Studying the Moisture Sources and the Stable Isotope Characteristic of Moisture in Northern Khorasan Province, North-Eastern Iran

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***Abstract*—**Iran is a semi-arid and arid country in south-western Asia in the Middle East facing intense climatological drought from the early times. Therefore, studying the precipitation events and the moisture sources and air masses causing precipitation has great importance in this region. In this study, the moisture sources and stable isotope content of precipitation moisture in three main events in 2015 have been studied in North-Eastern Iran. HYSPLIT model backward trajectories showed that the Caspian Sea and the mixture of the Caspian and Mediterranean Seas are dominant moisture sources for the studied events. This showed the role of cP (Siberian) and Mediterranean (MedT) air masses. Stable isotope studies showed that precipitation events originated from the Caspian Sea with lower Sea Surface Temperature (SST) have more depleted isotope values. However, precipitation events sourced from the mixture of the Caspian and the Mediterranean Seas (with higher SST) showed more enriched isotope values.

***Keywords*—**HYSPLIT, Iran, Northern Khorasan, stable isotopes.

I. INTRODUCTION

STABLE isotope (^{18}O and ^{2}H) as a reliable and precious method has been used firstly by [1] in hydrological studies, when when this study findings were published for the variations of $\delta^{18}O$ and ^{2}H in fresh water resources. The author discovered the relationship between $\delta^{18}O$ and $\delta^{2}H$ in fresh surface water and developed the first Global Meteoric Water Line (GMWL) (1).

$$\delta^{2}H=\delta^{18}O+10 \quad (1)$$

Craig line is global line and actually an average for many local meteoric water lines. Craig has also found that fresh water resources that originate from cold regions demonstrate more depleted isotope values, while enriched water resources associate with warm and tropical regions. The developed model by Craig has been improved by more stations and samples by [2] with (2).

$$\delta^{2}H=8.17(\pm0.07)\delta^{18}O+11.27(\pm0.65)‰VSMOW \quad (2)$$

Several factors have been identified as an influencing parameter on the stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) signature of precipitation. Several parameters including source condition of evaporated atmospheric moisture and air mass trajectory pattern, temperature effect, precipitation amount effect, altitude and latitude effect influence the stable isotope contents of precipitation.

Among the various parameters influencing isotopic content of precipitation, the moisture source and air mass trajectory consider as the most important parameter influencing the isotopic signature of precipitation. For instance, the moisture sourced from water bodies with higher SST and lower relative humidity demonstrate enriched D excess values, e.g. Mediterranean Sea with D excess 22‰, while moisture generates from water bodies with lower SST and higher relative humidity demonstrate more depleted D excess values e.g. Atlantic Ocean_10 ‰. Iran is semi-arid and arid country that faces large drought from the early times. Iran receives very low amount of precipitation around 250 mm which is unevenly distributed across the country. Some parts of the central Iran receive less than 100 mm of precipitation, while the Caspian Sea coastal area receives more than 1000 mm of precipitation [3]. Iran is under influence of five main air masses which bring the moisture of neighboring large water bodies including the Persian Gulf, the Caspian Sea, the Arabian Sea, the Mediterranean Sea and the Black Sea to Iran. Four main air masses including mP, cP (Siberian), cT (Suddan) and MedT influence Iran during Cold and wet periods (November to April), while due to intense atmospheric stability over Iran during dry period (May to October), only mT (known as monsoon) air mass influences large parts of south-eastern Iran. This air mass transfers large amount of moisture from the Oman Sea and Indian Ocean to Iran [4].

Northern Khorasan is one of the provinces of Iran located north-eastern part of the country with an area of 28434 km^2 and population of 867727 in 2011. Bojnourd is the capital and most populated city of this province with 192041 inhabitants in 2011 [5].

Bojnourd has a cold semi-arid climate (BSK) according to Koppen climatic classification. The average annual precipitation in Bojnourd city is 272.4 mm. The most wet month in this province is March with the average of 42.4 mm, and the driest month is August with 6.0 mm. The mean annual air temperature in this province is 13.3 °C. July average temperature is around 25.1 °C, and January average temperature is 1.5 °C as shown in Fig.1. Stable isotope studies in Northern Khorasan like the other parts of Iran are not very common, and a few studies including [5] and reports have been done previously in this province. In the following study,

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the moisture sources for three large precipitation events have been determined using HYSPLIT model backward trajectories in North eastern Iran. The contributions of different air masses which cause precipitation at 19 weather stations were determined using the HYSPLIT model and are presented in Fig. 1. This figure shows how the air masses role varied across the country in 19 stations.

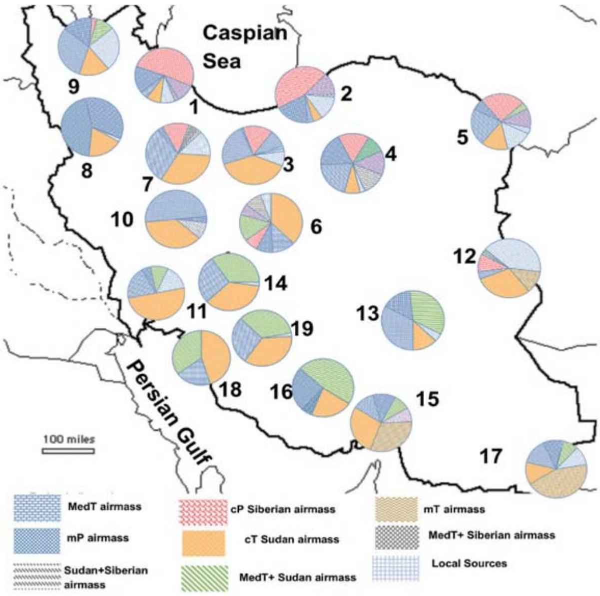

Fig. 1 Contributions of different air masses causing precipitation at 19 weather stations in Iran (1 Bandar Anzali, 2 Gorgan, 3 Tehran, 4 Shahrood, 5 Mashhad, 6 Isfahan, 7 Arak, 8 Marivan, 9 Tabriz, 10 Shahrkord, 11 Ahvaz, 12 Zahedan, 13 Sirjan, 14 Samyrom, 15Bandar Abas, 16 Darab, 17 Chabahar, 18 Bushehr, and 19 Shiraz) [4]

In addition, the role of various air masses in Northeastern Iran and the position of the Northern Khorasan is shown in Fig. 2.

II. Material and Method

In the following study, the moisture sources of three large precipitation events of 5 Feb 2015, 6 April 2015 and 7 May 2015 in Northern Khorasan province have been determined using HYSPLIT backward trajectories using 120-hour backward trajectory in 500, 1500, and 2500 masl elevations. HYSPLIT is an abbreviation for Hybrid Single Particle Lagrangian Integrated Trajectory and this software was developed by NOAA's air resources lab in 1982. The calculations in HYSPLIT are based on the simultaneous application of the two Lagrangian and Eulerian approaches. The HYSPLIT model is capable of computing both simple air parcel trajectories (backward and forward) and very complicated simulations. The input data in this software are calculated by entering temperature, wind speed, pressure, and solar radiation via NOAA FNL meteorological data base [6] in addition to the offline version of HYSPLIT model which can be run in Windows, Linux, and Mac. This software is also available online in a web-based version called Real Time Environmental Application and Display System (READY), which is totally free.

Fig. 2 Northern Khorasan position in Iran and the main air masses influence this province

The precipitation Samples were analyzed for stable isotopes (^{18}O and ^{2}H) using Delta plus XP isotope ratio mass spectrometer (IRMS) in G.G Hatch Stable Isotope Laboratory at Ottawa University in Canada. The results of stable isotopes were expressed relative to Vienna Standard Mean Ocean Water (VSMOW) with the uncertainty of ± 0.1‰ and ±1‰ for ^{18}O and ^{2}H, respectively. The stable isotope composition of the moisture for these precipitation events have been determined using the stable isotope composition of the precipitation events using (1) and (2) [7]. The total fractionation between water (precipitation) and vapor (moisture) is calculated using the below equation for ^{18}O and ^{2}H isotopes using (3) and (4).

$$\delta 18O\ water - \delta 18O\ vapor = \varepsilon 18O\ water\text{-}vapor + \Delta\varepsilon 18O\ water\text{-}vapor \quad (3)$$

$$\delta 2H water - \delta 2H\ vapor = \varepsilon 2H\ water\text{-}vapor + \Delta\varepsilon 2H\ water\text{-}vapor \quad (4)$$

In the above equation, ε is the enrichment in equilibrium between water and vapor (ε), and kinetic evaporation (Δε) is calculated using (5) and (6).

$$\Delta\varepsilon = 18O\ water\text{-}vapor = -14.2\ (1-h)‰ \quad (5)$$

$$\Delta\varepsilon = 2H water\text{-}vapor = -12.5\ (1-h)‰ \quad (6)$$

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where h represents the humidity. The equilibrium isotopic fractionation between water (precipitation) and vapor (cloud) in 25 C is -9.3 and -76‰ for 18O and 2H, respectively. In colder region, the isotopic fractionation and depletion of stable isotopes between water (precipitation) and vapor (cloud) is more intense 18O=-10.6 and 2H= -93 respectively. The kinetic evaporation is another process which influences the isotope content of precipitation. Kinetic effect influence on the stable isotope content is mainly depended on the humidity.

Using the stable isotope characteristic of moisture of each precipitation events and determination of each moisture sources using HYSPLIT model, the stable isotope characteristic of moisture sources has been determined. It is more useful to compare to the study of precipitation isotope characteristic as the influence of secondary evaporation in moisture is not important.

III. Results and Discussion

A. Determination the Moisture Sources for the Studied Precipitation Events in North-eastern, Iran

Detecting the moisture sources for the dominant precipitation events (>20 mm) in North-eastern Iran, Fig. 3 showed that Caspian Sea and the Black and Mediterranean Seas are the dominant moisture sources for these events.

B. Studying Stable Isotope (^{18}O and ^{2}H) Content of Moisture Sources in the Studied Events

The stable isotopes (^{18}O and ^{2}H) content of moisture in the studied events, according to (1) and (2), and also the stable isotope content of moisture has been defined (Table I).

TABLE I
THE STABLE ISOTOPE CHARACTERISTIC OF THE STUDIED PRECIPITATION EVENTS IN NORTH-EASTERN IRAN

Moisture				
Date	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	Source	Air mass
5-Feb-15	-19.6	-121.4	Caspian Sea	cP
6-Apr-15	-21.0	-134.8	Caspian Sea	cP
7-May-15	-16.1	-105.5	Caspian and Mediterranean Seas	cP+MedT

Plot of the precipitation samples on GMWL and Eastern Mediterranean Meteoric Water Line (EMMWL) in Fig. 4 showed that the precipitation events samples plotted between both GMWL [8] and EMMWL [9] due to this fact that both Mediterranean region moisture and moisture originated from other places dominantly influences the precipitation in this region.

In the final step, precipitation events have been plotted on two meteoric water lines, Eastern Mediterranean Meteoric Water Line (EMMWL) and also Siberian Meteoric Water Line (SMWL). EMMWL represents the moisture which comes from the Mediterranean region, while the SMWL represented the moisture originated from Siberian region. The Mediterranean and cP air masses bring the moisture from the Mediterranean Sea and Siberian region [10], respectively Fig. 5.

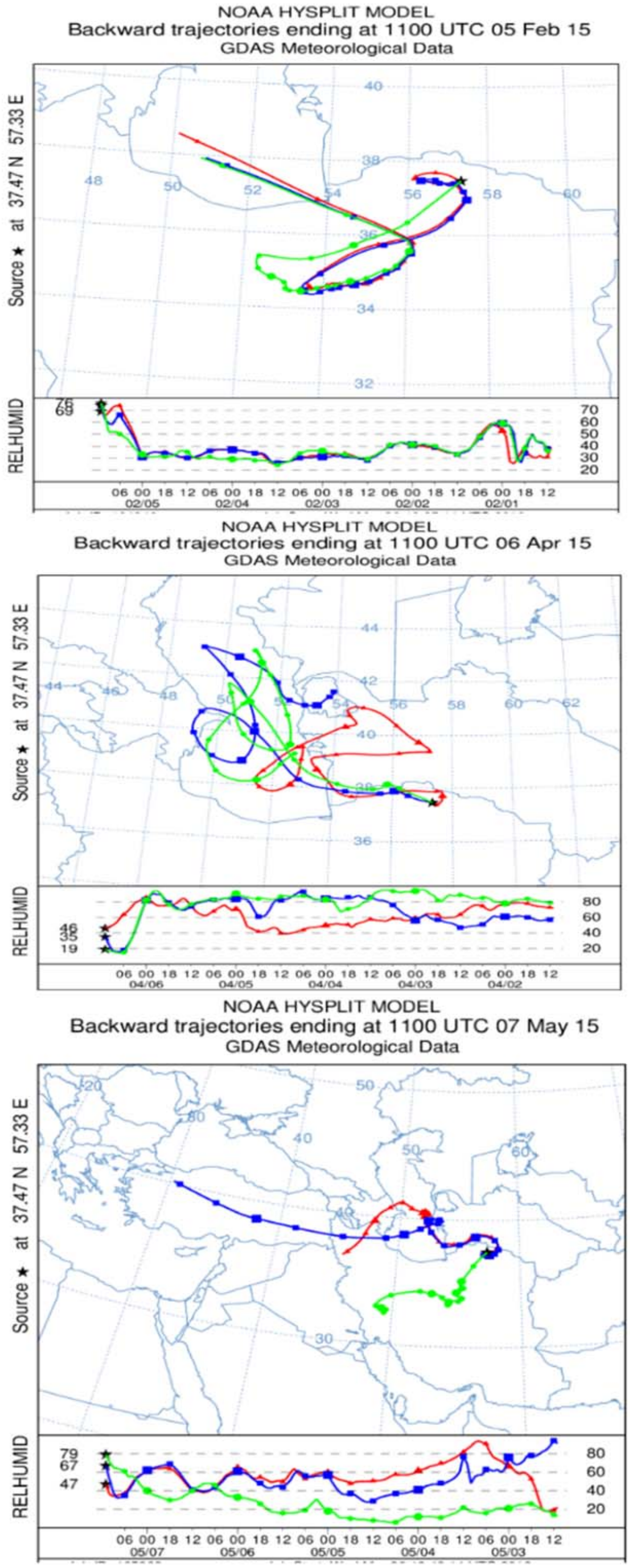

Fig. 3 Study of the dominant moisture sources for the studied precipitation events in north-western Iran

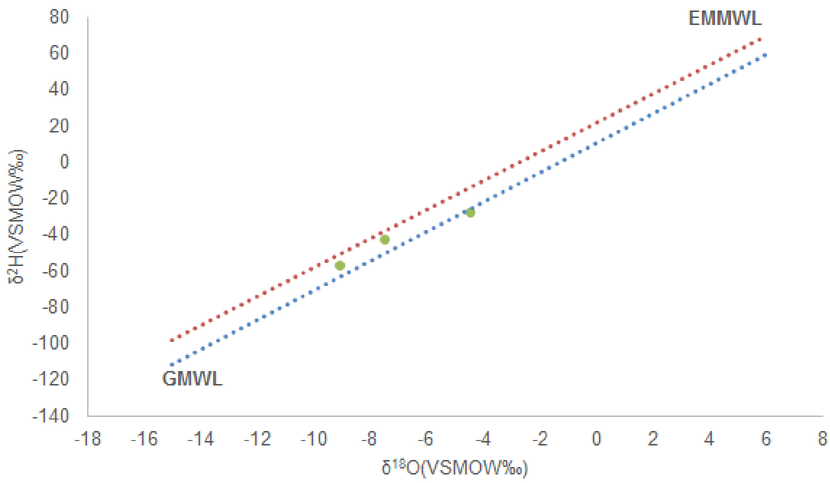

Fig. 4 Plot of North-eastern Iran precipitation on GMWL and EMMWL

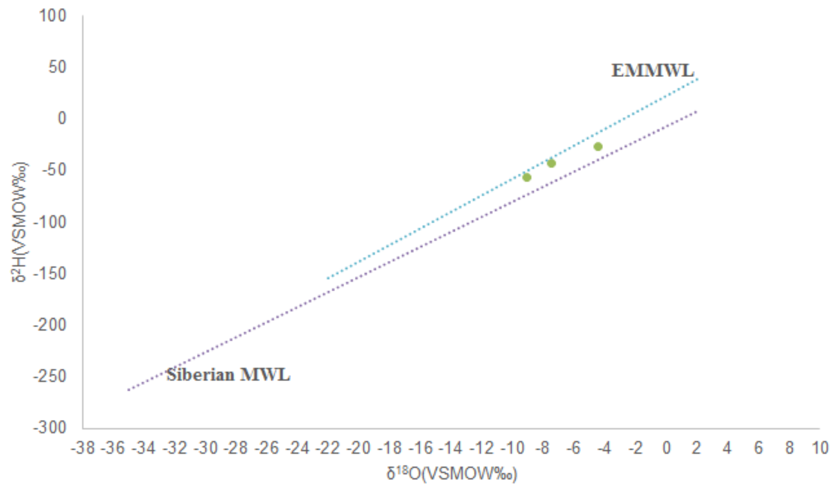

Fig. 5 Plot of precipitation samples on EMMWL and SMWL

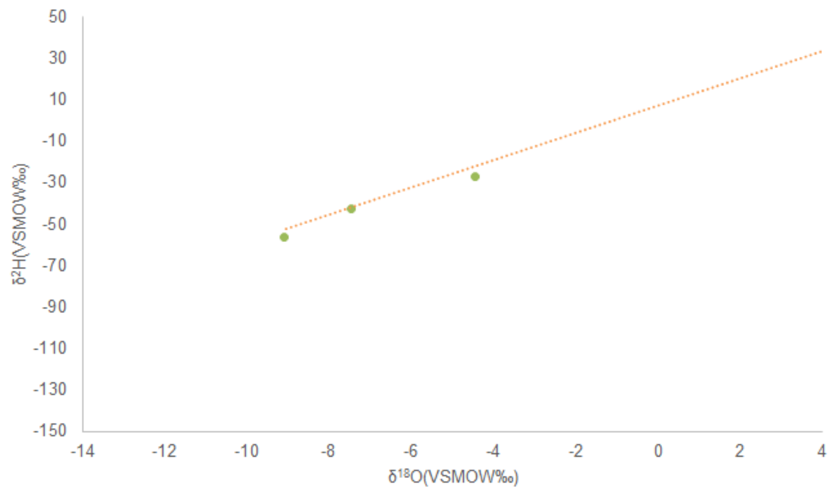

Fig. 6 Plot of the studied precipitation events on the mP air mass

In addition, the precipitation samples have also been plotted on the region where mP air mass originated. This air mass dominantly influences the precipitation in north western Iran, but it also influences the Northeastern Iran. It can be seen that the mP air mass also influences dominantly the studied precipitation events as shown İN Fig. 6.

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Plotting the studied precipitation events on Sudan air mass (cT) which has also dominant role in Iran precipitation showed that samples deviated from meteoric water lines of the regions where the cT air mass originated.

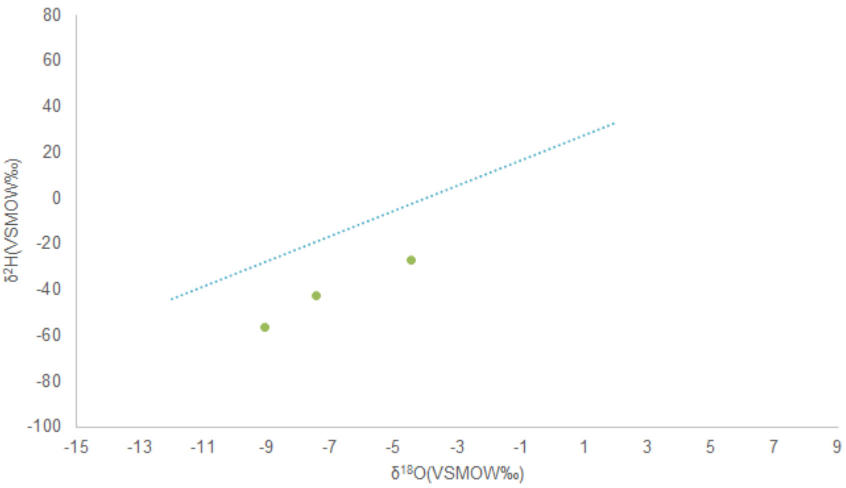

Fig. 7 Plot of precipitation samples on Sudan (cT) air mass

IV. Conclusion

Studied precipitation events in north-eastern Iran demonstrated that the Caspian Sea and the mixture of the Caspian, and the Mediterranean Seas is the main moisture source for the studied events. Stable isotopes characteristic of the precipitation moisture showed more depleted isotope values. However, moisture of the events caused by the mixture of the Caspian and Mediterranean (the simultaneous influence of MedT and cP air masses) showed more enriched isotope values. Plotting the studied precipitation events on EMMWL and GMWL showed that precipitation events were plotted between both meteoric water lines which are due to the importance of Mediterranean region moisture and also the moisture originated from other resources. Finally, plot of the studied precipitation events on Siberian, EMMWL and the regions where mP air masses originated shows that all the studied precipitation events were plotted on these meteoric water lines, while none of the samples were plotted over cT or Sudan air mass. The results are obtained by stable isotope techniques which confirmed the results obtained by the isotope studies.

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