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Application of Statistical Techniques to Study Stable Isotopes (^{18}O and ^{2}H) Characteristics of Precipitation in Iran (Southwest Asia) †

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

Keywords: Iran; precipitation; stable isotopes; cluster analysis

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1. Introduction

Iran is a semi-arid and arid country in the Middle East that has historically faced water shortage crises. Although the 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, the amount of annual precipitation is more than 1800 mm, while the precipitation notably decreases to less than 100 mm 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), a 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 lesser 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 latitude water bodies such as the North Atlantic Ocean to Iran. Finally, the 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.

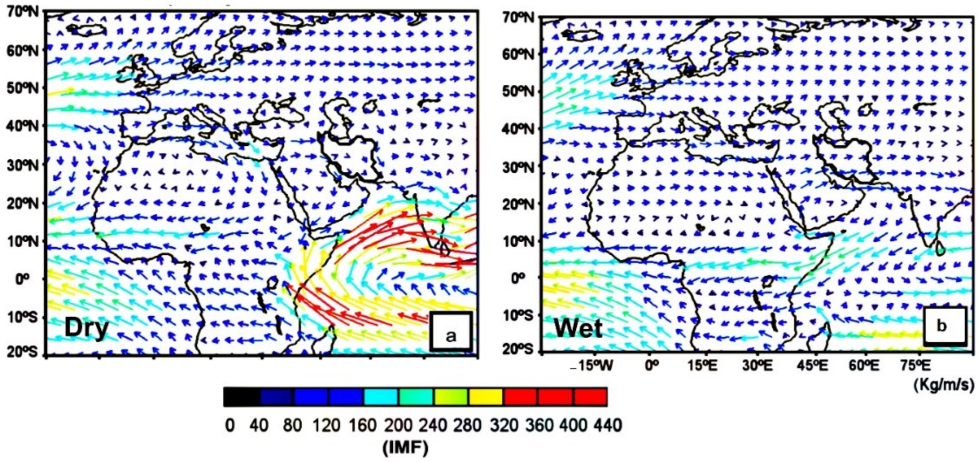

Figure 1. Vertically integrated northward and eastward moisture flux (VIMF) data from the ERA Interim Reanalysis with a resolution of 1° × 1° during dry (**a**) and wet (**b**) periods between 1981 and 2015 (data obtained from ERA-Interim [10]).

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), and 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 the various air masses influence Iran consideration of all aspects of precipitation has a dominant role. Therefore, precipitation characteristics across Iran should be studied using accurate and reliable methods. The stable isotopes technique can present an accurate and comprehensive view of Iran's precipitation characteristics.

The application of stable isotopes in water resource studies has been utilized since Craig, in 1961 [13], found that $^{18}O/^{16}O$ has a very close and strong correlation with $^{2}H/H$ variations in fresh water molecules [14]. The stable isotopes technique presents crucial information regarding the climate condition of the moisture's origin, as well as the climate condition in precipitation sampling sites. There have been many studies regarding the application of stable isotopes in precipitation in Iran. Most of these studies were local small scale investigations [6,7,9,15–19] or large scale studies that covered all of Iran [3,20,21]. The aim of this research was to perform a comprehensive study on the stable isotope 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 were studied in 34 stations across Iran. Stable isotope data are presented in delta notation (δ), which is the relative deviation of the sample from the standard (Vienna standard mean ocean water (VSMOW)) by Equation (1):

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

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 theses, as well as scientific papers.

As the number of studied stations across Iran is large, these stations were classified based on their stable isotope characteristics using cluster analysis (CA). Then, based on station classification by CA analysis and Koppen climatic zones across Iran, the stable isotope characteristics of precipitation in Iran were studied.

3. Results and Discussion

In this study, stable isotope signatures in 34 sampling stations across Iran were studied, as shown in Table 1.

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]					

3.1. Classifying the Precipitation Sampling Stations Based on Stable Isotope Characteristics Using Cluster Analysis (CA)

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

A significant number of the studied stations are in the first cluster, which are located in the 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 isotope contents of $\delta^{18}O$ and $\delta^{2}H$ in the stations located in this cluster are −5.34‰ and −23.51‰, respectively. Furthermore, the d-excess also shows high values of 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 a lower 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. The very high d-excess values in the stations located in this cluster (22.75‰) also confirm this. However, the $\delta^{18}O$ and $\delta^{2}H$ in the stations located in this cluster show depleted values of −6.95‰ and −33.30‰, respectively.

Table 2. The average stable isotope 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

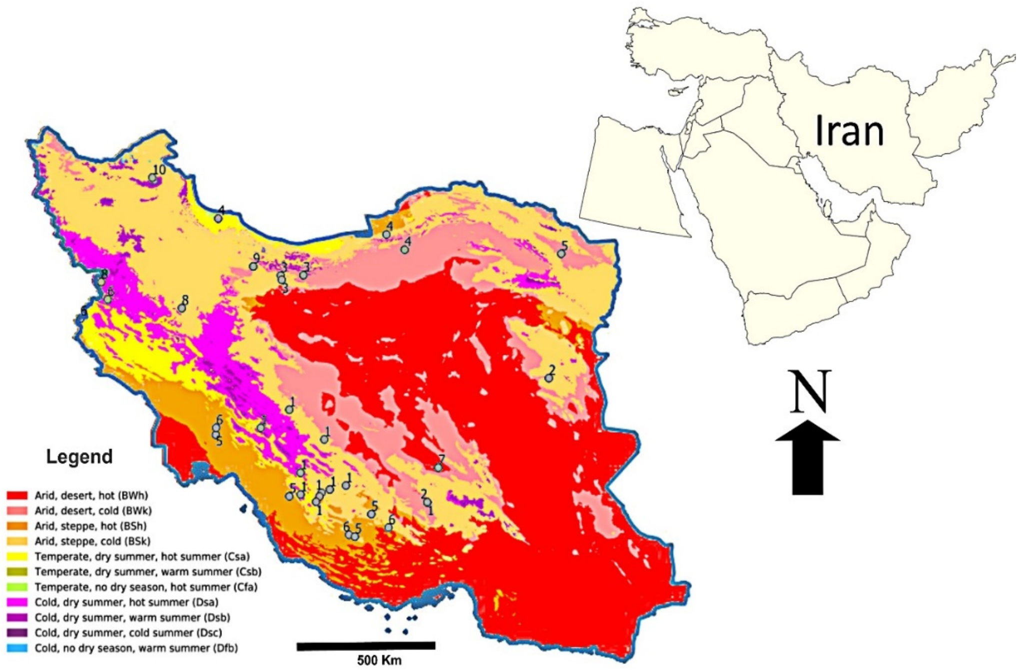

Figure 2. The spatial distribution of the studied stations based on their clusters across Iran, plotted on the Koppen climatic zones.

The stations in the third cluster are also classified in the BSk and BWk climate zones. In addition to the 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 a 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 the Shahroud, Gorgan, and Rasht stations. The Rasht station is located in the 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 the other stations across Iran, while Shahroud, located in an arid zone, receives a very low amount of annual precipitation.

In the fourth cluster, the role of the cP air mass and moisture originating from the Caspian Sea is dominant in providing moisture for precipitation. The 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 by −3.20‰ and −18.70‰, respectively.

The fifth cluster consists of the 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. Similarly to the fifth cluster, the stations located in the sixth cluster, including Kerend, Darab, Fasa, Paveh, Shiraz, and Shirinbahar, are also located in the Zagros region, but in the western part. These stations are mainly plotted in the BSh, except for the Kerend and Paveh stations, which are located in the 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, the stations are mainly under the influence of the 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, has a dominant role in the stations of this cluster. Although the moisture sources are the same for the fifth and sixth clusters, the d-excess values in the fifth cluster are lower (14.4‰) compared to the cluster sixth (19.87‰). This is due to the more intense secondary evaporation influence on the fifth cluster stations.

Rafsanjan is the only station in the seventh cluster that is located in the central part of Iran in the BWh climate zone. The central part of Iran receives a very low amount of precipitation compared to the other parts of Iran. Two large 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, characterized by high SST. The average $\delta^{18}O$ and $\delta^{2}H$ values in this station are −0.5‰ and 12.90‰, respectively. However, the d-excess in the precipitation events in this station shows high values (16.90‰), which confirms their origin from low latitude water bodies.

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

In the ninth cluster is only the Hashtgerd station. The role of the 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 the Hashtgerd station is located beside third cluster stations, 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) is only the Sabalan station. 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. It is mainly under the influence of the cP, MedT, and mP air masses and moisture originating from the Mediterranean Sea, Black Sea, and to a lesser extent the Caspian Sea. The d-excess in the precipitation events of this station show high values (17.10‰).

3.2. Studying Stable Isotope Signatures of Precipitation in Iran Based on the Koppen Climatic Zones

The stable isotopes in precipitation events across Iran are under the influence of various local and regional parameters. Plotting the average $\delta^{18}O$ and δ^2H 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.

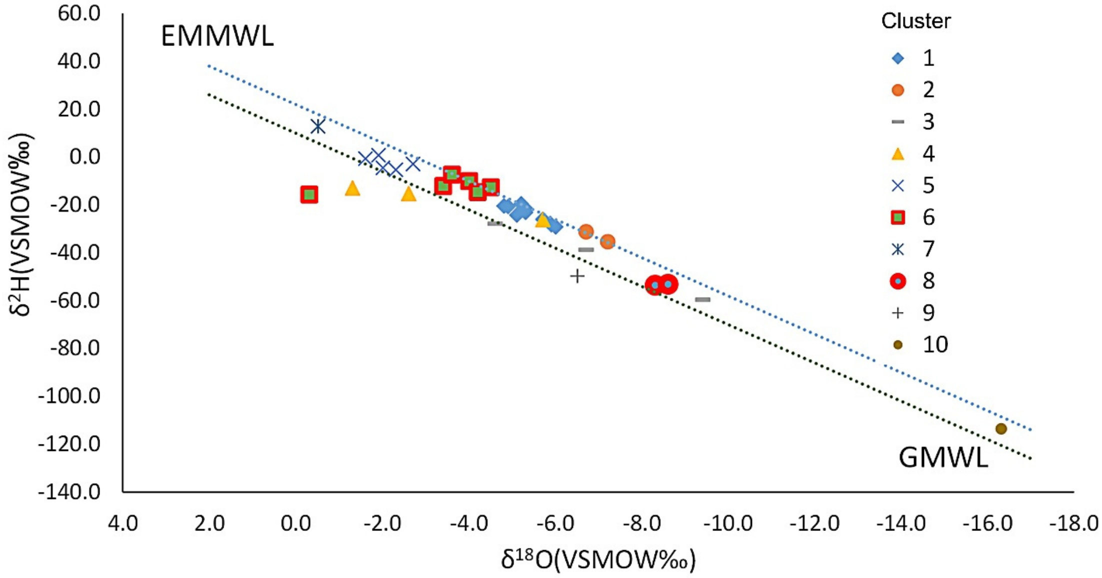

Figure 3. Plotting the stable isotope signatures in the studied stations across Iran on the GMWL and EMMWL.

The stations located in the Zagros mountain range in the first, second, sixth, and seventh clusters mainly plot on the 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. The 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 the Zagros region, a very mild deviation can also be observed from EMMWL. This is due to the secondary evaporation of precipitation events in the stations that exist in this cluster.

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

4. Conclusions

This study shows that stable isotope 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, the precipitation characteristics show spatial variations across the country. Using cluster analysis (CA), the studied stations were classified into 10 clusters according to the stable isotope characteristics of precipitation. Stations located in each cluster show some differences in $\delta^{18}O$ and δ^2H values and d-excess.

Furthermore, the spatial variations of stable isotope signatures in precipitation have been linked to the 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 precipitation sampling stations based on their stable isotope 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. Both authors have read and agreed to the published version of the manuscript.

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References

1. Alijani, B. *Iran Climatology*, 5th ed.; Payam Nour Publication: Tehran, Iran, 2000; ISBN 978-964-455-621-0.
2. Heydarizad, M. *Meteoric Water Lines of Iran for Various Precipitation Sources*; Shiraz University: Shiraz, Iran, 2018.
3. Heydarizad, M.; Raeisi, E.; Sorí, R.; Gimeno, L. An overview of the atmospheric moisture transport effect on stable isotopes ($\delta^{18}O$, δ^2H) and D excess contents of precipitation in Iran. *Theor. Appl. Climatol.* **2019**, *138*, 47–63. [CrossRef]
4. Heydarizad, M.; Raeisi, E.; Sorí, R.; Gimeno, L. The Identification of Iran's Moisture Sources Using a Lagrangian Particle Dispersion Model. *Atmosphere* **2018**, *9*, 408. [CrossRef]
5. Barati, G.R.; Heydari, I. Classification of Iran western Precipitation. In Proceedings of the First Iran National Climate Change Conference, Tehran, Iran, 2 May 2003; pp. 16–23.
6. Mohammadzadeh, H.; Mayvan, J.E.; Heydarizad, M. The effects of moisture sources and local parameters on the ^{18}O and ^2H contents of precipitation in the west of Iran and the east of Iraq. *Tellus B Chem. Phys. Meteorol.* **2020**, *72*, 1–15. [CrossRef]
7. Mohammadzadeh, H.; Heydarizad, M. $\delta^{18}O$ and δ^2H characteristics of moisture sources and their role in surface water recharge in the north-east of Iran. *Isotopes Environ. Health Stud.* **2019**, *55*, 550–565. [CrossRef] [PubMed]
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. [CrossRef]
9. Faroughi, A. *Characterizing Isotopic Signature of Precipitation in Fars Province, Iran*; Shiraz University: Shiraz, Iran, 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. [CrossRef]
11. Rudolf, G. "Klassifikation der Klimate nach W. Köppen" [Classification of climates after W. Köppen]. *Landolt-Börnstein–Zahlenwerte und Funktionen aus Physik Chemie Astronomie, Geophysik und Technik* **1954**, *3*, 603–607.
12. Rudolf, G. Überarbeitete Neuausgabe von Geiger, R.: Köppen-Geiger/Klima der Erde. *Klett-Perthes Gotha* **1961**, *3*, 16.
13. Craig, H. Isotopic Variations in Meteoric Waters. *Science* **1961**, *133*, 1702–1703. [CrossRef]
14. Clark, I.D.; Fritz, P. *Environmental Isotopes in Hydrogeology*; CRC Press/Lewis Publishers: Boca Raton, FL, USA, 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. [CrossRef]
16. Nickghoujag, Y.; Mohammadzadeh, H.; Naseri, H.R. The application of stable isotopes (^{18}O and ^2H) to determine the role of surface water in shallow groundwater resources in Gorgan rood basin. In Proceedings of the Second National Conference on Application of Stable Isotopes, Mashhad, Iran, 11 May 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. [CrossRef]
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. [CrossRef]
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 World Geothermal Congress, Bali, Indonesia, 25–30 April 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. [CrossRef]
21. Shamsi, A.; Kazemi, G.A. A review of research dealing with isotope hydrology in Iran and the first Iranian meteoric water line. *Geopersia* **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 1st National Conference on Application of Stable Isotopes, Mashhad, Iran, 8 May 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. [CrossRef]
24. Jahanshahi, R. *Environmental Effects of GoleGohar Iron Ore Mine on Groundwater of the Area*; Shiraz University: Shiraz, Iran, 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. [CrossRef]
26. IAEA/GNIP Global Network of Isotopes in Precipitation (GNIP). Available online: https://www.iaea.org/servises/networks/gnip (accessed on 14 September 2021).
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**, *2*, 75–120.
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. [CrossRef]
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). *Environ. Earth Sci* **2018**, *77*, 1–19. [CrossRef]
32. Feyzi, D. *Traceing Studies in Roudball Dam Site*; Iran Regional Water Authorities: 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. [CrossRef]
35. Mohammadi, Z. *Method of Leakage Study at Karst Dam Site, the Zagros Region*; Shiraz University: Shiraz, Iran, 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 1st International Applied Geological Congress, Islamic Azad University-Mashad Branch, Mashhad, Iran, 26 April 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 Second National Conference on Application of Stable Isotopes, Mashhad, Iran, 11 May 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. [CrossRef]