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Assessment of stable isotopes characteristics of rainwater in Baghdad city, Iraq

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Abstract

Stable isotopes of water have many environmental benefits and applications, including water management to determine the origin of water, the age of ground waters, and the main pollution sources. An analysis was conducted on stable isotopes $\delta^{18}O$ and $\delta\ ^{2}H$ in rain samples obtained from a single location in Baghdad between 2013 and 2023. A statistical study was employed to determine the factors that affect the spatial and temporal isotopic fluctuations in rainfall. This work aimed to examine the impact of temperature, humidity levels, and precipitation rates on the isotopic composition of precipitation in Baghdad. The results showed that the MWL of Baghdad city, with a d- excess value of 12.69 , was higher than that of the GMWL($\delta\ ^{2}H = 8\ \delta\ ^{18}O + 10$) and less than that of the Mediterranean ($\delta\ ^{2}H = 8\ \delta\ ^{18}O + 22$) . The effect of temperature on precipitation's isotopic composition indicates a positive correlation between temperature and $\delta^{18}O$ values ($R^2 = -0.032$), While a negative correlation exists between precipitation and $\delta^{18}O$ values ($R^2 = 0.104$). It means that the relationship between $\delta^{18}O$ and precipitation is not very strong, This could mean that precipitation is not a good indicator of changes in $\delta^{8}O$ compared to temperature. The Hybrid single-particle Lagrangian integrated trajectory (HYSPLIT) backward trajectory model is also used to identify the origins of humidity during precipitation occurrences. Two sources of humidity are the Mediterranean Sea and the Arab Gulf.

Keywords: Meteoric water line · Deuterium · Oxygen-18 · Precipitation. Humidity source

تقييم خصائص النظائر المستقرة في مياه الامطار في مدينة بغداد، العراق

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الخلاصه

النظائر المستقره لها العديد من الفوائد والتطبيقات البيئية ، بما في ذلك إدارة الموارد المائية لتحديد أصل المياه، وعمر المياه الجوفية، ومصادرالتلوث الرئيسية. تم اجراء تحليل على النظائر المستقره $\delta^{18}O$ و $\delta 2H$في عينات الامطار التي تم الحصول عليها من مكان واحد في بغداد بين عامي 2013 و 2023. وتم استخدام دراسة احصائية لتحديد العوامل التي تؤثر على التقلبات النظائرية المكانية والزمانية للامطار. يهدف

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هذا العمل الى دراسة تأثير درجة الحرارة ، مستويات الرطوبة ، ومعدلات الامطار على التركيب النظائري لمياه الامطار في بغداد. أظهرت النتائج ان قيمة الخط المطري لمدينة بغداد MWL بلغ (12.69) وهو اعلى من قيمة الخط المطري العالمي($\delta ^{2}H = 8 \delta ^{18}O + 10$) GMWL واقل من قيمة الخط المطري للبحر الابيض المتوسط MWWL ($\delta ^{2}H = 8 \delta ^{18}O + 22$) . أن تأثير درجة الحرارة على التركيب النظائري للامطار يشير الى وجود ارتباط موجب بين قيم درجة الحرارة وقيم $\delta ^{8}O$ ($R^2= - 0.032$)، بينما يوجد هناك ارتباط سالب بين قيم الهطول و $\delta^{18}O$ ($R^2= 0.104$). وهذا يعني ان العلاقة بين $\delta^{18}O$ وهطول الامطار ليست قوية جدا، وهذا يعني ان هطول الامطار ليس مؤشر جيد للتغيرات في $\delta^{18}O$ مقارنة بدرجة الحرارة . كما تم استخدام نموذج HYSPLIT لتحديد اصل الرطوبة اثناء حدوث هطول الامطار. مصدرين للرطوبة هما البحر الابيض المتوسط والخليج العربي.

Introduction

Freshwater availability is one of the most important challenges facing humanity today, if not the most important, given that its difficulties impact millions of people's lives. Since precipitation is a significant part of the water cycle, many studies have focused on determining the stable isotope composition of precipitation in various geographic areas. Precipitation contains stable isotopes, an essential mediator between the hydrological and climatic systems [1]. Rainwater is a fundamental component of the hydrological system and an inevitable outcome of the climatic system. Our methodological understanding of the water cycle is furthered by the determination of precipitation- stable isotopes, which are impacted by temperature, precipitation, wind speed, relative humidity, and water vapour sources. Quantification provides important information about precipitation formation and water vapor transfer. For many years, stable isotope compositions of precipitation have served as a diagnostic tool for comprehending the global hydrologic cycle, which includes climatological humidity recycling and movement [2]. Baghdad city has both semiarid and arid conditions [3], which means there is perpetual water scarcity in this area. Therefore, precise and reliable methods like stable isotope techniques should be used to study and regularly monitor the water resources in Iraq. These methods can offer a thorough understanding of the significant aspects of water resources, including their origin, composition, evolution, and contamination. Environmental isotopes are frequently employed in hydrogeological and geochemical research. To comprehend hydrogeological processes, including precipitation, groundwater recharge, groundwater-surface water interactions, and basin hydrology, oxygen and hydrogen isotopes of water are frequently employed as tracers [4]. The link between the values of $\delta^{18}O$ and $\delta^{2}H$ in meteoric water has led to the development of the Global Meteoric Water Line (GMWL). The Local Meteoric Water Line (LMWL) for the city of Baghdad was established for the first time by Al-Naseri in 2013 [5]. Different countries in the Mediterranean region have developed (LMWL) as a result of individual initiatives [6] (Table 1). This study aims to produce the LMWL of Baghdad, evaluate the correlation between precipitation and stable isotopes composition, as well as meteorological parameters, and determine the sources of atmospheric air mass.

Table 1: the revision of previous studies to obtain MWL

region	Equation	Reference
Syria	$\delta^2H = 7.80 . \delta^{18}O + 19.30$	Zuhair. K (1997) [7]
Lebanon	$\delta^2H = 7.13. \delta^{18}O + 15.98$	Zeinab .S et al. (2005) [8]
Iran	$\delta^2H = 6.89 . \delta^{18}O + 6.57$	Abdollah .S and Gholam. A Kazemi (2014) [9]
Saudi Arabia	$\delta^2H = 5.22 . \delta^{18}O + 14.8$	Nils . M et al. (2015) [10]
Kuwait	$\delta^2H = 6.10 . \delta^{18}O + 11.10$	Khaled . H et al. (2016) [11]

Study area

Baghdad is the capital of Iraq; the city represents the largest in terms of population distribution, with about 8 million, according to estimates by the Ministry of Planning. It is located on the side of the Tigris River, with coordinates at 33° 36′ N; 44° 40′ E, 34 m above sea level [12], as illustrated in Figure 1. Baghdad is divided into two sides: Al- Karkh and Al-Rusafa. Its area is estimated at 204 km^2 [13]. The climate of Baghdad is characterized by its being semi-arid, semi-tropical due to its flat and low topography. The summer season is hot, dry, and relatively long and extends from April until the beginning of October, while the winter season is characterized by being cold, moist, and relatively short and extends from December until the end of February. The maximum temperature in the summer may reach 51 C°[14], while the minimum temperature is -4 C°. the average annual rainfall is about 150 mm [15].

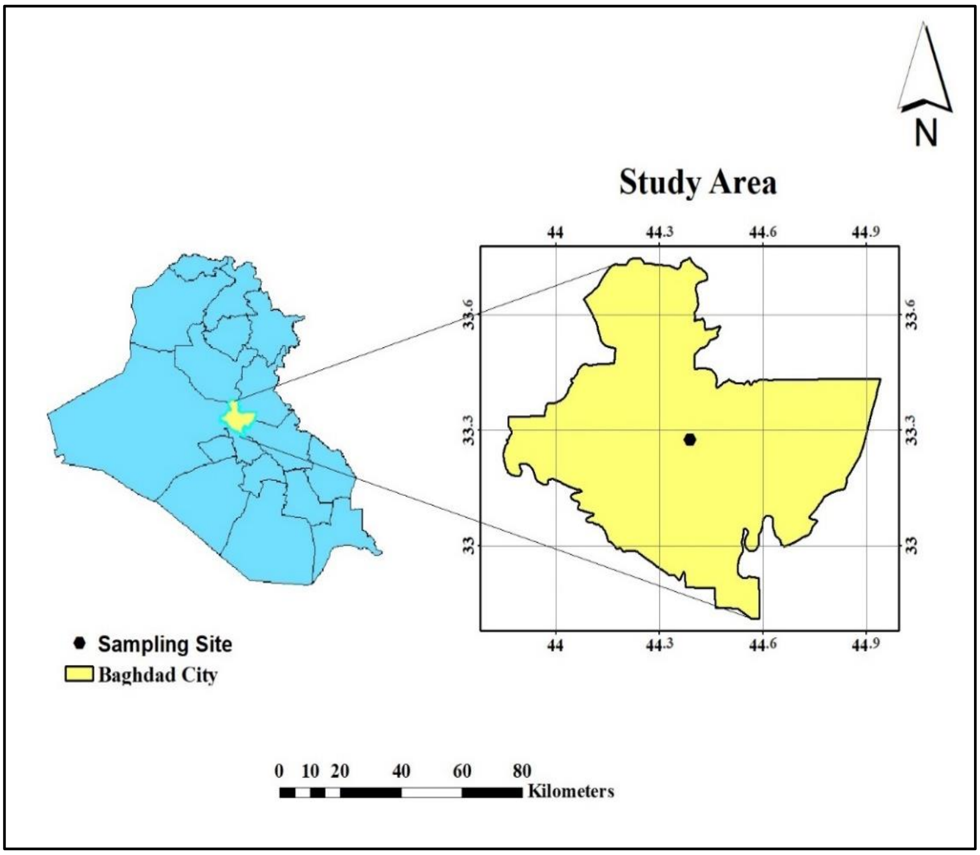

Figure1: Location of the study area (Baghdad)

Material and method

Sampling sites and Data analysis

Forty-nine rainwater samples were collected from one site at different times across Baghdad between 2013 and 2023 and were examined for their stable isotope composition [16]. The isotopic plenty of 18O and 2H were expressed using the δ notation in ‰ (per mil or ppt) relative to the International Atomic Energy Agency (IAEA) Vienna Standard Mean Ocean Water (V-SMOW) reference, following the equation: [17]

$$\delta_{\text{sample}}\,(‰) = \left[\frac{R\ sample}{R\ v{-}smow} - 1\right] \times 1000 \qquad (1)$$

Here, R represents the ratio of the heavier isotope to the lighter isotope (i.e., 18O/ 16O or 2H/ 1H).

Measurements were performed at the Environment, Water, and Renewable Energy / Iraq. The stable isotopes δ^2H and $\delta^{18}O$ were quantified using the liquid water isotope analyzer Model DLT-100 from LGR Company- USA. The measurement was expressed as δ2H and δ18O in ‰ (per mil or ppt) with reference to a VSMOW standard. The study employed stable isotope analyses on monthly precipitation samples gathered from one site across Baghdad from 2013 to 2023. Based on information from the literature published in 2023 [16], and updated measurements of precipitation samples taken after the period mentioned in the above literature were measured in the Environmental Isotope Laboratory in Environment, Water and Renewable Energy Directorate/ Ministry of Science and Technology.

The atomic mass of an element is calculated by taking the average of the atomic masses of the isotopes that exist naturally for that element, with each isotope's contribution weighted according to its abundance. Additionally, it is calculated by summing the masses of the element's isotopes, each multiplied by its natural abundance on Earth. When doing any mass calculations involving elements or compounds, always use average atomic mass, which can be found on the periodic table. The weighted average is calculated by multiplying the percentage of natural abundance by the actual mass of the isotope.

A weighted average is more advantageous than a conventional average due to its ability to provide more significant differentiation. It priorities reducing less important data and amplifying the impact of more substantial data on the final outcome. Additionally, it can be utilized to rectify inadequacies within a dataset. The mean weighted monthly precipitation values are calculated using the following equation [19].

$$\delta\,(‰) = \frac{\sum Pi \times \delta\,\mathrm{i}}{\sum Pi} \tag{2}$$

where Pi represents the amount of precipitation and δi represents the isotope levels ($\delta\,^{18}O$ and δ^2H). In contrast to specific isotopic composition, the deuterium excess is a function of the isotopic concentration of oxygen and hydrogen in water, as constricted by [20] .

$$\text{d-excess} = \delta\,^2H - 8 \times \delta^{18}\,O \tag{3}$$

The (GMWL) is defined by Harmon .C (1961) as the global annual average relationship between hydrogen and oxygen isotope ratios in natural meteoric waters [21] and is given by the equation.

$$\delta\,^2H = 8\,\delta\,^{18}O + 10 \tag{4}$$

The (LMWL) is a regression line representing the relationship between the isotopic compositions of δ^2H and $\delta^{18}O$ in precipitation. It provides information about water sources, the extent of sub cloud evaporation in a specific region, and the climatic and topographical conditions of that region. Figure (2) illustrates the usage of stable isotope ratios of ($\delta^{18}O$) and (δ^2H) to trace the history of water bodies. The x-axis represents $\delta^{18}O$ values, and the y-axis represents δ^2H values. The tilted line in the middle of the plot is the (MWL), which means the typical relationship between $\delta^{18}O$ and δ^2H in precipitation. Precipitation that falls far from the MWL has likely been subjected to evaporation or condensation processes, altering its isotopic composition. The diagram also shows variations of $\delta^{18}O$ and δ^2H values depending on the source of the water vapor and the prevailing climate conditions. Additionally, deuterium excess (d-excess) is important in this context, providing further insight into the climatic processes influencing the isotopic composition. The d-excess is the deviation from the MWL and is influenced by humidity and temperature at the moisture source. Thus, the figure represents a helpful tool for hydrological studies, allowing researchers to trace the origin , history and climatic influences on water bodies.

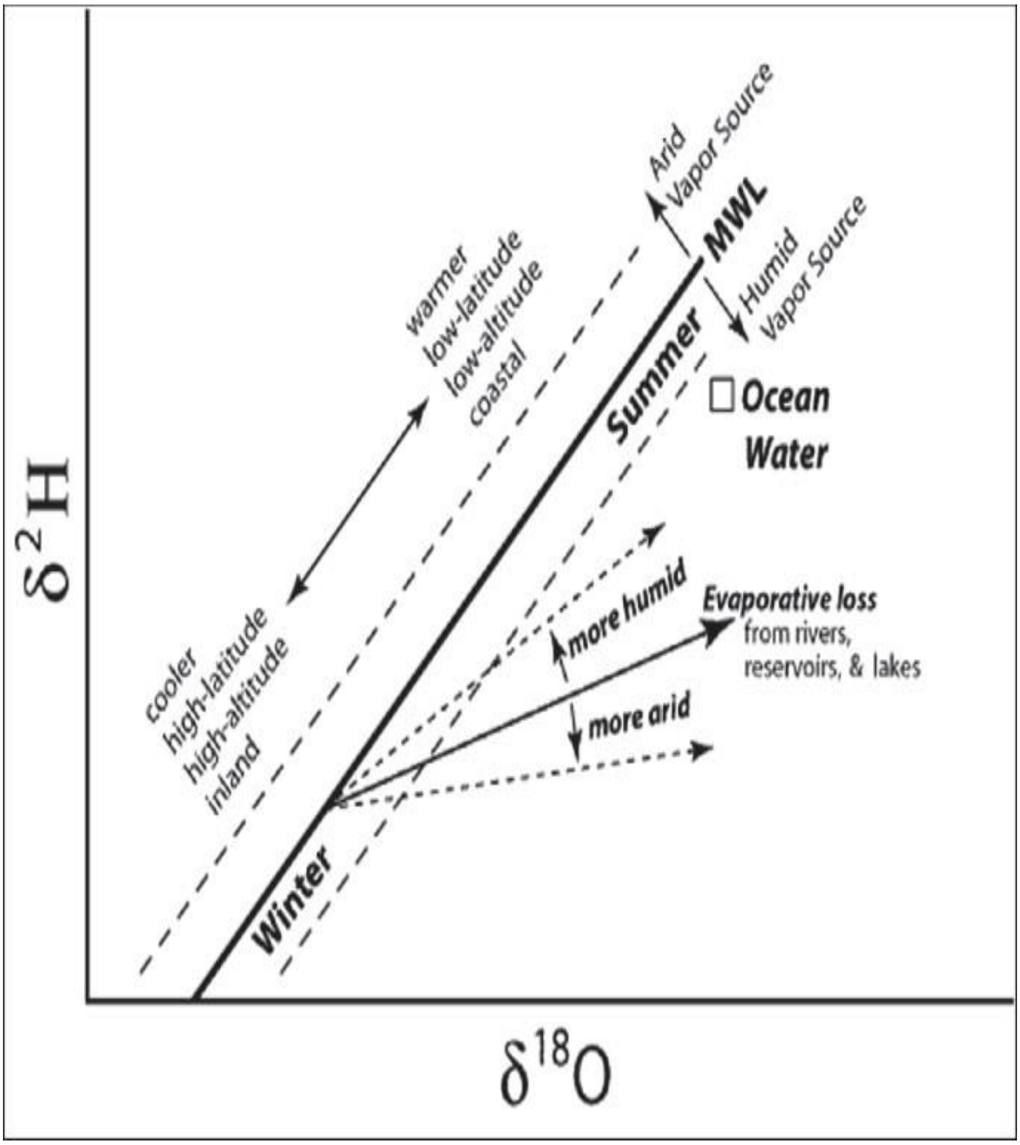

Figure 2: Deuterium excess diagram [18].

The concentration of isotopes may have been changed due to the partial evaporation of the descending droplets, resulting in the enrichment of heavy isotopes in the rainwater. Meteorological data, including ambient temperature, relative humidity, and precipitation amount, were obtained from Meteorology and Seismic Monitoring of Iraq and the Global Network data for the website titled– NASA POWER /Data Access Viewer, https://power.larc.nasa.gov/data-access-viewer/ . To identify the meteorological factors that influence the variation of stable isotopes in atmospheric precipitation, we established a correlation between the isotopic composition of precipitation and meteorological variables. This was accomplished by analyzing the monthly average characteristics of each meteorological variables and the isotopic concentrations with a confidence level 95% [22]. The analysis of humidity sources in this study was adopted using the HYSPLIT Model.

Results and Discussion

The sampling station locations, the precipitation weighted average of the measured values of $\delta^{18}O$ and $\delta^{2}H$, and additional details about the collected samples are listed in (Table 2).

Table 2: Isotopes weighted monthly mean for the period 2013-2023 of Baghdad city

Date	$\delta^{18}O$ (%)	$\delta^{2}H$ (%)	d-excess	P(mm)	T(C°)	RH(%)
Jan-13	-4.56	-18.95	15.4	4.45	8.95	75
Feb-13	-0.46	11.7	15.2	6	10	77
Mar-13	2.71	27.8	7.3	5	17.8	40
May-13	-1.042	5.3	9.95	24.5	24.8	55
Oct-13	-0.51	12.3	16.16	52	20.8	26
Nov-13	-9.22	-52.12	17.65	68	18.7	73
Dec-13	-2.15	-5.48	10.79	10.8	13.5	82
Jan-14	2.11	19.75	3.78	1.31	14.7	60
Feb-14	-2.11	0.993	17.26	9.08	10.1	68.5
Mar-14	-0.724	3.84	8.89	6.48	19.15	39
Oct-14	-2.09	8.67	24.49	7.68	30.3	24
Feb-15	-5.5	-20.83	20.8	42.3	19	55
Oct-15	-4.69	-21.82	13.7	91.17	36.5	33.45
Nov-15	-2.5	-8.4	11.55	1.7	24.77	28.77
Dec-15	-2.42	-3.37	12.9	10.97	14.2	55.8
Jan-16	-0.12	12.44	13.3	14.3	14.72	47
Feb-16	-0.75	6.23	11.9	29.21	18	63.78
Dec-16	-0.7	-0.74	4.85	23.5	14.1	53.21
Jan-17	-4.09	-15.73	15.2	9	20	55
Feb-17	-2.06	6.6	22.2	8	20	43.5
Mar-17	-0.22	14.82	16.8	10	20.72	53
Feb-18	-2.89	-8.77	11	30.13	17.46	66
Apr-18	-0.96	0.97	8.2	31	30	27
May-18	-2.35	-9.08	8.7	10	35	33
Nov-18	-3.33	-9.41	15.86	14.3	18.66	81.33
Dec-18	0.52	18.75	14.8	15.23	17	86
Jan-19	-2.98	-8.38	14.2	27.53	12.6	91
Feb-19	-5.28	-22.77	18.35	0.175	11.8	72.5
Mar-19	-2.34	4.67	22.4	1.66	14	66
Apr-19	-4.65	-18.95	16.2	11.61	14.3	80
Nov-22	-5.77	-29.73	13.45	25.61	21	48
Dec-22	-6.099	-28.12	18	8.43	12.7	81
Jan-23	-3.49	26.95	9.3	13.43	11.53	87.6

Temporal Variation of $\delta^{2}H$, $\delta^{18}O$, Temperature, Relative humidity, precipitation

Based on the isotope data from 2013 to 2023 in Baghdad (Table 2), the change of $\delta^{18}O$ monthly weighted average of atmospheric precipitation is shown in Figure 3. The range of $\delta^{18}O$ varies from -9.22 ‰ to 2.71 ‰, with an average value of – 2.44 %, a standard deviation of 2.46 ‰, and a standard error of 0.43 %. The Annual Variation Trend (AVT) value of $\delta^{2}H$ in atmospheric precipitation is shown in Figure 4, which ranges from – 52.12 ‰ to 27.8 ‰, with an average value of – 3.05 %, a standard deviation of 17.7 ‰, and a standard error of 3.08 % . Annual Variation Trend $\delta^{18}O$ and $\delta^{2}H$ (Fig. 3) and (Fig. 4) from the time series analysis of isotopic values throughout the precipitation period (2013–2023) demonstrate that enriched isotopic values were typical of precipitations in March, whereas depleted values were detected in February. It was noticed that the isotope quantities were steadily declining from December to February, but an enrichment was found in March.

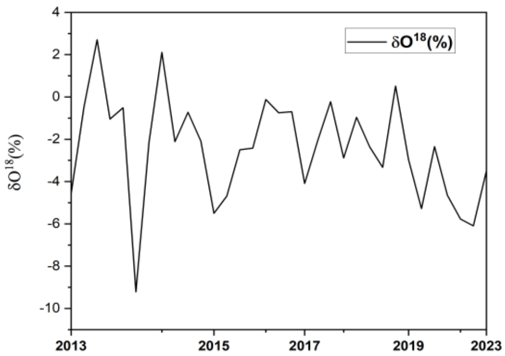

Figure 3: Annual Variation Trend (AVT) of $\delta^{18}O$ in Baghdad

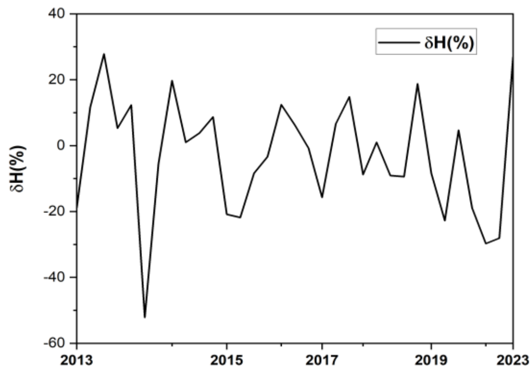

Figure 4: Annual Variation Trend (AVT) of $\delta^{2}H$ in Baghdad

These changes in isotope concentration, which are influenced by meteorological variables, including temperature, relative humidity (RH), and rainfall amount, may be regarded as a regional phenomenon. Figure 5 shows that RH values gradually increased from December to February. The RH ranged from 24 ‰ to 91 ‰ , with an average value of 58.40 % ,a standard deviation of 19.887 ‰, and a standard error of 3.46 %. The d-excess of precipitation exhibited significant variability, as shown in Figure 6. The range of values observed was from 3.73 to 24.49 ‰, with an average value of 13.95%. The standard deviation was calculated to be 4.90%, and a standard error was found to be 0.85. It was determined that the precipitation levels in January and February exhibited a relatively greater d-excess, whereas lower d-excess values were recorded in March. The fluctuations in d-excess precipitation can be ascribed to variations in the origin of humidity (continental and marine), interruptions in rainfall, and variability in relative humidity in the area. The (AVT) value of precipitation and temperature is shown in Figure 7. The precipitation values ranged from 0.175 mm to 91.17 mm , with an average value of 18.92 mm, a standard deviation of 19.98, and a standard error of 3.47 .The temperature values vary from 8.95 C ° to 36.5 C°, with an average of 18.38 C°, a standard deviation of 6.84 , and a standard error of 1.19. Figure 7 depicts how the temperature fluctuates almost throughout the rainy season, dropping in November and gradually increasing in March. The higher the temperature, the faster evaporation occurs. The lower the relative humidity, the drier the air and the greater the evaporation rate. March experienced high temperatures with little rainfall and relative humidity (RH). Consequently, this month shows an increase in isotope measurements.

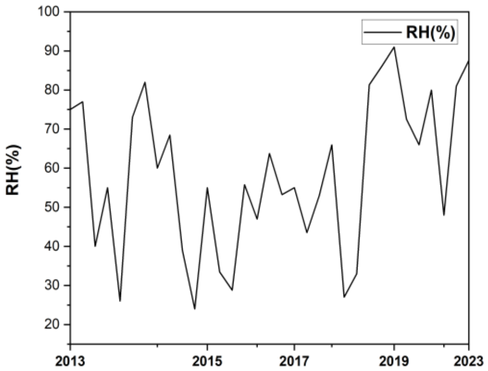

Figure 5 : Annual Variation Trend (AVT) of RH in Baghdad

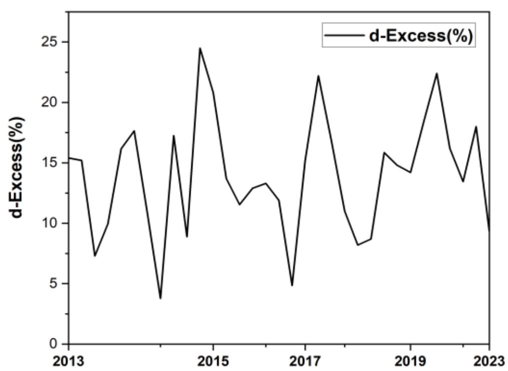

Figure 6: Annual Variation Trend (AVT) of d-excess in Baghdad

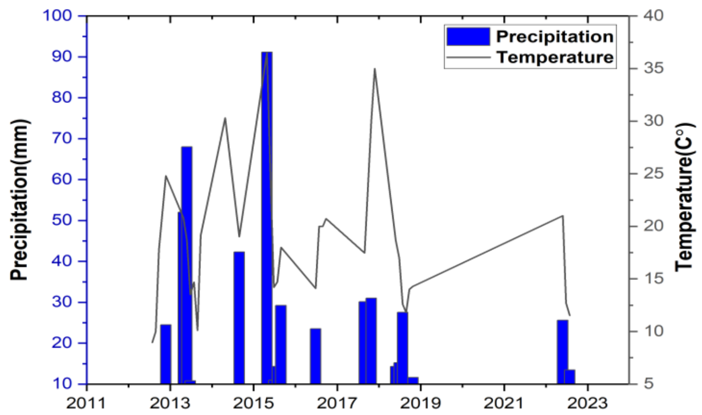

Figure 7 : Annual Variation Trend (AVT) of precipitation and temperature in Baghdad

Relationship between δ^2H and $\delta^{18}O$, and deuterium excess

This study examines the link between δ^2H and $\delta^{18}O$ for data gathered over the Central area of Iraq, represented by Baghdad, between 2013 and 2023. Figure 8 shows a linear regression line known as the meteoric water line of Baghdad (BMWL). Demonstrated to be compatible with precipitation observed regionally at a 95% confidence level .The BMWL ($\delta^2H = 6.4416\,\delta^{18}O + 12.69$) , with a slightly lower slope and higher intercept than those of the GMWL ($\delta^2H = 8\,\delta^{18}O + 10$) , and lower slope and intercept compared to the last LMWL for Iraq that was produced by Al-Naseri ($\delta^2H = 8\,\delta^{18}O + 15.16$) [5], and also have lower slope and intercept compared the Mediterranean Meteoric Water Line MMWL ($\delta^2H = 8\,\delta^{18}O + 22$) [23].The deviations from the LMWL can indicate that the water sample has experienced evaporation or other processes that have changed its isotopic composition and led to being enriched. This study is consistent with other studies in neighboring cities in Iraq and showed a slightly similar LMWL result for each of Al- Anbar [24] , Al-Diwaniyah [25], Maysan [26] and Diyala [27].

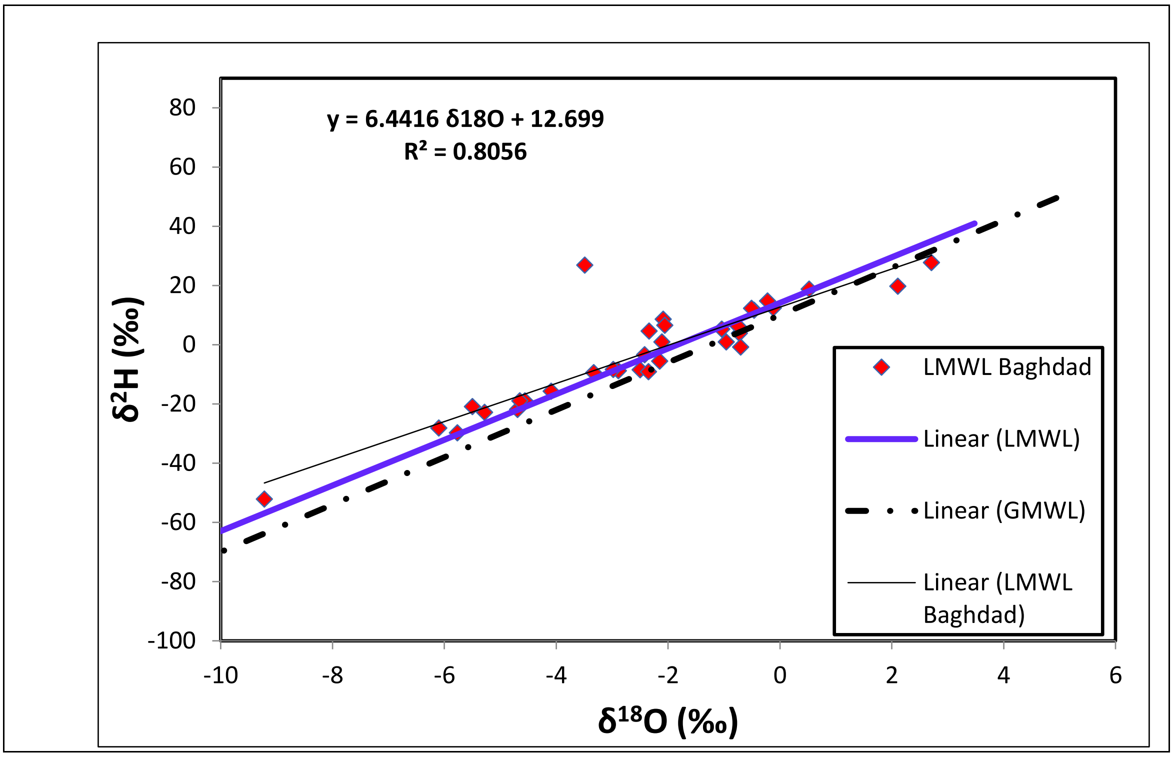

Figure 8: Relationship between δ^2H and δ^{18}O for precipitation of Baghdad city, and relation with LMWL and GMWL

Examination of Baghdad's Influential Factors for Isotope Variation

Temperature effect

Stable isotopes are powerful tools for understanding the water cycle on the Earth's surface. With the use of these isotopes, rainwater may be tracked back to its source, its course identified, and the physical and chemical processes controlling it comprehended. The concentration of stable isotopes in rainwater is influenced by several key parameters, including temperature, humidity, and precipitation amount. The stable isotope values of precipitation, δ^{18}O and δ^2H, are mainly determined by the meteorological and climatic conditions at the precipitation sample location [28]. This area was part of an investigation that looked at the relationships between stable isotopes of precipitation and meteorological conditions. The study examined the link between stable isotopes δ^{18}O and temperature, relative humidity, and precipitation. The temperature effect positively correlated with local air temperature and precipitation stable isotope values [29].

The linear regression equation between stable isotopes δ^{18}O and temperature for all samples in the study area (Fig 9) is established as: $T = 0.0028\ \delta^{18}O - 2.499$ ($R^2 = -0.032$).

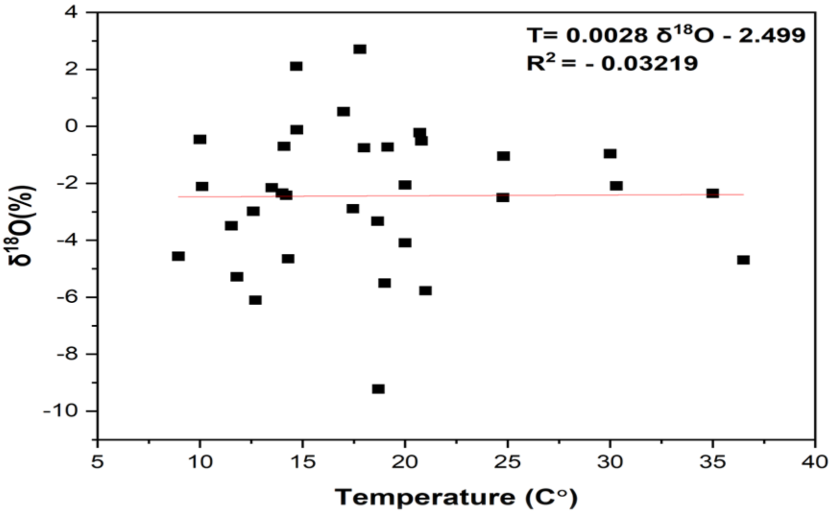

Figure 9: Relation between monthly volume weighted average values of $\delta^{18}O$ and temperature in Baghdad.

This indicates a positive correlation between temperature and $\delta^{18}O$ values, meaning that as temperature increase, $\delta^{18}O$ values increase or vice versa.
This result is reasonable and accepted by many references, particularly in paleoclimatology and isotope geochemistry. For example, Carol. K and Eric A. Caldwell (1998), provided a comprehensive overview of isotope behavior in hydrological systems, including the relationship between temperature and $\delta^{18}O$ values [30]. Another study by Eelco J. Rohling and Heiko. P (2005), this paper explores $\delta^{18}O$ changes and their temperature dependencies, providing insights into the temperature-isotope relationship [31].
however, the precise relationship varies based on time of year, location, and other environmental conditions. In addition to that, Different time scales exhibit various correlations between temperature and precipitation $\delta^{18}O$.
Relative humidity influences precipitation isotope values through its impact on evaporation. The Lower relative humidity typically leads to greater evaporation rates, which concentrate heavier isotopes in precipitation. As water vapor favorable escapes into the air, heavier isotopes like ^{18}O and ^{2}H are left behind in the remaining liquid water, resulting in higher d-excess values [32]. The linear regression equation between stable isotopes $\delta^{18}O$ and RH (%) (Figure11) is established as RH = -0.034 $\delta^{18}O$ - 0.453 (R^2= 0.045) .The results indicate a negative relationship between the two variables, but this negative relationship was not significant (Figure 10) .This means that as the $\delta^{18}O$ value increases, the RH value tends to decrease. This relationship is typically due to the fractionation of oxygen isotopes during the processes of evaporation and condensation [33] . Notably, the correlation between relative humidity and $\delta^{18}O$ can be complicated and subject to different effects. Although there is often a negative association, the specific connection varies based on the geographical area, year's season, and meteorological circumstances. The process of subcloud evaporation causes a decrease in humidity. This process has resulted in a negative correlation between $\delta^{18}O$ values and atmospheric humidity in the study area. The study area has a dry and semiarid climate with low humidity. This lack of humidity has increased the difference in kinetic fractionation between $\delta^{18}O$ and $\delta^{2}H$ isotopes in precipitation [34].

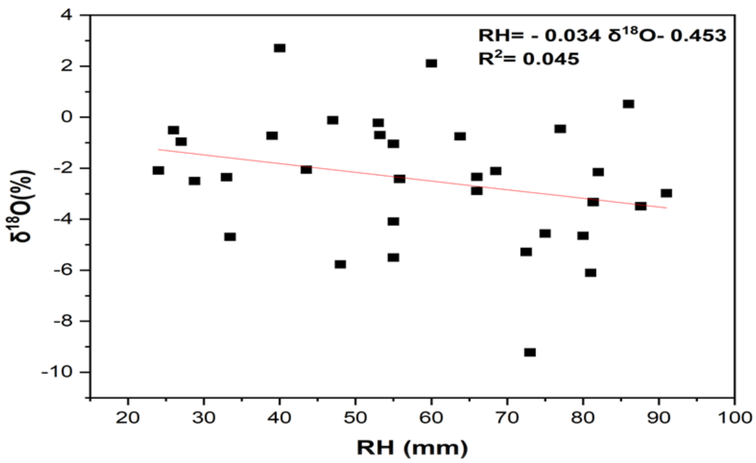

Figure10: Relation between monthly volume weighted average values of $\delta^{18}O$ and Relative humidity in Baghdad

The amount effect

A negative correlation exists between the amount of rainfall and the stable isotope composition of precipitation. This is because the concentration of heavy isotopes decreases as the rainfall continues. The monthly stable isotopic composition ratio in precipitation and the monthly amounts of precipitation in low- to mid-latitude oceans, islands, and monsoon regions have been found to have a significant relationship. This relationship is called the amount effect [25]. In the research area, the linear regression equation between stable isotopes $\delta^{18}O$ and precipitation (%) is P = -0.044 $\delta^{18}O$ –1.594 (R^2= 0.104) for all samples (Figure11). Data shows a negative association between the variables. However, this negative connection was insignificant for all event samples (Figure 11). The study found that the dried areas and semiarid climate evaporates much precipitation before it reaches the ground. As a result, the concentration of $\delta^{18}O$ is usually higher during the start of rainfall, and as the rainfall increases, the heavier isotopes in the rain clouds are gradually removed, resulting in a decreasing trend of $\delta^{18}O$ measurements. In simple terms, there is a significant influence during precipitation since the $\delta^{18}O$ decreases significantly over time. Recycling local humidity is responsible for the variability of $\delta^{18}O$ during precipitation [35].

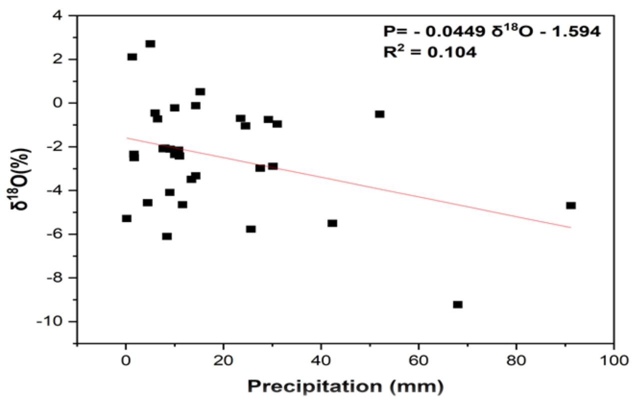

Figure 11 : Relation between monthly volume weighted average values of $\delta^{18}O$ and precipitation amount in Baghdad

Back wared trajectory HYSPLIT Analysis

Hybrid single-particle Lagrangian integrated trajectory (HYSPLIT) model developed by the National Oceanic and Atmospheric Administration and the Air Resources Laboratory, incorporates the Global Data Assimilation System (GDAS). Its an important and useful tool in calculating and simulating the trajectories of air masses. The model feasible is available for download on the NOAA Air Resources Laboratory (ARL) webpage https://www.ready.noaa.gov/HYSPLIT.php. This model is applied to determine the origin of humidity in precipitation in addition to tracking the isotope composition variability. HYSPLIT analysis) was performed for 24 h (in an interval of 6 UTC) during the four rainfall events in October, November 2013, October 2015 and February 2018 To determine the origins of humidity that contribute to precipitation. Baghdad has two potential humidity source zones: the Mediterranean Sea and the Arab Gulf. The primary source of humidity in November 2013, October 2015, and February 2018 was the Arabian Gulf, except in one case in October 2013, which originated from the north, i.e., the Mediterranean Sea.

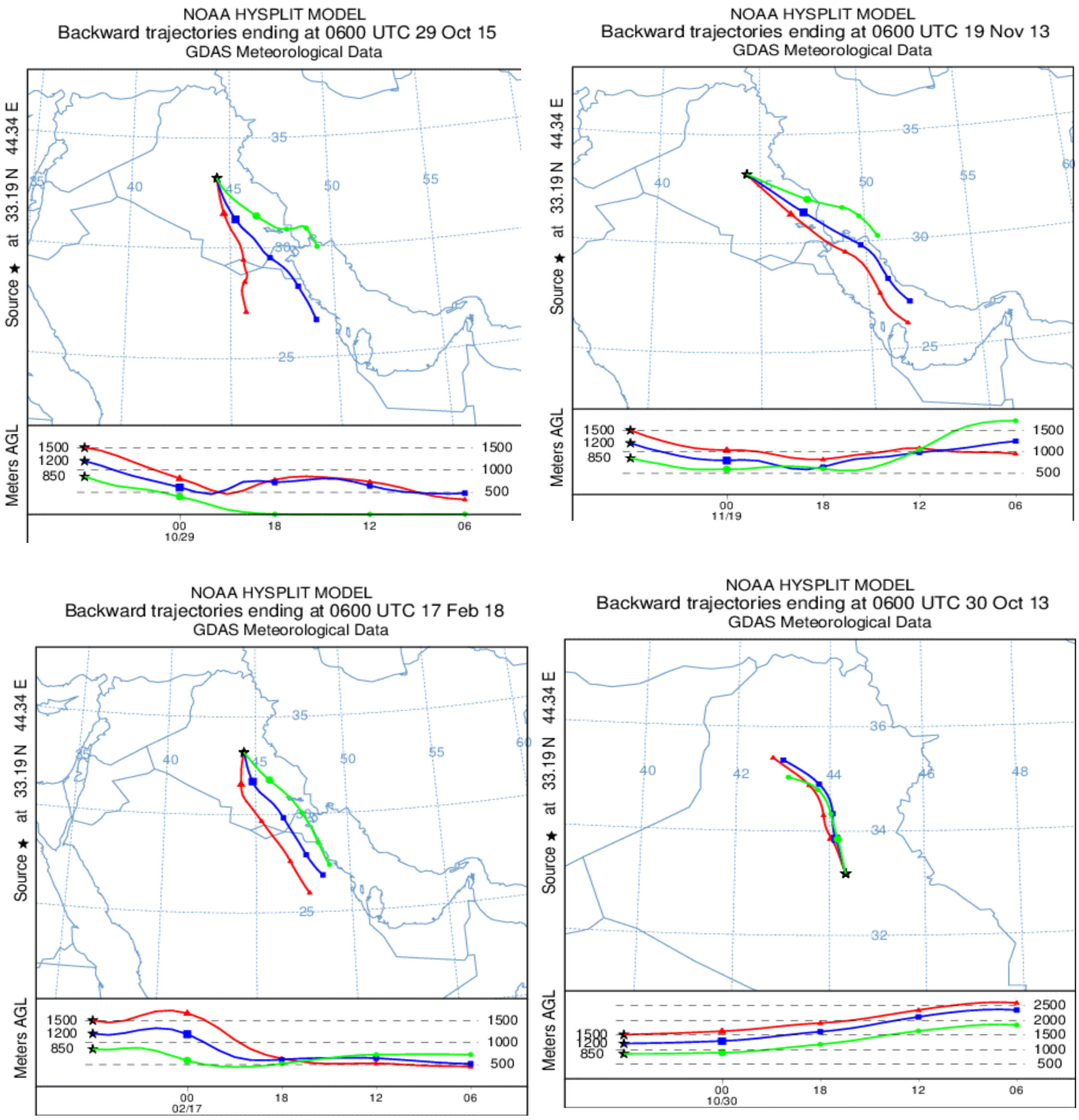

Figure 12: Examination of the backward trajectory model for a higher rainfall event in 2013–2023. The colorful lines in the air trajectory figure represent different paths of humidity sources.

Conclusion

In order to determine the major factors affecting stable isotopes in the precipitation of that region in examination, this study investigated the stable isotope data of Baghdad City from 2013 to 2023. The ultimate findings of this study involve the establishment of (LMWL) for the city of Baghdad. The Baghdad Meteoric Water Line BMWL is given by ($\delta\ ^2H = 6.4416\ \delta\ ^{18}O + 12.69$) .The d-excess value (12.69) of this LMWL is slightly lower than that of the last LMWL for Baghdad that was produced by Al-Naseri ($\delta\ ^2H = 8\ \delta\ ^{18}O + 15.16$) and lies between the Global Meteoric Water Line GMWL ($\delta\ ^2H = 8\ \delta\ ^{18}O + 10$) and Mediterranean Meteoric Water Line MMWL ($\delta\ ^2H = 8\ \delta\ ^{18}O + 22$). This is because Baghdad experiences higher air temperatures and higher evaporation rates than the average for the world. In order to examine the meteorological and climatological variables influencing the stable isotope in precipitation in Baghdad, this study used a regression model. There is a statistically observed positive correlation between the temperature and $\delta^{18}O$ concentration, While there is a negative correlation between the amount of precipitation, relative humidity and $\delta^{18}O$ concentration, which represent the key meteorological elements affecting the presence of stable isotope $\delta^{18}O$ in precipitation.

Based on trajectory analysis by the HYSPLIT model, The primary sources of humidity are primarily from the Arab Gulf and, to a lesser extent, from the Mediterranean Sea. Overall, precipitation amounts density, high temperature, and lower relative humidity affect the isotopic composition of the analyzed samples. Finally, climatological and meteorological factors play an important role in determining stable isotope concentrations of $\delta^{18}O$ and δ^2H in the environment, which varies widely depending on geographic location and climatic conditions. In contrast, isotope analysis can be used to measure a wide range of phenomena, such as climate change, hydrological cycles, pollution, and biodiversity

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