environmental sciences proceedings

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Proceeding Paper

A Comparative Analysis of Analytical Hierarchy Process and Machine Learning Techniques to Determine the Fractional Importance of Various Moisture Sources for Iran's Precipitation †

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† Presented at the 5th International Electronic Conference on Atmospheric Sciences, 16–31 July 2022; Available online: https://ecas2022.sciforum.net/.

Abstract: Iran is a semi-arid and arid region in southwest Asia. Hence, studying the moisture sources of precipitation in this country has great importance. Iran's moisture sources were determined for dry (May to October) and wet (November to April) periods. Understanding the importance of each moisture source influencing Iran has great application in climatological models. In this study, the fractional importance of various water bodies providing moisture for Iran was determined for more than 35 years (1981–2015) by various machine learning as well as analytical hierarchy process (AHP) and fuzzy AHP models. Finally, the accuracy of the developed models was validated by the coefficient of determination (R^2) and mean squared error (MSE).

Keywords: Iran; moisture sources; fractional importance; machine learning techniques; FLEXPART model

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Citation: Heydarizad, M.; Pumijumnong, N.; Gimeno, L. A Comparative Analysis of Analytical Hierarchy Process and Machine Learning Techniques to Determine the Fractional Importance of Various Moisture Sources for Iran's Precipitation. *Environ. Sci. Proc.* **2022**, *19*, 29. https://doi.org/10.3390/ecas2022-12839

Academic Editor: Anthony Lupo

Published: 20 July 2022

1. Introduction

Iran is a semi-arid and arid country in the Middle East region with an annual precipitation average of 252 mm, which has faced a water shortage crisis from the early times. Hence, various elements of the hydrological cycle should be studied deeply and accurately in this country. The hydrological year in Iran is divided into dry (May to October) and wet (November to April) periods [1,2]. Iran's climate is under the influence of various air masses, such as continental polar (cP) from the north, maritime polar (mP) from the northwest, Mediterranean (MedT) from the west, continental tropical (cT) from the southwest, all belonging to wet and cold periods. However, during hot and dry periods, only a maritime tropical (mT) air mass from the southeast direction influences Iran [1,2]. This is due to the high-pressure Azores, which expands over large parts of Iran and prevents air masses and moisture from entering the country [1,2]. These various air masses bring the moisture from the nearby water bodies. Numerous studies have been dedicated to the variations of precipitation across Iran, including Refs. [1,3–6]. However, small number of studies, including Refs. [1,7–9], focus on the moisture sources and their trajectories toward Iran. This is maybe due to a much more complicated process and software needed to monitor moisture sources.

The moisture sources of Iran's precipitation were determined using the Lagrangian particle dispersion model (FLEXPART) version 9.0 developed by Stohl and James [10,11]. This model was applied to track the air particles residing over Iran for 10 days backward in time, which is the average residence time of the vapor in atmosphere [12]. The FLEXPART divides the atmosphere into 2 million particles with an equal mass and then moves these particles by time in three (one vertical and two horizontal) dimensional wind fields [13,14]. In each particle trajectory, the specific humidity in the particle can be estimated considering the content of evaporation (e) and precipitation (p) in the particle using Equation (1) [10,11].

$$(\mathrm{e}-\mathrm{p}) = \mathrm{m}\ (\mathrm{dq}/\mathrm{dt}) \tag{1}$$

In this equation, the mass of each particle (m) constant may cause a small error. However, according to Stohl and James [11], the particles' mass changes are so slight through the removal or addition of water. Finally, resolving the above equation for all the particles residing over the area (A) will result in the calculation of the surface freshwater flux (representing the difference of area evaporation (E) and area precipitation (P)) by Equation (2).

$$(\mathrm{E}-\mathrm{P}) \sim \frac{\sum_{k=1}^{k}(e-p)}{A} \tag{2}$$

For each parcel's backward trajectory, the (E−P) > 0 values indicate a region where evaporation exceeds precipitation. However, the region with (E−P) < 0 indicates higher precipitation compared to evaporation. Finally, the moisture uptake from each water body is calculated by masking each nearby water body area from the (E−P) > 0 maps (Figure 1).

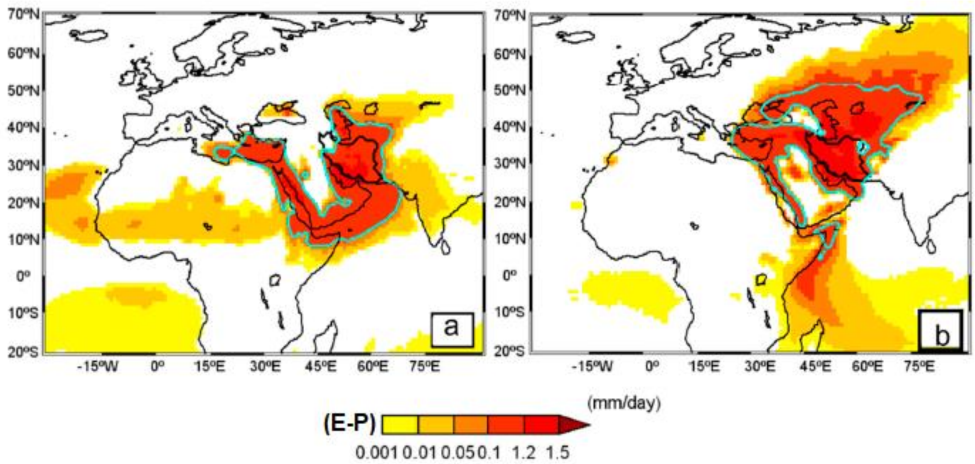

Figure 1. Seasonal variation of (E−P) > 0 (mm/day) for wet (**a**) and dry periods (**b**) between 1981 and 2015 [9].

The results of the FLEXPART model outputs also show that the Arabian Sea, with a share of 28.3% of total moisture uptake (Figure 2), is the dominant source of Iran's moisture during the wet periods, followed by the Persian Gulf, with a share of 21.5%, and the Mediterranean Sea, with a share of 17.3%. However, during dry periods, the Red Sea plays the dominant role, with a contribution of 52.2%, followed by the Caspian Sea, with a contribution of 16.7% [9]. In the Karimi and Farajzadeh study [15], they believed that the Arabian Sea and the Mediterranean Sea, with a share of 39% and 38%, are the main moisture providers for Iran's precipitation. There is an important difference between their study and Heydarizad et al.'s study [9]. Karami and Farajzadeh considered the moisture uptake sources in Iran for the rainy season, while Heydarizad et al. considered moisture uptake sources for both dry and hot, as well as wet and cold, periods. This is the reason why the results of Karami and Farajzadeh's study are so similar to the wet period results in Heydarizad et al.'s study.

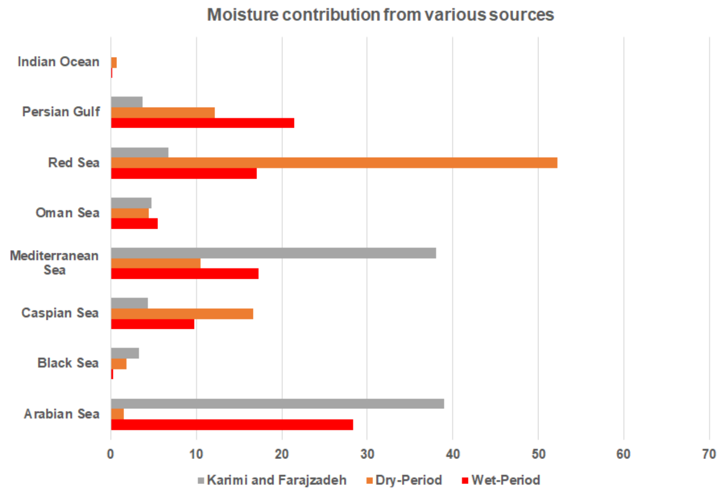

Figure 2. The contribution percentage of various moisture sources in Iran for wet and dry periods.

Although obtaining the contribution of each moisture source compared to total moisture uptake is extremely important, it is also necessary to understand the fractional importance of each moisture source influencing precipitation amounts across Iran. To study the fractional importance of each moisture source influencing the precipitation amount, various methods, including analytical hierarchy process (AHP), and machine learning techniques can be applied. The application of AHP methods to organize and analyze complicated scenarios has been conducted in numerous studies since Thomas L.Saaty had developed this method in the 1970s [16]. In addition to AHP, artificial intelligence and machine-learning techniques can also be applied to investigate the fractional importance of each moisture source affecting precipitation in Iran. The application of machine learning models in different aspects of the sciences has been increased dominantly over the last few years.

The aim of the following survey is to determine the fractional importance of various moisture sources influencing Iran during wet and dry periods using AHP and machine learning techniques.

2. Materials and Methods

To determine the fractional importance of various moisture sources influencing Iran, the (E−P) values for each nearby water bodies were used as input to the machine learning models. These (E−P) values were used to simulate the precipitation amount across Iran using the AHP and machine learning models, including simple artificial neural network (ANN), deep neural network (DNN), decision tree and random forest. Finally, the accuracy of the adopted models was validated by a comparison between real and simulated precipitation values on the testing subset using the coefficient of determination (R^2) and mean squared error (MSE) using Equation (3).

$$\mathrm{MSE} = \frac{1}{\mathrm{N}} \sum_{\mathrm{i}=1}^{\mathrm{N}} (\mathrm{fi} - \mathrm{yi})^2 \quad (3)$$

where N is the number of data points, fi is the value simulated by the model, and yi is the actual value for data point i.

3. Results and Discussion

To study the fractional importance of the various water bodies which provide moisture for Iran precipitation, firstly, the (E−P) values for each water body for the period 1981 to 2015 by the FLEXPART model were used [2,9]. The (E−P) values were entered as the input in various machine learning models to simulate the precipitation amount across Iran, and the results are shown in Figure 3. It can be seen that during wet periods, when in most parts of Iran precipitation occurs, the Arabian Sea has a dominant role in influencing the precipitation amounts in Iran, according to all the developed models. However, during dry periods, the dominant moisture sources vary in different developed models. For instance, the Arabian Sea has the dominant role according to DNN and AHP models. The Black Sea has the dominant role in influencing the precipitation amounts according to the ANN model, the Indian Ocean according to the fuzzy model and the Mediterranean Sea according to the random forest model.

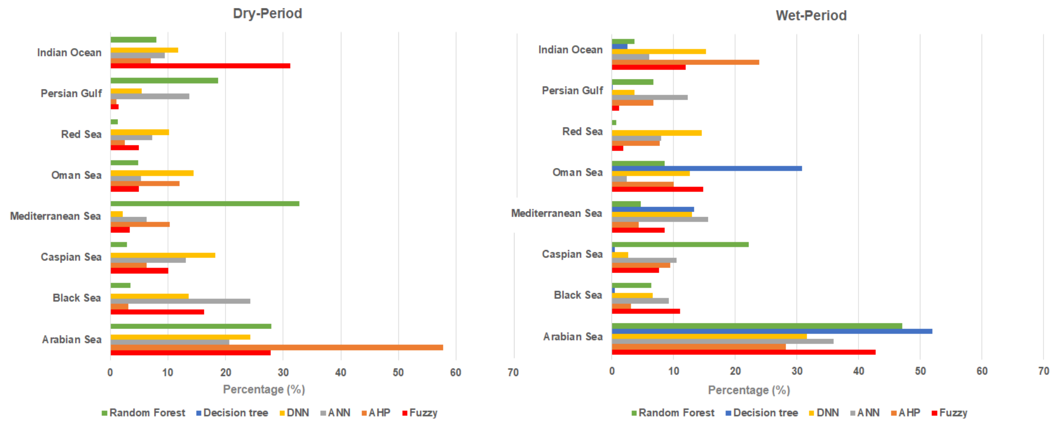

Figure 3. The fractional importance of various moisture sources influences precipitation across Iran during wet and dry periods.

During wet periods, the Arabian Sea, which is the dominant moisture provider (with a share of 28.3%), influences the precipitation amounts (with a fractional importance of 35.9%). However, the Red Sea and the Persian Gulf, which have a high contribution to the provision of moisture (17.1% and 21.5%), have a weak role in influencing the precipitation amounts (with a fractional importance of 8.0% and 12.3%). In contrast, the Black Sea and the Indian Ocean, which have a very weak contribution to the provision of moisture (with a share of 0.31 % and 0.23%), have stronger roles in influencing the precipitation amount (with a fractional importance of 9.2% and 6.1%, respectively). These differences between the moisture contribution and the fractional importance of moisture sources influencing the precipitation are due to local parameters, which influence the moisture in the atmosphere and provoke the precipitation. For instance, the moisture from the Red Sea and the Persian Gulf normally cannot be transferred deep inside the Iranian plateau, and they normally influence low-elevation regions near the coastal area in the southern part of the Zagros mountains. In this region, the climatology situation is not appropriate for precipitation to occur. However, the Black Sea moisture is transferred to Iran via a maritime polar (mP) air mass, which influences the northwest part of Iran and normally causes intense precipitation in this region. On the other hand, the Red Sea, which has a dominant role in providing moisture during dry periods (with a share of 52.2%), has a very low influence on the precipitation amount (with a fractional importance of 10.2%). As mentioned earlier, although the evaporation and moisture originating from the Red Sea and, to a lower extent, from the Persian Gulf, are extremely significant, due to high air temperatures during dry periods, their influence on Iran's precipitation amount is scarce. This is because of a significant role of atmospheric stability that exists in this region, which prevents moisture from turning into precipitation. In contrast to the Red Sea, the contribution of the moisture uptake from the Arabian Sea, the Black Sea and the Indian Ocean is so scarce (with a share of 1.5%, 1.9% and 0.7%, respectively), but their influence on the precipitation amount across Iran is stronger (fractional importance of 24.3%, 13.6% and 11.7%, respectively). Regarding the Black and Arabian Seas, the elevation at which these water bodies' moisture is transferred to Iran and the local situation are appropriate for precipitation to take place. For the Indian Ocean, the moisture originating from this water body is transferred via maritime tropical (mT) air mass and causes intense monsoon precipitation in the southeast part of Iran.

Studying the performance of the developed models according to the R^2 and MSE shows that none of the developed models are reliable and applicable during dry periods (Table 1). This is because the small amount of precipitation, which occurs during the dry periods in Iran, is mainly under the influence of the local moisture sources and small-scale climatology processes. During the dry periods, although the amount of evaporation and (E−P) values are high, the parameters that are responsible for precipitation are not strong and active enough to cause precipitation. The main reason that prevents precipitation from occurring during the dry periods in large parts of Iran is atmospheric stability [9]. In stable atmospheric conditions, if an air parcel is lifted over a mountain or blown upward by an updraft, the lifted air parcel will sink down to the earth due to the fact that this air parcel is cooler than the air particles around it. This phenomenon will prevent precipitation from taking place during dry periods in Iran [8]. In October (the beginning of cold and wet periods), the air temperature reduces, which enables the ascending motion of the air parcels which result in the instability of the atmosphere, helping precipitation to take place. During the wet periods, the ANN model had the best performance among the developed models, while the DNN model was the second-best model. However, the decision tree model performance was the worst among the studied models (Table 1).

Table 1. Performance of the developed models in the training and testing stage.

Model	Wet Periods				Dry Periods			
	MSE		R^2		MSE		R^2	
	Training	Test	Training	Test	Training	Test	Training	Test
ANN	469	519	0.67	0.63	126	251	0.16	0.03
DNN	546	694	0.67	0.48	107	228	0.11	0.11
Decision tree	870	959	0.41	0.26	_	_	_	_
Random forest	517	889	0.43	0.28	244	412	0.12	0.01

4. Conclusions

The results of this study show that the contribution percentage of moisture uptake from the various sources does not totally match the fractional importance of various moisture sources influencing the precipitation amount in Iran. This mainly occurs during dry and hot periods when the local phenomena predominantly control precipitation amount across this country.

Author Contributions: Conceptualization, M.H., L.G. and N.P.; methodology, N.P.; software, M.H.; validation, M.H. and L.G.; formal analysis, M.H.; investigation, M.H.; resources, L.G.; writing—original draft preparation, M.H.; supervision, N.P. and L.G.; project administration, N.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the faculty of Environment and Resource studies, Mahidol university, grant number MU-PD-2021-13 and Iran ministry of higher education.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be available on request.

Acknowledgments: Special thanks to our friends in Vigo university, Ourense campus in Spain. The first author also acknowledges the postdoctoral fellowship (no. MU-PD-2021-13) from the faculty of environment and resource studies, Mahidol university.

Conflicts of Interest: The authors declare no conflict of interest.

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