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Long-term monthly evapotranspiration modeling by several data-driven methods without climatic data

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ABSTRACT

In this study, the ability of four different data-driven methods, multilayer perceptron artificial neural networks (ANN), adaptive neuro-fuzzy inference system (ANFIS) with grid partition (GP), ANFIS with subtractive clustering (SC) and gene expression programming (GEP), was investigated in predicting long-term monthly reference evapotranspiration (ET_0) by using data from 50 stations in Iran. The periodicity component, station latitude, longitude and altitude values were used as inputs to the applied models to predict the long-term monthly ET_0 values. The overall accuracies of the multilayer perceptron ANN, ANFIS-GP and ANFIS-SC models were found to be similar to each other. The GEP model provided the worst estimates. The maximum determination coefficient (R^2) values were found to be 0.997, 998 and 0.994 for the ANN, ANFIS-GP and ANFIS-SC models in Karaj station, respectively. The highest R^2 value (0.978) of GEP model was found for the Qom station. The minimum R^2 values were respectively found as 0.959 and 0.935 for the ANN and ANFIS-GP models in Bandar Abbas station while the ANFIS-SC and GEP models gave the minimum R^2 values of 0.937 and 0.677 in the Tabriz and Kerman stations, respectively. The results indicated that the long-term monthly reference evapotranspiration of any site can be successfully estimated by data-driven methods applied in this study without climatic measurements. The interpolated maps of ET_0 were also obtained by using the optimal ANFIS-GP model and evaluated in the study. The ET_0 maps showed that the highest amounts of reference evapotranspiration occurred in the southern and especially southeastern parts of the Iran.

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1. Introduction

Evapotranspiration (ET) is a process of losing water to the atmosphere via the combined process of evaporation from the soil and transpiration from the plants. In agriculture science especially in arid and semiarid areas, proper prediction of the given crop evapotranspiration (ETc) is important. Therefore, the ability to obtain or estimate evapotranspiration (ET) is of great importance for operating irrigation systems (Karimadldini et al., 2012). ETc can be calculated by multiplying ET_0 (reference evapotranspiration) to the crop coefficient (Kc) of the crop.

Several methods and techniques could be applied for calculating or estimating ET including (1) direct, (2) indirect and (3) data-driven methods. Direct measurement method by using lysimeter is the best options for obtaining ET crop and ET_0 but is a difficult task because it is time-consuming and needs potential financial and environmental resources. As a result, a large number of indirect methods such as empirical, semi-empirical equations and data driven models have been developed for measuring ET_0 from meteorological data (Karimadldini et al., 2012). Some of the indirect ET_0 estimation methods can be named as simple pan evaporation-based methods and combination methods such as (Penman, 1963), Penman–Monteith (Monteith, 1965) and etc.

One of the best known indirect method is the Food and Agricultural Organization of the United Nations (FAO) method in which combines the equation of Penman–Monteith modified by Allen in 1998 (FAO-56 PM equation) as a reference equation for ET_0 estimation. The FAO-56 Penman–Monteith (PM-56) equation is influenced by several weather parameters including measurement of the maximum and minimum air temperature, maximum and minimum relative air humidity, wind speed and solar radiation. With an exception to the air temperature which is available at most weather stations, the remaining variables are often

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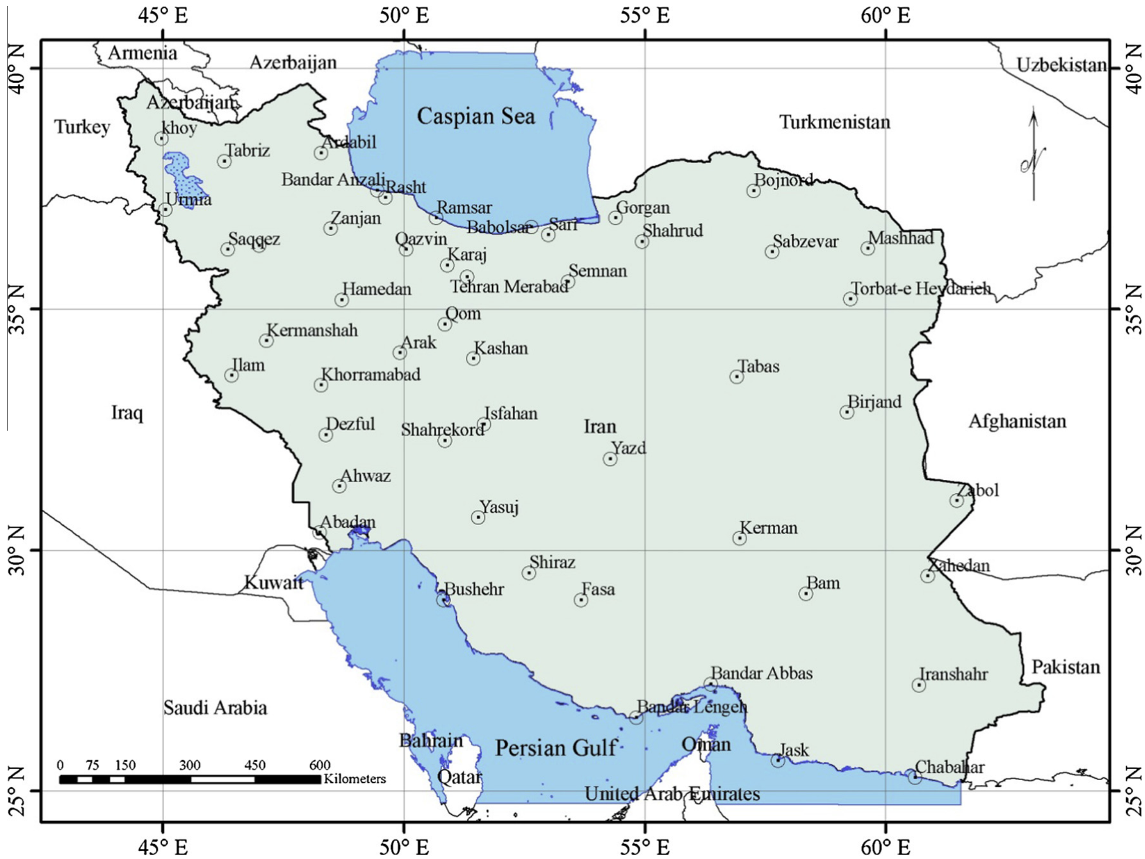

Fig. 1. The location of the stations in Iran.

Table 1
The geographical information of the stations used in the study.

No	Station	Long. (E)		Lat. (N)		Alt. (m)	ET_0 (mm/day)	No	Station	Long. (E)		Lat. (N)		Alt. (m)	ET_0 (mm/day)
1	Tehran Merabad	51	19	35	41	1191	4.76	26	Ramsar	50	40	36	54	−20	2.24
2	Sanandaj	47	0	36	20	1373	3.87	27	Babolsar	52	39	36	43	-21	2.53
3	Rasht	49	37	37	19	-8.6	2.32	28	Saqqez	46	21	36	15	1523	3.56
4	Ahwaz	48	40	31	20	22.5	6.20	29	Sabzevar	57	39	36	12	972	5.46
5	Zanjan	48	29	36	41	1663	4.04	30	Torbat-e Heydarieh	59	16	35	13	1451	4.15
6	Urmia	45	3	37	40	1328	3.10	31	Khoy	44	58	38	33	1103	2.88
7	Ardabil	48	17	38	15	1332	2.87	32	Kashan	51	27	33	59	982	3.39
8	Gorgan	54	24	36	54	0	2.84	33	Fasa	53	41	28	58	1288	4.69
9	Sari	53	0	36	33	23	2.78	34	Bandar Anzali	49	27	37	29	-23.6	2.41
10	Arak	49	55	34	6	1708	3.68	35	Bandar Lengeh	54	50	26	32	22.7	5.58
11	Kermanshah	47	9	34	21	1319	4.34	36	Jask	57	46	25	38	5.2	5.23
12	Ilam	46	26	33	38	1337	4.52	37	Bam	58	21	29	6	1067	6.47
13	Khorramabad	48	17	33	26	1148	4.11	38	Abadan	48	15	30	22	6.6	6.68
14	Shahrekord	50	51	32	17	2049	3.46	39	Dezful	48	23	32	24	143	5.00
15	Qazvin	50	3	36	15	1279	3.83	40	Zabol	61	29	31	2	489	8.42
16	Yasuj	51	33	30	41	1816	3.89	41	Mashhad	59	38	36	16	999	3.86
17	Bojnord	57	16	37	28	1112	3.59	42	Bandar Abbas	56	22	27	13	9.8	5.29
18	Birjand	59	12	32	52	1491	5.10	43	Semnan	53	25	35	35	1127	4.05
19	Zahedan	60	53	29	28	1370	5.84	44	Shiraz	52	36	29	32	1484	4.90
20	Yazd	54	17	31	54	1237	5.45	45	Kerman	56	58	30	15	1754	5.43
21	Bushehr	50	49	28	58	9	5.06	46	Tabriz	46	17	38	5	1361	4.11
22	Tabas	56	55	33	36	711	4.67	47	Hamedan	48	43	25	12	1679	3.93
23	Iranshahr	60	42	27	12	591	6.10	48	Qom	50	51	34	42	877	4.83
24	Chabahar	60	37	25	17	8	4.67	49	Isfahan	51	40	32	37	1550	4.42
25	Shahrud	54	57	36	25	1349	4.00	50	Karaj	50	54	35	55	1313	4.11

incomplete or not always available for many locations and even not always reliable (Rahimikhoob, 2010). Regarding the above contexts, there are so many factors affecting ET estimation based on indirect methods, thereafter it is extremely difficult to formulate the ET_0 equation that can produce reliable estimates.

The main problem with modeling ET process is its nonlinear dynamic and high complexity, in this respect, using data-driven methods (e.g. ANN, ANFIS, SVM ...) based on soft computing techniques could be considered as proper methods for estimating ET_0. These methods are known for their ability in dealing with

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