values, threshold values were determined with a set of continuous conditioning variables (as raster maps). For each of the socio-environmental variables (precipitation, temperature, elevation, slope, distance from the lake, distance from river, and distance from road), PC was created based on the selected model (that with the highest accuracy). Optimum ranges for all socio-environmental variables and based on all constructed RWH systems between lowest and highest thresholds were then considered.

3. Results

3.1. Contribution of socio-environmental variables

The most important socio-environmental variables for SVM model prediction were slope, precipitation, LULC and CN, those for MaxEnt were slope, precipitation, soil type and LULC, and those for GARP were LULC, soil type, precipitation, CN and slope (Table 2). For the ensemble model, the most important variables, with the lowest correlation (Cor-test) and autocorrelation (AC-test), were LULC (Cor-test 0.000, AC-test 0.000), precipitation (Cor-test 0.001, AC-test 0.000), soil type (Cor-test 0.002, AC-test 0.000), CN (Cor-test 0.0013, AC-test 0.0001) and slope (Cor-test 0.0018, AC-test 0.001) .

Table 2. SOMWHERE HERE

3.2. Model performance

The precision and proficiency of the SVM, MaxEnt, GARP and ensemble models, based on ROC-AUC and Kappa index, are shown in Table 3. The highest ROC-AUC values were obtained for the ensemble model (0.957 and 0.865 for training and testing datasets, respectively), followed by GARP (0.935 and 0.847, respectively), MaxEnt (0.838 and 0.829, respectively) and SVM (0.830 and 0.781, respectively) (as shown in Table 3). The AUC values for the training and testing datasets for all models are presented in Fig. 5.

Fig. 5. SOMWHERE HERE

For Kappa index, SVM, MaxEnt, GARP and the ensemble model achieved a value of 0.789, 0.814, 0.892 and 0.922, respectively, for the training dataset, and 0.758, 0.802, 0.880 and 0.901, respectively, for the training dataset, indicating excellent performance of all models (Table 2).

Table 3. SOMWHERE HERE

3.2. Suitable RWH area

Based on the spatial distribution of RWH structures using the SVM, MaxEnt, GARP and ensemble models, the most suitable areas for RWH systems were mapped (Fig. 6a-6d). All models gave a similar overall spatial pattern, with high suitability for RWH in the south and southwest of Maharloo-Bakhtegan basin, but the spatial detail of each model varied at local scales. Regions with the lowest (0.00) and highest (1.00) suitability for RWH systems were effectively identified using all four models. Using the natural break method in ArcGIS 10.7, the spatial distribution of RWH suitability was divided into five classes: very low, low, moderate, high and very high suitability, the spatial distribution zones for which are presented in Fig. 6e-6h. The RWH suitability maps obtained with all models indicated that the south and southeast of the basin are best suited for RWH systems.

Fig. 6. SOMWHERE HERE

Table 4 presents information on the area and percentage area of the different RWH suitability zones. In terms of area, the RWH suitability zone maps obtained with the SVM, MaxEnt, GARP and ensemble models (Fig. 6e-6h) showed that the area with very high suitability represented 7.57%, 8.72%, 11.72%, and 9.73% of total basin area according to SVM, MaxEnt, GARP and the ensemble model, respectively (Table 4). The maps also revealed that most of Maharloo-Bakhtegan basin was in the low suitability zone, which occupied 29.29%, 29.27%, 29.81% and 32.21% of total area according to SVM, MaxEnt, GARP and the ensemble model, respectively.

Table 4. SOMWHERE HERE

3.5. Probability curves (PC) for ensemble model

Fig. 7 shows the proposed PC, which represent P1 of RWH structures. Using PC, optimum ranges (or recommended ranges) for construction of RWH systems for all continuous variables (precipitation, temperature, elevation, slope, distance from lake, distance from river and distance from road) were determined based on the ensemble model (which showed the best performance) and threshold values. Threshold values were varied at 50% P1 and P0 for each continuous variable. Table 5 presents threshold values and optimum ranges for the different socio-environmental variables. As shown in Fig. 7a, for precipitation values >357 mm, P1 was greater than P0 for RWH systems and P1 increased strongly with increasing precipitation. However, for precipitation values >380 mm, P1 for RWH systems increased very slowly. Thus 357-428 mm was considered the optimum precipitation range (α_{prcp}) for implementation of RWH systems. P1 for RWH systems increased with increasing temperature (Fig. 7b). With temperature ≤12.80 °C, P1 for RWH systems was lower than P0, while with temperature >12.80 °C, P1 was greater than P0 and increased with increasing temperature. Thus 12.80-15.16 °C was considered the optimum temperature range (α_{temp}) for implementation of RWH systems. PI for RWH systems increased with increasing slope, but at slope >6% P1 was less than P0 (Fig. 7c). Thus 3-6% was considered the optimum slope range (α_{slope}) for implementation of RWH systems. At elevation up to 1975 m asl, P1 was greater than P0 for RWH systems, while at altitude 1975-2150 m asl P1 was less than P0. Thus 1612-1975 m asl was considered the optimum elevation range ($\alpha_{elevation}$) for implementation of RWH systems. As shown in Fig. 7e and Fig. 7f, P1 for RWH systems increased as distance from lake and distance from river increased (these two variables showed similar P1 values). The optimum range for distance from lake (α_{lake}) and distance from river (α_{river}) for implementation of RWH systems was considered to be 32-45 km and 11.4-15.9 km, respectively. The average probability of success for RWH systems decreased with increasing distance from road, with P1 being greater than P0 up to 4.8 km from road (Fig. 7g). The optimum range for both distance from river (α_{river}) and distance from road (α_{road}) for establishment of RWH systems was considered to be up 11.4 and 4.8 km. Table 5 summarises the optimum range (α) for all socio-environmental variables.

Table 5. SOMWHERE HERE

Fig. 7. SOMWHERE HERE

4. Discussion

During the last decades, a rapid increase in population and problems related to an inefficient water supply, ensuring water availability is a challenging issue in arid and semi-arid regions with unexpected weather events (drought and floods events) and an intensive climate. RWH is a green technique for improving agricultural productivity and it is a well-known method for collecting and storing rainwater for different purposes (potable, agricultural, engineering, and comprehensive purposes). Rainwater harvested as an unconventional water alternative and well-known technology delivers many profits to the environment and society, which should be considered as a socio-environmental responsibility of communities over the world in water resources management and conservation to reduce rising demand on conventional water resources (Hafizi Md Lani et al., 2018; Sheikh, 2020). Under future changes, it can provide a water supply in periods of water shortages and can mitigate flooding following extreme rainfall events in arid and semi-arid regions (Sepaskhah and Fooladmand, 2004; Sepehri et al., 2018; Rahaman et al., 2019; Gonela et al., 2020). Recently, numerous studies have focused on how to use harvested rainwater effectively, e.g. by avoiding the use of potable water for non-potable usages and by reducing small-scale drawdowns outside the main system. However, most studies have found that small-scale RWH structures are frequently used to supply drinking water at household level in rural areas (Domènech and Saurí, 2011; Naddeo et al., 2013; Alim et al., 2020a; Alim et al., 2020b). In contrast, there are bigger projects which collect and harvest rainfall from a bigger area (e.g. basin) which provide more water for environmental, agricultural, and even rural community consumptions and usually invested by the government and local communities therefore we called them "RWH planing at large-scale". Some researchrers have reported that RWH from the rooftops and tank systems were considered as small-scale and they mentioned that the feasibility of RWH at the small-scale intended to produce drinking water for rural communities (Lani et al., 2018; Alim et al., 2020a; Cardoso et al., 2020). Several parameters such as roof size, tank size, water demand, and daily filtration rate were taken into consideration to examine the performance RWH for the small-scale (Rahman et al., 2012; Alim et al., 2020a). Methodology presented in this studt was considered a RWH planing at the large-scale and it was useful for water supply and runoff potential collection. RWH planinig at the large-scale is suitable with the point of use for farmers and natural ecosystems and water collected has the acceptable quality for agricultural purposes (harvested runoff water from rainwater is in large quantities and volume, it is contaminated by sediment on the catchment). Other benefits include increasing soil moisture levels and increasing the groundwater level via artificial recharge. Rainwater harvesting and its application to achieving higher crop yields can encourage farmers to diversify their enterprises, such as increasing production, upgrading their choice of crop, purchasing larger livestock animals, or investing in crop improvement inputs such as irrigation infrastructure, fertilizers, and pest management (FAO, 2003; De Winnaar et al., 2007; Mbilinyi et al., 2007; Kahinda et al., 2008; Adham et al., 2018).

The present study considered the feasibility of RWH suitable spatial mapping in arid and semi-arid regions where rainfall is low and freshwater availability is limited. Direct use of stored rainwater in dryland can increase agricultural productions. RWH at the large-scale, has considerable volume of rainwater and runoff which can be collected in water conservation structures such as recharge pond or check/cross dams. However, by using efficient methods that rely on scientific principles, efficiency planning can be implemented RWH structures at the large-scale and help to achieve the sustainable management of water resources. Usually RWH systems at small size scale are used for the water supply of one or several plants, humans, or animals such as rooftop harvesting. On the other hand, some usual RWH structures are improved to supply urban population demand, groundwater recharge, agriculture and hydroelectric power which are at large size scale such as flood spreading systems, pitting, furrowing and banquette, dams, Check dams. Future management of water resources in arid and semiarid areas will need to adapt to climate change, particularly in developing regions such as the Rift Valley dryland of Ethiopia (Muluneh et al., 2017). This is critical in achieving food security and sustainable development. Sannigrahi et al. (2020) concluded that climate change will also result in changes in ecosystem services and that RWH can help combat water shortages and secure the ecosystem services that nature provides to humankind. RWH as a nature-based solution can also help prevent land degradation (Keesstra et al., 2018) and support afforestation and farming, with trees contributing to global warming reductions by sequestering carbon (Abbas et al., 2017) and irrigated agricultural crops enriching the soil with organic matter (Novara et al., 2019). This study mapped suitable locations for rainwater harvesting in Maharloo-Bakhtegan basin, which is providing information for decision-makers, hydrologists, and natural resources planners for designing future RWH systems.

5. Conclusions

Rainwater harvesting (RWH) strategies at the large-scale are an important primary water source that can be a useful climate change adaptation policy by RWH's multi-functionality and high adaptability in many arid and semi-arid zones, which comprise 40% of land on Earth. It is the main and most important method for drinking water supply in arid and semi-arid parts of Iran, where people have stored rainwater in underground reservoirs (especially in the Fars province) for centuries. In recent decades, low prices and easy access to groundwater resources through technological developments have made extraction of groundwater a more widely used water resource. This is leading to declining groundwater resources and depletion of aquifers, so to meet the growing demand for water use of RWH is being reconsidered. Recent developments in GIS and remote sensing techniques, accompanied by experimental and traditional applications of RWH systems, have made it possible to develop new approaches and procedures to identify suitable sites for RWH structures. In this study, the criteria for various RWH structures were determined based on FAO guidelines, which set ideal limits for RWH conditioning environmental and human factors. Mean annual precipitation of 350-390 mm/year was identified as a suitable range for most RWH structures and a steep slope for RWH structures was shown to be unsuitable. The suitability of areas for constructing RWH structures increased with increasing distance from lakes and dams, especially in the upstream direction. However, according to field data, only 17 out of 167 existing RWH structures (~10%) have been constructed upstream of dams (Doroudzan, Sivand and Mollasadra reservoir dams). Also, the main conclusions of this study are as follows:

- RWH suitability mapping can be conducted using AIAs, providing reliable results without expensive field surveys and complicated data.
- Remote sensing and GIS are useful techniques for locating and implementing RWH structures in regions with little data.
- RWH suitability maps can be used in risk reduction strategies when implementing RWH systems.
- Appropriate design of RWH at the large-scale is essential for sustainable water resource management and efficient planning to level out water availability intra-annually and mitigate natural hazards such as floods and droughts.
- A new approach for RWH suitability mapping based on probability curves, threshold values and optimum ranges for conditioning socio-environmental variables proved useful.

- Considering the dynamic of some conditioning variables in determining the suitable locations of RWH structures leads to different results over time. For example, precipitation and temperature are variable over time, and they have temporarily been affecting model outputs. Therefore, precipitation and temperature were considered as dynamic variables over time, and long-term (1989-2019) precipitation and temperature data were considered.
- Since in this study the relationship between the catchment area and capacity of the RWH structures were not assessed, it would be highlighted the analysis relationship between catchment area and capacity of the RWH structures, can be considered as future work and directions.
- However, harvested runoff water from rainwater is in large quantities and volume, it is contaminated by sediment on the catchment, and construction and treatment costs are very high. Therefore, compared to other rainwater harvesting methods (e.g. roof water harvesting), RWH at the basin scale is commonly preferred to use related to low-water quality consumptions and it is a cost-effective technique.
- Generally, our methodology assessed the implementation aspect of RWH at the large area and the findings highlight a potential solution to the sustainable water utilization given global climate change.
- However, the methodology as presented in this study provides a valuable screening of large areas, it can easily be adapted to include other information or criteria with other spatio-temporal resolutions.

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