proceedings

Type of the Paper (Abstract, Meeting Report, Preface, Proceedings, etc.)

Application of statistical techniques to study stable isotopes (^{18}O and ^{2}H) characteristics of precipitation in Iran (Southwest Asia)

Mojtaba Heydarizad [1]*, and Rogert Sorí [2, 3]

[1] Department of Geography, Ferdowsi University of Mashhad, Mashhad, Iran; e-mail: mojtabaheydarizad@yahoo.com
[2] Environmental Physics Laboratory (EPhysLab), CIM-UVigo, Universidade de Vigo, 32004 Ourense, Spain. ; rogert.sori@uvigo.es
[3] Instituto Dom Luiz (IDL), Facultade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal.

* Correspondence: mojtabaheydarizad@yahoo.com; Tel.: (+989151171768)

Abstract: Various climatic and geographic parameters influence precipitation in Iran which makes the interpret of stable isotopes signatures in precipitation very complicated. Thus, precipitation sampling stations for stable isotopes analyses in Iran have been classified by cluster analysis (CA) to 10 clusters based on their stable isotopes characteristics. The classification of stations by CA also has a close correlation with Koppen climatic zones across Iran. Finally, the stations in each cluster have plotted on GMWL and EMMWL. This study shows that classifying precipitation sampling stations can simplify the interpretation of stable isotopes in precipitation of the regions with complicated climatic systems.

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Proceedings* **2021**, 65, x. https://doi.org/10.3390/xxxxx

Keywords: Iran; precipitation; stable isotopes; cluster analysis

Received: date
Accepted: date
Published: date

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Iran is a semi-arid and arid country in the Middle East that has faced a water shortage crisis from an early time. Although annual precipitation in Iran is low 341 mm [1], this amount of precipitation is also unevenly distributed across the country. In the Caspian Sea coastal area mainly its western parts, annual precipitation amount is more than 1800 mm, while the precipitation notably decreases to less than 100 in the central part of Iran [1]. The dominant moisture sources and air masses causing precipitation also show large variations across Iran. During the wet and cold period (November to April), cP (continental polar), cT (continental tropical), mP (maritime polar), and MedT air masses influence Iran. However, during the dry and hot period (May to October), mT (maritime tropical) air mass influences this country [1–3]. The cP air mass mainly transfers the moisture from the Caspian Sea, the Mediterranean Sea, and to the lower extent the Black

Sea to Iran. The cT air mass mainly transfers the moisture of the Arabian Sea, the Persian Gulf, the Red Sea, and the Oman Sea to Iran. The mP air mass transfers the moisture of the Black Sea and high latitudes water bodies such as the North Atlantic Ocean to Iran. Finally mT air mass transfers the moisture of the Oman Sea and the Indian Ocean to Iran [4–9].

The integrated moisture fluxes over Iran from 1981 to 2015 are shown in Figure 1. The pattern of moisture fluxes over Iran during the dry period is different from that of the cold and wet period. During the dry period, strong moisture fluxes are observed over the Arabian Sea and the Indian Ocean causing monsoons in India which sometimes influence the southeast of Iran Figure 1a. However, in the cold and wet period, moisture fluxes are observed over the Black Sea, the Mediterranean Sea, the Red Sea, and the Persian Gulf Figure 1b.

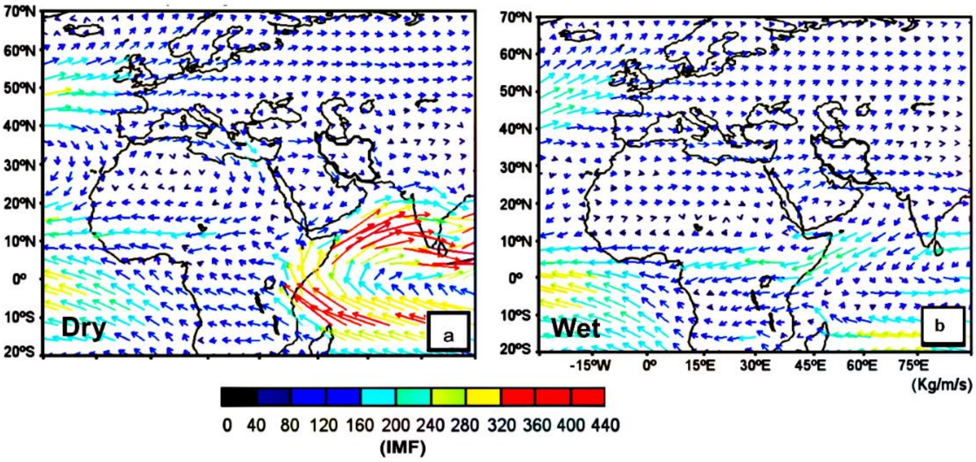

Figure 1. The vertically integrated northward and eastward moisture flux (VIMF) data from the ERA Interim Reanalysis with a resolution of 1° × 1° during dry (a) & wet (b) periods between 1981-2015 (data obtained from ERA-Interim [10]).

The large variations observed in the precipitation amount across Iran have a significant influence on the climate of this country. According to the Koppen classification of climate zones, Iran has been classified into various zones including BWh (arid, desert, and hot), BWk (arid, desert, and cold), BSh (arid, steppe, and hot), BSk (arid, steppe, and cold), Csa (temperate, dry summer, and hot summer), Csb (temperate, dry summer, and warm summer), Cfa (temperate, no dry season, and hot summer), Dsa (continental, dry summer, and hot summer), Dsb (continental, dry summer, and warm summer), Dsc (cold, dry summer, and cold summer), Dfb (continental, no dry season, and warm summer), Dfc (continental, no dry season, and cold summer) [11,12].

Due to Iran's low average annual precipitation amount, significant spatial variations of precipitation amount across the country, and various climate zones in Iran considering all the aspects of precipitation as the significant part of the water cycle has a dominant role. Therefore, precipitation characteristics across Iran should be studied using accurate and reliable methods. Stable isotopes technique can present an accurate and comprehensive view of Iran precipitation characteristics.

Application of stable isotopes in water resources studies has been started since Craig 1961 [13] has found that $^{18}O/^{16}O$ has a very close and strong correlation with $^{2}H/H$ variations in fresh water molecules [14]. Stable isotopes technique presents crucial information regarding the climate condition of the moisture origin as well as climate condition in precipitation sampling sites. There are so many studies regarding the application of stable isotopes in precipitation in Iran. Most of these studies are local small scale investigations [6,7,9,15–19] or large scale studies that cover all of Iran [3,20,21]. The aim of this reseacrh is to perform a comprehensive study on stable isotopes characteristics of precipitation in Iran using statistical techniques.

2. Materials and Methods

In this study, stable isotopes (^{18}O and ^{2}H) and d-excess have been studied in 34 stations across Iran. Stable isotopes data have been presented in delta notation (δ), which is the relative deviation of the sample from the standard (Vienna Standard Mean Ocean Water (VSMOW)) by Eq. 1:

$$\delta 18O sample = \left(\frac{\left(\frac{18O}{16O}\right) sample}{\left(\frac{18O}{16O}\right) reference} - 1 \right) * 1000‰ \quad VSMOW \tag{1}$$

The analytical standard uncertainties for precipitation samples were ± 0.1‰ and ± 1 ‰ for $\delta^{18}O$ and $\delta^{2}H$, respectively. Stable isotopes data have been gathered from PhD and MSc thesis as well as scientific papers.

As the number of the studied stations across Iran is large, these stations have been classified based on their stable isotopes characteristics by Cluster analysis (CA). Then based on stations classification by CA analysis and Koppen climatic zones across Iran, the stable isotopes characteristics of precipitation in Iran have been studied.

3. Results and Discussion

In this study, stable isotopes signatures in 34 sampling stations across Iran have been studied Table 1.

3.1. *Classifying the precipitation sampling stations based on stable isotopes characteristics using cluster analysis (CA)*

Studying the variations of stable isotopes in precipitation across Iran is difficult due to various climate zones that exist in this country. Therefore, CA has been used to classify the studied stations based on their stable isotopes characteristics. The CA has classified the studied stations into 10 groups Table 2. Studying the spatial distribution of clusters across Iran and comparing it with the Koppen climatic zones map presented valuable results Figure 2.

Table 1. The studied precipitation sampling stations across Iran.

Row	Station	N	E	References	Row	Station	N	E	References
1	Abadeh	52.7	31.2	[9]	26	Shirinbahar	49.5	31.5	[22]
2	Abolabas	49.5	31.3	[23]	27	Sirjan	55.7	29.4	[24]
3	Alvand	45.6	34.5	[25]	28	Marvdasht	52.8	29.8	[9]
4	Ardekan	52.0	30.3	[9]	29	Tehran	51.4	35.7	[26]
5	Arsanjan	53.0	29.9	[9]	30	Tehran-Airport	51.4	35.6	[26]
6	Bajgah	52.6	29.7	[9]	31	Zarghan	52.4	29.5	[9]
7	Darab	54.5	28.7	[9]	32	Zarivar	46.2	35.5	[27]
8	Dasht Arjan	52.0	29.6	[28]	33	Birjand	59.2	32.9	[29]
9	Damavand	52.1	35.7	[30]	34	Dorfak-Gilan	49.6	37.2	[31]
10	Estahban	54.0	29.1	[9]					
11	Fasa	53.4	28.5	[9]					
12	Gorgan	54.5	36.8	[16]					
13	Hamadan	48.5	34.8	[32]					
14	Hashtgerd	50.6	35.9	[33]					
15	Isfahan	51.6	32.0	[34]					
16	Jahrom	53.6	28.5	[9]					
17	Kazeroon	51.6	29.6	[9]					
18	Khersan	50.8	31.5	[35]					
19	Mashhad	59.6	36.3	[36]					
20	Paveh	46.4	35.0	[37]					
21	Rafsanjan	56.0	30.4	[38]					
22	Sabalan	48.0	38.4	[19]					
23	Sarcheshmeh	55.7	29.4	[17]					
24	Shahrood	55.0	36.4	[15]					
25	Shiraz	52.5	29.6	[9]					

Table 2. The average stable isotopes signatures in the studied stations based on their clusters across Iran.

Cluster	Climate Zone	Ave.$\delta^{18}O$	Ave.$\delta^{2}H$	Ave. D-excess	Station
			(‰VSMOW)		
1	BSk	-5.34	-23.51	19.30	Abadeh, Ardekan, Arsanjan, Bajgah, Dahte-Arjan, Isfahan, Khersan, Zarghan, Takht Jamshid, Sarcheshmeh
2	BSk and BWk	-6.95	-33.30	22.75	Sirjan and Birjand
3	BSk and BWk	-6.90	-42.03	13.40	Damavand, Tehran, Tehran airport
4	Cfa, BWk, and BSk	-3.20	-18.07	7.70	Gorgan, Shahroud, Rasht

5	BSh	-2.10	-5.30	14.40	Abolabas, Jahrom, Mashhad, Kazeroun, Estahban
6	BSh, DSa	-3.35	-12.12	19.87	Alvand, Darab, Shirin bahar, Fasa, Paveh, Shiraz
7	BWh	-0.50	12.90	16.90	Rafsanjan
8	DSa, BSk	-8.45	-53.40	14.10	Zarivar and Hamadan
9	BSk	-6.50	-49.70	2.50	Hashtgerd
10	Dfb	-16.30	-113.6	17.10	Sabalan

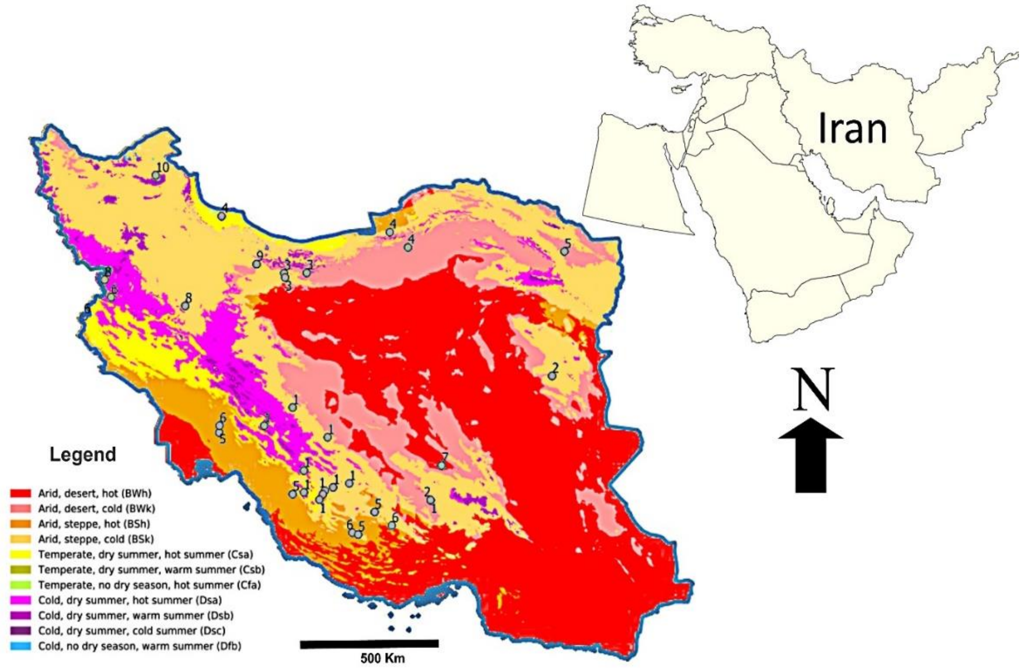

Figure 2. The spatial distribution of the studied stations based on their clusters across Iran plotted on the Koppen climatic zones.

A significant number of the studied stations are in the first cluster, which are located in arid, steppe and cold region (BSK) climatic zone. These stations are located in the southern and southwestern parts of the Zagros region. Precipitation in these stations occurs by moisture supply from the Persian Gulf, the Red Sea and the Arabian Sea via cT and MedT air masses. The average stable isotopes contents $\delta^{18}O$ and $\delta^{2}H$ in the stations located in this cluster are -5.34‰ and -23.51‰, respectively. Furthermore, d-excess also shows high values 19.30‰.

In the second cluster, the studied stations are located in the central part of Iran and classified as BSk and BWk climate zones. These stations receive less amount of annual precipitation compared to the other stations in Iran. In this cluster, the role of moisture originating from low latitude water bodies such as the Persian Gulf, the Red Sea, and the Arabian Sea is significant. Very high d-excess values in the stations located in this cluster

22.75‰ also confirm it. However, $\delta^{18}O$ and $\delta^{2}H$ in the stations located in this cluster show depleted values -6.95‰ and -33.30‰, respectively.

The stations in the third cluster are also classified in BSk and BWk climate zones. In addition to cT and MedT air masses which influence precipitation in this region, cP air mass also has a dominant role in the stations located in this cluster. The cP air mass significantly transfers the moisture of water bodies with low sea surface temperature (SST) such as the Caspian Sea to these stations. The average $\delta^{18}O$ and $\delta^{2}H$ values in precipitation in the stations in this cluster are -6.90‰ and -42.03‰, respectively. The low d-excess values 13.40‰ in the studied stations in this cluster also confirm the role of moisture originating from low SST water bodies such as the Caspian Sea.

The fourth cluster consists of Shahroud, Gorgan, and Rasht stations. Rasht station is located in Cfa, Gorgan is located in BSk, and Shahroud is located in BWk climate zones according to the Koppen classification. Rasht in the western part of the Caspian Sea central area receives the highest amount of precipitation compared to other stations across Iran, while Shahroud located in a arid zone receives very low amount of annual precipitation.

In the fourth cluster, the role of cP air mass and moisture originating the Caspian Sea is dominant in providing moisture for precipitation. Very low d-excess values 7.70‰ in the precipitation of the stations in this cluster also confirm its origin in the moisture supply from the Caspian Sea. The average $\delta^{18}O$ and $\delta^{2}H$ values in precipitation of the studied stations in this cluster are enriched -3.20‰ and -18.70‰, respectively.

The fifth cluster consists of Abolabass, Estahban, Jahrom, Kazeroon, and Mashhad stations. All the stations except for Mashhad are located in the south part of the Zagros region and all of them are classified in the BSh climate zone. The average $\delta^{18}O$ and $\delta^{2}H$ values in the stations of this cluster are -2.10‰ and -5.30‰, respectively. Same as the fifth cluster, the stations located in the sixth cluster including Kerend, Darab, Fasa, Paveh, Shiraz, and Shirinbahar also exist in the Zagros region, but in the western part. These stations are mainly plot in BSh, except for Kerend and Paveh stations which locate in Dsa zone. The average $\delta^{18}O$ and $\delta^{2}H$ values in the stations of this cluster are -3.35‰ and -12.12‰, respectively. In the fifth and the sixth clusters, stations are dominantly under the influence of cT and MedT air masses and moisture originating from high SST water bodies such as the Persian Gulf, the Red Sea, the Arabian Sea, The Mediterranean Sea have a dominant role in the stations of this cluster. Although the moisture sources are the same for the fifth and sixth clusters, d-excess values in the fifth cluster are lower (14.4‰) compared to the cluster sixth (19.87‰). This is due to more intense secondary evaporation influence the fifth cluster stations.

Rafsanjan is the only station in the seventh cluster locates in the central part of Iran in BWh climate zone. The central part of Iran receives a very low amount of precipitation compared to the other parts of Iran. Large two deserts "Dashteh-Lut" and "Dashteh-Kavir" also exist in this part of Iran. Rafsanjan receives moisture from low latitude water bodies such as the Persian Gulf, the Red Sea and the Arabian Sea, characterised with high SST. The average $\delta^{18}O$ and $\delta^{2}H$ values in this station are -0.5‰ and 12.90‰, respectively.

However, d-excess in the precipitation events in this station shows high values (16.90 ‰) which confirms its origin from low latitude water bodies.

In the eighth cluster, Hamadan and Zarivar stations are located in the western part of Iran, in the Zagros region. These stations are dominantly under the influence of MedT air mass and the Mediterranean Sea with high SST. The average $\delta^{18}O$ and $\delta^{2}H$ values in this cluster stations are -8.45‰ and -53.40‰, respectively. The average d-excess in these stations shows a high value 14.10‰.

In the ninth cluster, only Hashtgerd station exists. The role of cP air mass and moisture originated from the Caspian Sea is dominant in providing moisture for the precipitation over this station.. This is the reason for the very low d-excess value (2.50‰) in this station. The average $\delta^{18}O$ and $\delta^{2}H$ values in the station in this cluster are -6.50‰ and -49.70‰, respectively. Although Hashtgerd station is located beside third cluster stations, but it has been classified in a separate cluster (ninth cluster). This is because Hashtgerd is in the boundary zone, between climatic zones BWk and BSk.

In the last cluster (tenth cluster), only the Sabalan station exists. This station is located in a very cold zone with a high amount of annual precipitation. This cluster shows the most depleted isotope values compare to other stations Table 2. This is dominantly under the influence of the cP, MedT and mP air masses and the moisture originating from the Mediterranean Sea, Black Sea, and to a lower extent the Caspian Sea. The d-excess in the precipitation events of this station shows high values 17.10 ‰.

3-2-*Studying stable isotopes signatures of precipitation in Iran based on the Koppen climatic zones*

Stable isotopes in precipitation events across Iran are under the influence of various local and regional parameters. Plotting the average $\delta^{18}O$ and $\delta^{2}H$ values in the studied stations based on their clusters on the global meteoric water lines (GMWL) and Eastern Mediterranean meteoric water line (EMMWL) demonstrate valuable results Figure 3.

The stations located in Zagros mountain range in the first, second, sixth, and seventh clusters dominantly plot on EMMWL. This is because the precipitation events in the stations located in this part of Iran are mainly provided by the moisture originating from the Mediterranean Sea, as well as from other water bodies such as the Persian Gulf, the Arabian Sea, and the Red Sea. Shirin bahar station in the sixth cluster shows significant deviation from both GMWL and EMMWL due to the huge secondary evaporation effect. Although the stations located in the fifth cluster are also located in Zagros region, a very mild deviation can also be observed from EMMWL. This is due to the secondary evaporation on precipitation events in the stations that exists in this cluster.

On the other hand, stations located in the northern part of Iran including ninth, third, and fourth clusters plot on, or in the vicinity of GMWL. There are only two exceptions Rasht and Gorgan stations in the fourth cluster. Rasht station plot on EMMWL, which is due to the effect of local events such as numerous lagoons which influence stable isotope contents of precipitation in this area. Gorgan station deviates from both GMWL and EMMWL due to the evaporation effect. Finally, Sabalan station which locates in high elevations of Sablan mountain hills in the northern part of Iran demonstrates high d-excess values and plots in the vicinity of EMMWL. This is because this region is dominantly under the influence of moisture transported from the Mediterranean Sea.

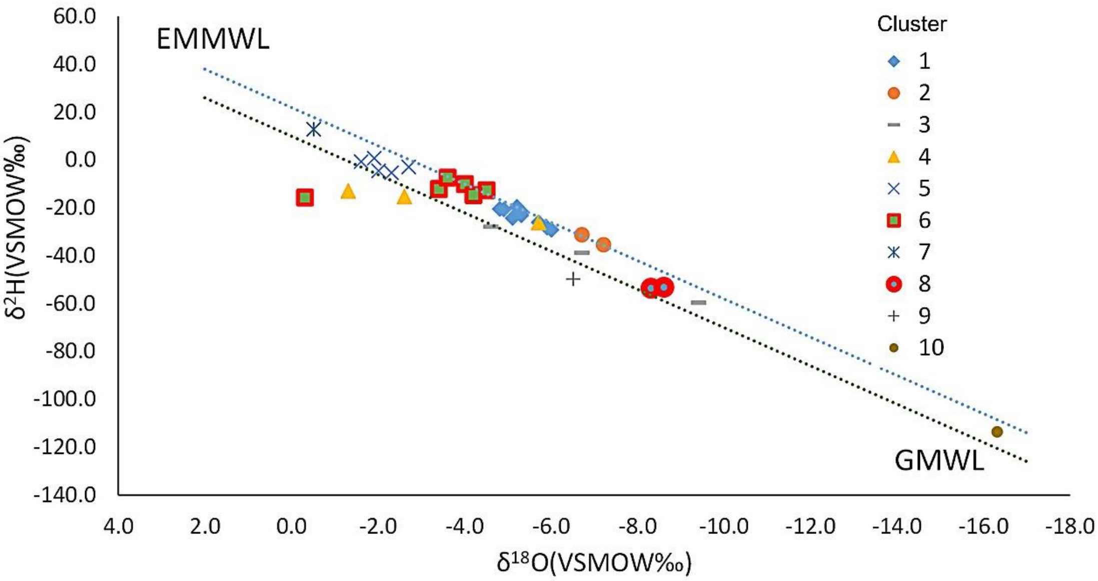

Figure 3. Plotting the stable isotopes signatures in the studied stations across Iran on GMWL and EMMWL.

4. Conclusion

This study shows that stable isotopes signatures in precipitation across Iran are significantly under the influence of the climatic conditions of the sampling stations as well as precipitation moisture source regions. Therefore precipitation characteristics show spatial variations across the country. By Cluster analysis (CA), the studied stations have been classified into 10 clusters according to stable isotopes characteristics of precipitation. Stations located in each cluster show some differences in $\delta^{18}O$ and $\delta^{2}H$ values and d-excess. Furthermore, the spatial variations of stable isotopes signatures in precipitation have been linked to climatic zones where the studied stations are located. The method used in this study can also be applied in other parts of the world to classify the precipitation sampling stations based on their stable isotopes characteristics.

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

Funding: This research received no external funding.

Data Availability Statement: Data will be available by request.

Acknowledgments: Our special thanks are extended to our colleagues at Ferdowsi University of Mashhad in Iran for their support during this study. R.S acknowledges the Xunta of Galicia by the postdoctoral fellowship (ED481B 2019/070).

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

References

1. Alijani, B. *Iran climatology*; fifth.; Payam nour publication: Tehran, 2000; ISBN 978-964-455-621-0.
2. Heydarizad, M. Meteoric water lines of Iran for various precipitation sources, Shiraz University, Iran, 2018.
3. Heydarizad, M.; Raeisi, E.; Sorí, R.; Gimeno, L. An overview of the atmospheric moisture transport effect on stable isotopes (δ^{18}O, δ^{2}H) and D excess contents of precipitation in Iran. *Theor. Appl. Climatol.* **2019**, doi:10.1007/s00704-019-02798-9.
4. Heydarizad, M.; Raeisi, E.; Sorí, R.; Gimeno, L. The Identification of Iran's Moisture Sources Using a Lagrangian Particle Dispersion Model. *Atmosphere (Basel).* **2018**, *9*, 408.
5. Barati, G.R.; Heydari, I. Classification of Iran western Precipitation. In Proceedings of the The first Iran national climate change conference; Iran Meteorological Organization: Tehran, 2003; pp. 16–23.
6. Mohammadzadeh, H.; Mayvan, J.E.; Heydarizad, M. The effects of moisture sources and local parameters on the 18O and 2H contents of precipitation in the west of Iran and the east of Iraq. *Tellus B Chem. Phys. Meteorol.* **2020**, *72*, 1–15, doi:10.1080/16000889.2020.1721224.
7. Mohammadzadeh, H.; Heydarizad, M. δ^{18}O and δ^{2}H characteristics of moisture sources and their role in surface water recharge in the north-east of Iran. *Isotopes Environ. Health Stud.* **2019**, doi:10.1080/10256016.2019.1680552.
8. Heydarizad, M.; Raeisi, E.; Sorí, R.; Gimeno, L.; Nieto, R. The Role of Moisture Sources and Climatic Teleconnections in Northeastern and South-Central Iran's Hydro-Climatology. *Water* **2018**, *10*, 1550, doi:10.3390/w10111550.
9. Faroughi, A. Characterizing isotopic signature of precipitation in Fars Province, Iran, Shiraz University, 2008.
10. Dee, D.P.; Uppala, S.M.; Simmons, A.J.; Berrisford, P.; Poli, P.; Kobayashi, S.; Andrae, U.; Balmaseda, M.A.; Balsamo, G.; Bauer, P.; et al. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc.* **2011**, *137*, 553–597, doi:10.1002/qj.828.
11. Rudolf, G. "Klassifikation der Klimate nach W. Köppen" [Classification of climates after W. Köppen]. *Landolt-Börnstein – Zahlenwerte und Funktionen aus Phys. Chemie, Astron. Geophys. und Tech. alte Ser.* **1954**, *3*, 603–607.
12. Rudolf, G. Überarbeitete Neuausgabe von Geiger, R.: Köppen-Geiger / Klima der Erde. *Klett-Perthes, Gotha* **1961**, *3*.
13. Craig, H. Isotopic Variations in Meteoric Waters. *Science.* **1961**, *133*, 1702–1703, doi:10.1126/science.133.3465.1702.
14. Clark, I.D; Fritz, P. *Environmental isotopes in hydrogeology*; CRC Press/Lewis Publishers, 1997; ISBN 1566702496.
15. Kazemi, G.A.; Ichiyanagi, K.; Shimada, J. Isotopic characteristics, chemical composition and salinization of atmospheric precipitation in Shahrood, northeastern Iran. *Environ. Earth Sci.* **2015**, *73*, 361–374,

doi:10.1007/s12665-014-3430-3.

16. Nickghoujag, Y.; Mohammadzadeh, H.; Naseri, H.R. The application of stable isotopes (^{18}O and ^{2}H) to determine the role of surface water in shallow groundwater resources in Gorgan rood basin. In Proceedings of the The second National Conference on Application of Stable Isotopes; Mashhad, Iran, 2016.
17. Parizi, H.S.; Samani, N. Environmental Isotope Investigation of Groundwater in the Sarcheshmeh Copper Mine Area, Iran. *Mine Water Environ.* **2014**, *33*, 97–109, doi:10.1007/s10230-014-0277-5.
18. Rahimzadeh, F.; Asgari, A.; Fattahi, E. Variability of extreme temperature and precipitation in Iran during recent decades. *Int. J. Climatol.* **2009**, *29*, 329–343, doi:10.1002/joc.1739.
19. Porkhial, S.; Ghomshei, M.M.; Yousefi, P. Stable Isotope and Elemental Chemistry of Mt. Sabalan Geothermal Field, Ardebil Province of North West Iran. In Proceedings of the Proceedings World Geothermal Congress; Bali, Indonesia, 2010.
20. Heydarizad, M.; Raeisi, E.; Sorí, R.; Gimeno, L. Developing Meteoric Water Lines for Iran Based on Air Masses and Moisture Sources. *Water* **2019**, *11*, 2359.
21. Shamsi, A.; Kazemi, G.A. A review of research dealing with isotope hydrology in Iran and the first Iranian meteoric water line. *JGeope* **2014**, *4*, 73–86.
22. Kalantari, N.; Mohamadi Behzad, H. Investigation source of recharge to Sabzab and Bibi Talkhon karstic springes by application of ^{18}O and ^{2}H stable isotopes. In Proceedings of the Proceedings of the 1st National Conference on Application of Stable Isotopes; Mashhad, 2013.
23. Zarei, H.; Akhondali, A.M.; Mohammadzadeh, H.; Radmanesh, F.; Laudon, H. Runoff generation processes during the wet-up phase in a semi-arid basin in Iran. *Hydrol. Earth Syst. Sci. Discuss.* **2014**, *11*, 3787–3810, doi:10.5194/hessd-11-3787-2014.
24. Jahanshahi, R. Environmental effects of GoleGohar Iron ore mine on groundwater of the area, Shiraz university, 2013.
25. Karimi, H.; Raeisi, E.; Bakalowicz, M. Characterising the main karst aquifers of the Alvand basin, northwest of Zagros, Iran, by a hydrological approach. *Hydrogeol. J.* **2005**, *13*, 787–799, doi:10.1007/s10040-004-0350-4.
26. IAEA/GNIP Global Network of Isotopes in Precipitation (GNIP).
27. Mohammadzadeh, H.; Ebrahimpour, S. Application of stable isotopes and hydrochemistry to investigate sources and quality exchange Zarivar catchment area. *J. Water Soil* **2012**, *26*, 1018–1031.
28. Rezaei, M.; Karimi, H.; Jokar, B. Studies of Kazeroon-Persian gulf karstic basins. *Iran Karst hard rock Natl. Res. Cent.* **1998**.
29. Jafari, H.; Sudegi, A.; Bagheri, R. Contribution of rainfall and agricultural returns to groundwater recharge in arid areas. *J. Hydrol.* **2019**, *575*, 1230–1238, doi:https://doi.org/10.1016/j.jhydrol.2019.06.029.

30. Ghazban, F. Geological and geochemical investigation of Damavand geothermal prospect, central Alborz mountain, northern Iran. *Geotherm. Resour. Counc. Trans.* **2000**, *24*, 24–27.

31. Ghobadi, M.H.; Dehban Avan Stakhri, M. h.; Mirarabi, A. Investigating the hydrogeological properties of springs in a karstic aquifer in Dorfak region (Guilan Province, Iran). *Env. Earth Sci* **2018**, *77*.

32. Feyzi, D. *Traceing studies in Roudball dam site*; Shiraz, Iran, 1998;

33. Saadati, H.; Sharifi, F.; Mahdavi, M.; Ahmadi, H.; Mohseni, M. Determining origin of groundwater recharge resources, drought and wet periods by isotopic tracers in Hashtgerd plain. *Manag. J. Range Water shed* **2009**, *62*, 49–63.

34. Khademi, H.; Mermut, A.R.; Krouse, H.R. Isotopic composition of gypsum hydration water in selected landforms from central Iran. *Chem. Geol.* **1997**, *138*, 245–255, doi:https://doi.org/10.1016/S0009-2541(97)00017-X.

35. Mohammadi, Z. Method of leakage study at karst dam site, the Zagros Region, Shiraz university, 2006.

36. Mohammadzadeh, H. The Meteoric Relationship for ^{18}O and ^{2}H in Precipitations and Isotopic Compositions of water resources in Mashhad Area (NE Iran). In Proceedings of the The 1 st International Applied Geological Congress; Islamic Azad University - Mashad Branch: Mashhad, 2010; pp. 555–559.

37. Mohammadzadeh, H.; Eskandari, E.; Najafi, M. Studying the stable isotope content of precipitation in Paveh region. In Proceedings of the The second National Conference on Application of Stable Isotopes; Mashhad, Iran, 2016.

38. Farpoor, M.H.; Khademi, H.; Eghbal, M.K.; Krouse, H.R. Mode of gypsum deposition in southeastern Iranian soils as revealed by isotopic composition of crystallization water. *Geoderma* **2004**, *121*, 233–242, doi:https://doi.org/10.1016/j.geoderma.2003.11.013.