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Analyzing the Temporal and Spatial Variation of Fog Days in Iran

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Abstract—In order to study the temporal and spatial variation of fog days in Iran, the data of 115 synoptic meteorological stations have been analyzed for years 1960–2005. The results revealed that different types of fogs form all over the country, apart from central areas of Iran that are located in the big dessert of Iran. Advection fogs are common in the south coast (Persian Gulf) and north coastal (Caspian Sea) regions. Upslope fogs form in the mountainous areas of the northwest and north parts of Iran. This study shows no height dependence relationship on fog days for all types of fogs in overall. The trend analysis of fog days during the last 20 years shows some significant negative and positive trends. The frequency of advection fogs shows positive trends and most upslope fogs show negative trends. The results show that there are suitable places for fog collection projects in the north and south coastal regions during the year, especially in cold months.

Key words: Fog, Fog days, Fog collection, Persian Gulf, Iran.

1. *Introduction*

There is an ever-growing need to identify new sources and methods for collecting water in both the developed and developing countries, specially in arid and semi-arid regions, and it is clear that serious consideration needs to be given to unconventional water supplies (ACOSTA BALADON, 1995). One of these methods is fog collection. A broader look at the meteorological and oceanographic condition on a worldwide basis, as well as the topography, leads us to the conclusion that many countries may have the potential to benefit from fog collection (SCHEMENAUER AND CERECEDA, 1997). One of the largest projects has provided, since March 1992, an average of 11,000 L of water per day to a village of 330 people in the arid coast desert of North Chile (AL-FENADI, 2001).

Fog water deposition is not only relevant for single plants, but is also contributing to the hydrological budget of an area and can contribute to the recharge of ground water (WERNER EUGSTER, 2008).

Water can be collected from fogs under favorable climatic conditions. Fog is defined as a mass of water vapor condensed into small water droplets at, or just above, the Earth's surface. The small water droplets present in the fog precipitate when they come in contact with objects (SCHEMENAUER AND CERECEDA, 1991). Fog collection rates are typically 1–10 L m^{-2} of vertical collecting surface per day but can reach values of 30–40 L m^{-2}/day (SCHEMENAUER AND CERECEDA, 1994). The large fog-water collectors consist of a double layer of mesh made from a 1 mm wide flat polypropylene ribbon. The theoretical collection efficiencies of a 1 mm wide ribbon, for droplets with the observed median volume diameter (MVD), at wind speeds from 2 to 8 m s^{-1}, are 75–95%. Studies show that the mesh shows a marked decrease in droplet collection as the ribbon width increases, while maintaining a constant percentage areal coverage (SCHEMENAUER AND JOE, 1989).

Iran is located in southwest Asia and borders the Oman Sea, Persian Gulf, and Caspian Sea. Most of the country is located in regions of subtropical high pressure and more than 75% of its area is arid and semi-arid. The average annual rainfall of all the country is about 250 mm.

Iran consists of rugged, mountainous rims surrounding high interior basins. The main mountain chain is the Zagros Mountains, a series of parallel ridges interspersed with plains that bisect the country from northwest to southeast. Many peaks in the Zagros exceed 3,000 m above sea level, and in the south-central region of the country there are at least five peaks that are over 4,000 m (Fig. 1).

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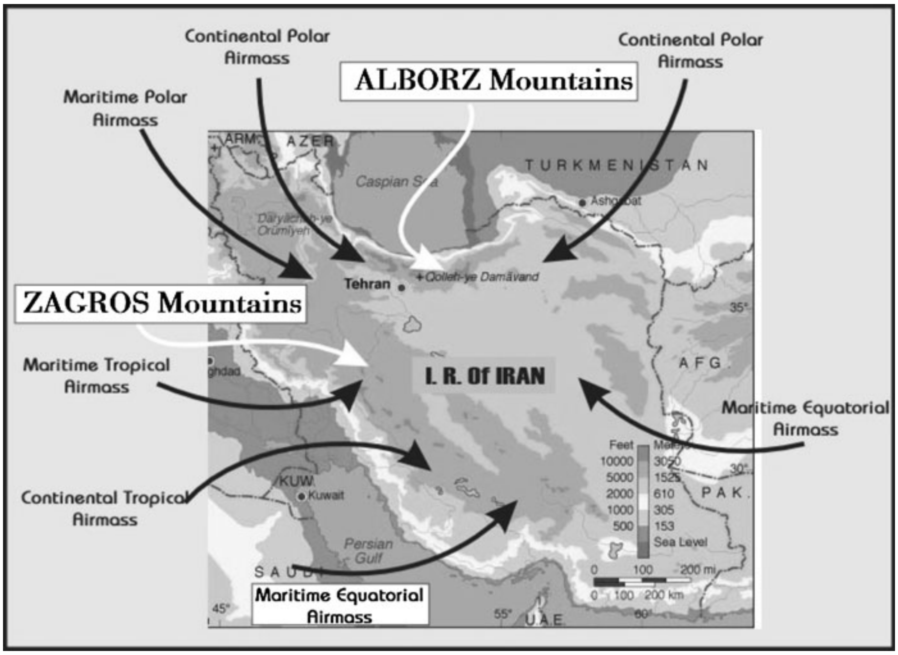

Figure 1
Geographical regions and air masses of Iran

As the Zagros continue into southeastern Iran, the average elevation of the peaks declines dramatically to under 1,500 m. Rimming the Caspian Sea littoral is another chain of mountains, the narrow but high Alborz Mountains. Volcanic Mount Damavand, 5,610 m, located in the center of the Alborz, is not only the country's highest peak but also the highest mountain on the Eurasian landmass west of the Hindu Kush.

The center of Iran consists of several closed basins that collectively are referred to as the Central Plateau. The average elevation of this plateau is about 900 m, but several of the mountains that tower over the plateau exceed 3,000 m. The eastern part of the plateau is covered by two salt deserts, the Dasht-e Kavir (Great Salt Desert) and the Dasht-e Lut. Except for some scattered oases, these deserts are uninhabited.

Iran has only two expanses of lowlands: the Khuzestan Plain in the southwest and the Caspian Sea coastal plain in the north. The former is a roughly triangular-shaped extension of the Mesopotamia plain and averages about 160 km in width. It extends for about 120 km inland, barely rising a few meters above sea level, and then meets abruptly with the first foothills of the Zagros. Much of the Khuzestan plain is covered with marshes.

Iran has a variable climate. In the northwest, winters are cold with heavy snowfall and subfreezing temperatures during December and January. Spring and fall are relatively mild, while summers are dry and hot. In the south, winters are mild and the summers are very hot, having average daily temperatures in July exceeding 38°C. On the Khuzestan Plain, summer heat is accompanied by high humidity. The main air masses affecting Iran are shown in Fig. 1.

In general, Iran has an arid climate in which most of the relatively scant annual precipitation falls from October through April. In most of the country, yearly precipitation averages 250 mm or less. The major exceptions are the higher mountain valleys of the Zagros and the Caspian coastal plain, where precipitation averages at least 500 mm annually. In the western part of the Caspian, rainfall exceeds 1,000 mm annually and is distributed relatively evenly throughout the year. This contrasts with some basins of the Central Plateau that receive 10 cm or less of precipitation annually.

The Alborz Mountains are elongated from west to east in the north part of the country and capture all humidity of air masses which come from the north and take humidity from the Caspian Sea that creates the central deserts. The Zagros Mountains (northwest to southeast) take the humidity of systems which come from the Persian Gulf. The windward part of these mountains is green and the other parts of Iran are mainly semi-arid and arid.

However, in the northern parts (Caspian Sea coasts) the annual rainfall is about 1,200 mm, whereas in central parts of Iran annual rainfall is about 60 mm. These common conditions, and specific conditions such as droughts, make it necessary to quest for new resources and methods for water supply (Fig. 2).

Research interests related to fog are often closely linked with geographical places where fog occurs frequently and thus are considered a relevant component of the respective climate (Werner Eugster, 2008). Because of the geography of Iran, upslope fogs form in mountainous areas. Proximity to the Persian Gulf in the south and the Caspian Sea in the north of Iran provides suitable conditions to form advection fogs. The wet and warm air from the sea comes over the land and forms fog when it reaches the cold surface of the neighboring land area.

Since advection and upslope fogs form regularly in most parts of Iran, fog collection is a candidate for a suitable operational method of water supply. Esfandiarnejad *et al.* (2010) studied the feasibility of water harvesting from fog and atmospheric moisture in the south coast region of Iran. According to their findings the Persian Gulf coast has high potential for water harvesting from fog and also dew.

2. Materials and Methods

The length of the fog season in a region should be determined. Analyzing the data of fog days could be useful in this step. However, the duration of fog in a day is also important for water collected from fog. A fog day is a day that fog has been observed in an observational point (American Meteorological Society, 2000). There is a difference between water collected from a 1 h fog day and a 20 h fog day. The other point that should be considered is the density of

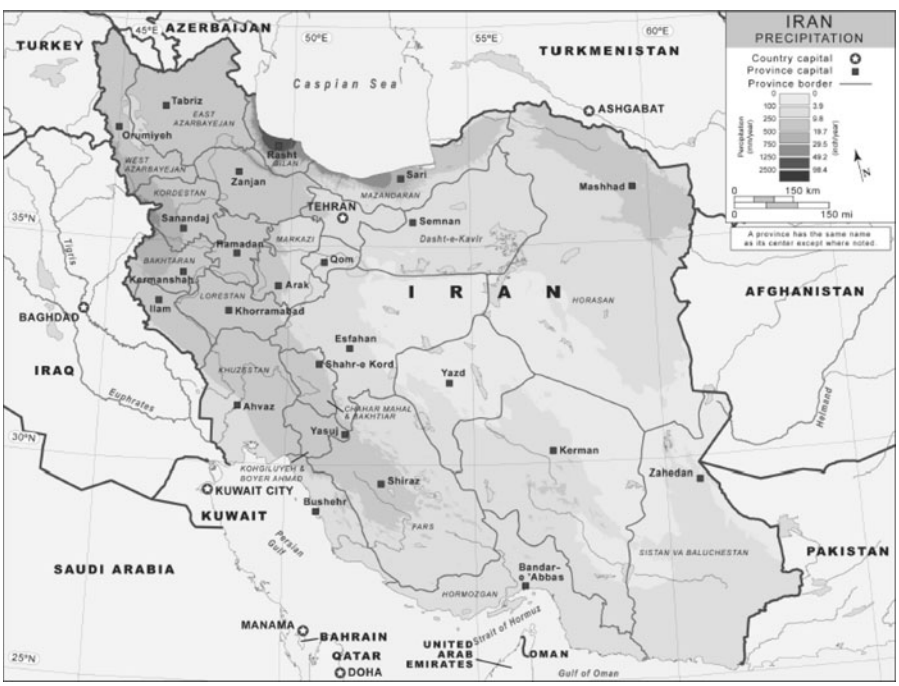

Figure 2
Precipitation map of Iran

fog. Mist and dense fog have different water collection productivity. In conclusion, the number of fog days, fog duration in a day and the density of fog are important factors of water productivity of a fog event in a given place.

If the region is recognized to have potential fog days, through travel in a region, discussion with the local people, and meetings with government officials and meteorologists, an idea can be obtained as to whether there are high elevation regions with a water requirement and frequent fog.

A more sophisticated program uses standard fog collectors of 1 m^2 to measure the fog water production rates on specific terrain features. Because fog collection is a non-conventional method of obtaining water, a public education program should be started early in any project. The next step is to design a system of collection, transport and distribution of the fog water.

We have undertaken the first step of a fog collection program. Determining the fog days is necessary to define potential places for fog collection projects.

The study area includes all of Iran, which is about 164 $million^2$ km. The data of more than 115 synoptic stations from the I.R. Iran Meteorological Organization (IRIMO) are used to determine fog days (IRIMO, 2007). Locations of these stations are shown in Fig. 3.

A fog day is a day when fog is observed at an observation point. Data included fog days in each month throughout the year. However, since synoptic and airport stations mainly are located in flat areas and low level lands near the cities, the fog days in highlands and mountainous areas are greater than at neighboring synoptic stations. The distribution of stations over the country seems to cover well the fog days. The fog days data is an average of a long term period that is different for each station. However, for most of the stations this period exceeds 20 years. Since there are some trends in temporal variation of fog days during past 10 years because of climate change, we did not consider the WMO suggested base period of time (i.e. 1961–1990) as we need to know the current situation of fog days in the country. Map zoning of fog days was done for all the country. The interpolation method for mapping of fog days was inversed distance weighting (IDW). In this method the value of each point in the map varies with inverse distance from the known input of near station with given fog days.

Using this method, areas with a high number of fog days were determined for the map. The places with no stations would also be recognized and the fog days interpolated. Also, the graphs of fog days variation during the year were determined for some specific stations. There are four stations, each representative of a topo-climatological area including coastal, island, highland, and low level stations. The last two types are far from the sea.

In order to investigate altitude dependence, a correlation relationship between altitude and fog days was developed. However, in this survey we select just stations that are located inland and far from the sea. Since most fogs in stations near the sea are advections fogs and do not depend on altitude, no significant correlation was anticipated.

3. Results

Table 1 shows the fog days in stations which have more than 50 fog days in a year. As is clear from the table, most of the fog types in island and coastal stations are advection and upslope fogs. Advection fogs especially occur at night because the land becomes colder than the sea and condensation occurs. Since island stations are encircled by water, they have more fog days than coastal stations. Islands include the Kish and Siri Islands. Regarding coastal stations such as Astara, Bandar Abbas, and Abadan, the fog days decrease by distance from the sea. This issue is related to advection fogs and is not relevant for other types of fog.

In land sites far from the sea, such as Parsabad and Ardabil, radiation fogs and upslope fogs frequently form due to low temperature and high altitudes. In some regions all kinds of fog form together and increase the fog days. Astara is a good example of this. Astara is located in the northwest highlands in the west coast of the Caspian Sea. The average length of the fog season in Astara is 220 days/year.

The map of fog days is shown in Fig. 4. The high amount of fog days in the northern and southern

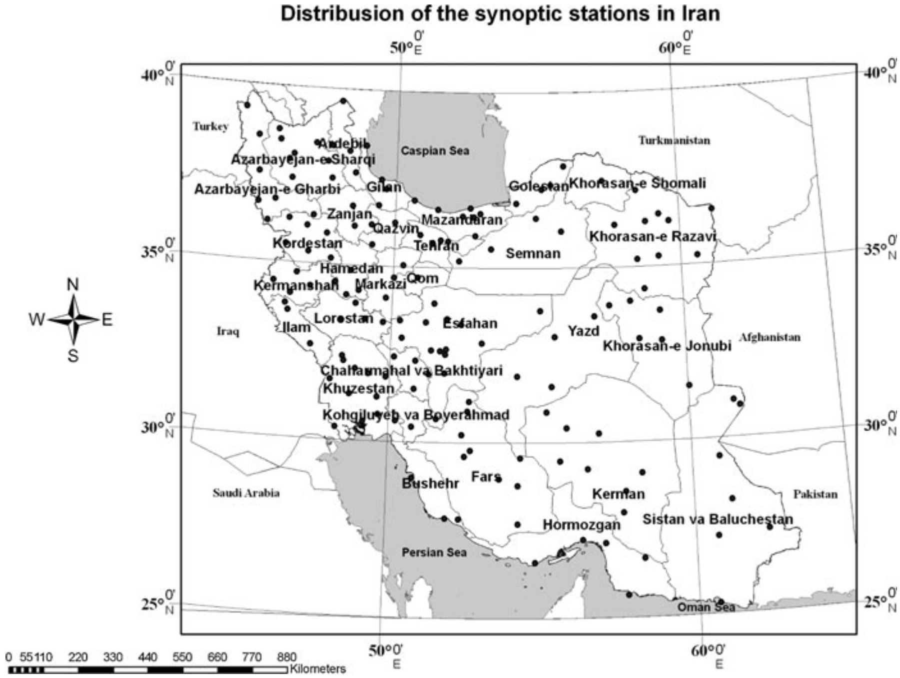

Figure 3
Synoptic meteorological stations

Table 1

Stations with annually fog days more than 50 days

Station	Altitude (MASL)	Fog days	Trend	R^2	Station	Altitude (MASL)	Fog days	Trend	R^2
Astara Coast	−18	220	−12.1	0.69	Dogonbadan	699.5	83	NS	–
Kish Island	30	213	NS	–	Bostan	7.8	83	NS	–
Konarak	12	191	NS	–	Jiroft	601	79	NS	–
Qaem Shahr	14.7	159	NS	–	Masjed soleyman	32.5	78	NS	–
Siri Island	4.9	154	NS	–	Ahar	1390.5	78	−3.2	0.6
Parsabad	31.9	152	−8.6	0.73	Omidieh	34.9	77	2	0.43
Booshehr Coast	8.4	151	NS	–	Mashad	999.2	72	NS	–
Ardabil	1332	146	−4.2	0.47	Lar	792	70	NS	
Rasht	−6.9	143	NS	–	Ramsar	−20	67	−3.79	0.65
Bandar Abbas	9.8	128	2.4	0.36	Hamedan	1741.5	66	NS	–
Jask Coast	4.8	117	2.6	0.37	Abadan	6.6	65	NS	–
Safi Abad	82.9	110	−3.4	0.33	Ahvaz	22.5	63	NS	–
Booshehr Coast	19.6	106	−4.1	0.67	Kangavar	1468	62	NS	–
Ravansar	1379.7	103	−6.6	0.58	Isfahan	1543	61	NS	–
Dezfool	143	103	NS	–	Makoo	1411.3	60	NS	–
Lengeh Port	14.2	100	NS	–	Hamedan	1678.7	58	NS	–
Chabahar	8	99	NS	–	Goochan	1287	55	NS	–
Minab	27	94	NS	–	Golmakan	1176	55	NS	–
Noshahr Coast	−20.9	89	NS	–	Gazvin	1279.2	51	NS	–
Mahshahr Port	6.2	87	NS	–	Myaneh	1110	50	NS	–
Agajari	27	85	−3.2	0.48	Gorveh	1906	50	NS	–

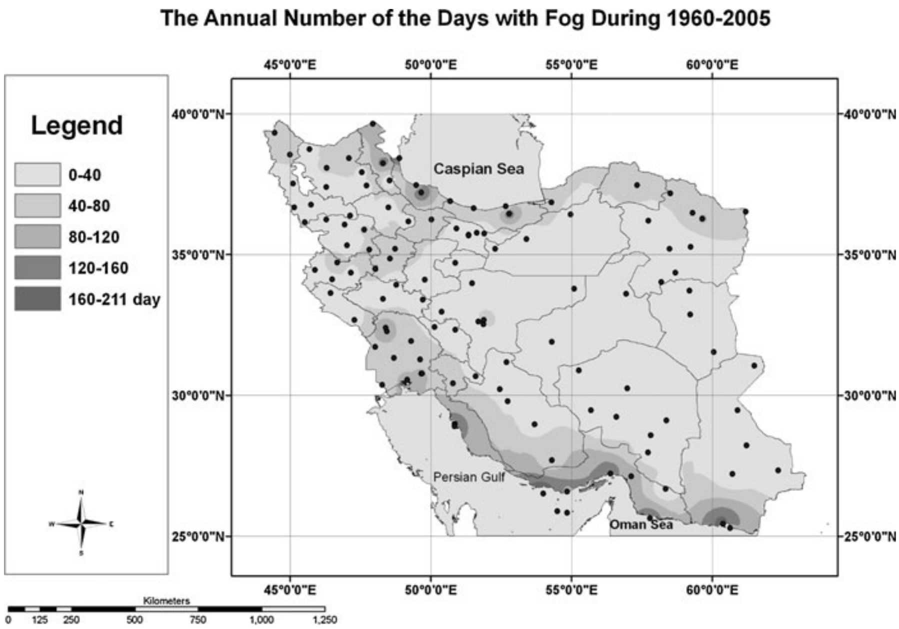

Figure 4
Annual number of fog days (1960–2005)

coastal regions is clear in the map. The farther from the sea, the lower the number of fog days.

There is also a monthly variation in fog days. Figure 5 shows the distribution of fog days in Astara, Kish Island, Anzali, Bandar Abbas, and Qaem Shahr throughout the year. In Astara fog forms during all months of the year but there are more fog days in colds months. In the Kish Islands fog occurs mostly during warm months. On the northern coastline of Iran (Anzali), fog mostly occurs in cold months. On the southern coast of Iran (Bandar Abas), fog occurs mostly in warm months. In some regions (Qaem Shahr) fog forms equally in all months.

The trends of fog days during the study period were also studied. Table 1 shows also the trend of fog days during 1986–2005 with related correlation coefficient (R^2). There are negative and positive trends. However, some trends were non-significant (NS). The trends show the amount of increase or decrease of fog days per year. The significant trends mostly are negative, corresponding to decreasing fog days in these areas. Most of these places are mountainous and upslope fogs are more frequent than other types. This is consistent with global warming effects in this part of world. Upslope fog formation and frequency decreases as temperature increases. Only three stations, namely Bandar Abbas, Jask, and Omidyeh exhibit positive trends of fog days. This is consistent with advection fogs being common along the Persian Gulf coasts. As temperature increases, the evaporation will also increase, and fog formation conditions will increase.

4. Conclusion

Countries located in arid and semi-arid zones such as Iran can use fog collection to supply water. In this regard fog collection by man-made collectors may be a non-conventional source of water. The water source is sustainable over periods of hundreds and probably thousands of years because the driving forces for the formation of the cloud decks are global in nature and will change only slowly.

Most fogs in Iran are advection fogs and because of proximity to the Persian Gulf in the south and the Caspian Sea in the north of the country. However, a small number of fogs are upslope fogs.

The results show that Iran is a country with special potential for fog occurrences. The northern

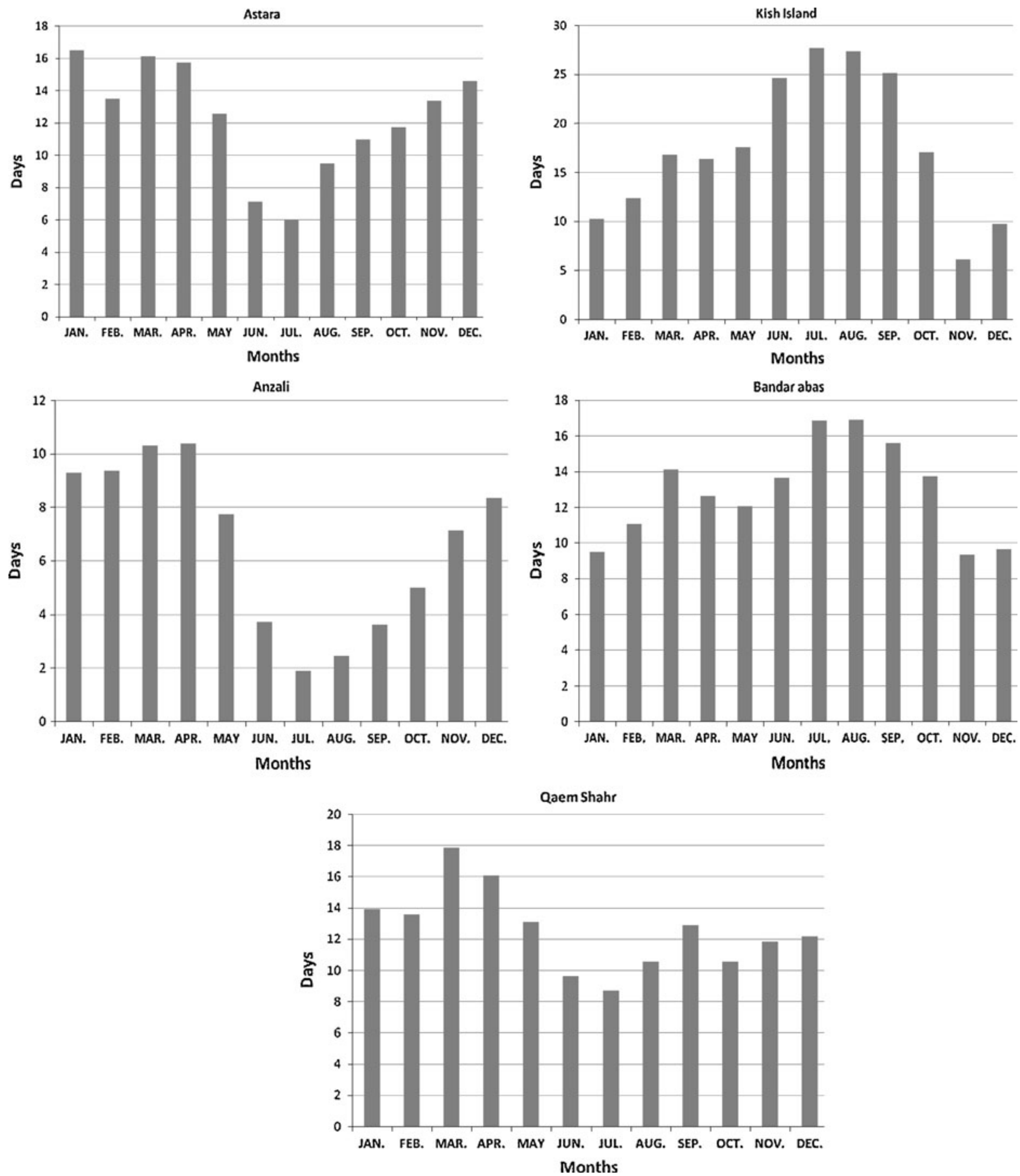

Figure 5
Temporal variation of long term monthly fog days (1960–2005)

coastline with its high relative humidity is suitable for fog collection projects. Also many fog-bearing winds pass over the Caspian Sea where they gain humidity from the sea and increase the number of fog days. The same conditions occur in southern coastal regions. Some fog places are located inside the country, such as Parsabad, and Qaem Shahr are far from the waters but have high elevation.

The north of Iran is suitable for rice cultivation. Rice requires a lot of water during growing season. In spite of high precipitation (Fig. 2), in some years the annual rainfall is not enough for rice production. Fog collected water would be a suitable option to supplement existing rainfall to provide water requirements for rice crops.

In the south coastal region of Iran (Persian Gulf coast) the water shortage is always a big problem for drinking water. The amount of precipitation is low and so water from other resources is necessary. Fog collection projects in this area could be cost effective and necessary.

Because of the unique climate and topography of Iran, many kinds of fogs occur in the northwest, north coast, northeast, and south coast regions of Iran. Defined places would be suitable for implementation of fog collection assessment projects.

The author would like to recommend that water resources planners and managers take this issue into more consideration and initiate fog water collection projects in suitable locations.

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