# Determination of the Meteoric Water Line Using Stable Isotopes in Precipitations at Several Locations In Baghdad

**Saadi Kadhim Abd Al-Hussein Al-Naseri**    **Hassan Abbas Zain Al-abidin**

**Ali Hasan Falih**    **Safaa Abdulrazzaq Abdulhussein Al-Kinani**

Ministry of Science and Technology/ Environment and Water Directorate

Baghdad-Iraq

**E-mail:** saadikadhum@gmail.com

**Abstract**

Precipitation represents the input to the hydrological system, and in many cases it is the source or recharge for surface water reservoirs and ground water aquifers. Stable isotopes ($^2H$ and $^{18}O$) ratios were measured during 2011 for precipitation water samples at several locations in Baghdad. The isotopic results for the precipitation were implemented to produce a Local Meteoric Water Line (LMWL) for the first time in Baghdad. When the slop of the line was fixed to equal the Global Meteoric Water Line (GMWL) of 8, Deuterium excess, according to the produced line (15.16), falls between the GMWL of 10 and the Mediterranean meteoric water line of 22. This is because of the continental effect with less humidity and higher temperature than the Mediterranean area.

**Key word**: Deuterium, Oxygen-18, and Meteoric water line

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## تحديد معادلة الخط المطري باستخدام النظائر المستقرة في مياه الأمطار لمواقع مختلفة من بغداد

**سعدي كاظم عبد الحسين الناصري**    **حسن عباس زين العابدين**    **علي حسن فالح**

**صفاء عبد الرزاق عبد الحسين الكناني**

وزارة العلوم والتكنولوجيا/دائرة البيئة والمياه

بغداد-العراق

**المستخلص**

تمثّل الأمطار عامل مهم في الدراسات الهيدرولوجية وغالبا ما تمثّل مصدر التغذية لخزانات المياه السطحية أو الجوفية. تم قياس تركيز نسب النظائر الثقيلة في المياه ($^2H$ و$^{18}O$) لنماذج من مياه أمطار جمعت من مناطق مختلفة في بغداد. تم الاستفادة من نتائج التحليل ألنظائري لمياه الأمطار خلال عام 2011 لرسم خط المطر المحلي ولأول مرة في بغداد (LMWL) ومقارنته بخط المطر العالمي (GMWL). بينت النتائج إنه عند مساواة ميل الخط المطري المحلي لميل الخط المطري العالمي 8، إن الزيادة في الديوتيريوم حسب معادلة الخط المطري المحلي 15.16 تقع بين تلك المستنتجة للخط المطري العالمي 10 وتلك المستنتجة للخط المطري لحوض البحر المتوسط 22. وهذه النتيجة جاءت بسبب التأثير القاري الذي يميز المنطقة برطوبة أقل وحرارة أعلى من تلك التي فوق البحر المتوسط.

**الكلمات المفتاحية:** الديوتيريوم، اوكسجين-18 و الخط المطري

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## Introduction

The scarcity of freshwater is one of the great threats facing mankind today. Clearly, efforts must intensify to protect existing water resources, develop new sources of sustainable water supplies, and improve water distribution and control.

Isotope techniques play an important role in the assessment, management, and protection of water resources. Stable isotopes are a powerful tool to study the sources of water bodies, allowing a better appraisal of their capacity and more rational exploitation. They also can be used to evaluate the sources and potential risk of contamination and to investigate the transport and fate of those contaminants. Isotopes help to identify flow patterns and to distinguish between water movement and contaminant movement, the latter which is usually slower due to interaction with the rock matrix. Stable isotopes of water are intrinsic to the water molecule and do not undergo reaction with rock matrix at environmental temperatures (Aggarwal, 2005).

The naturally occurring light stable isotopes of hydrogen and oxygen ($^2$H and $^{18}$O) can provide a unique fingerprint of a water resource. The isotopic ratios $^2$H/$^1$H and $^{18}$O/$^{16}$O of fresh water varies with atmospheric temperature, resulting in wide and systematic differences observed with latitude and altitude (Shawan, *et al.*, 2012; Lihe, *et al.*, 2011). For example, runoff derived from mountain precipitation is easily distinguished from runoff derived from low elevation precipitation. Extensive evaporation also causes differential enrichment between the $^2$H/$^1$H and $^{18}$O/$^{16}$O ratios, and consequently evaporated water is easily distinguished from pristine rainfall.

Accordingly, as a first evaluation for the isotopes concentrations in Tigris River in Baghdad, sampling will cover precipitation samples in addition to water samples from the river. Collecting such information will enable researchers to draw the local meteoric water line (LMWL) for the city and compare it with global meteoric water line (GMWL).

In nature, two stable isotopes of hydrogen ($^1$H, protium and $^2$H, deuterium) and three stable isotopes of oxygen ($^{16}$O, $^{17}$O, $^{18}$O)were exist. Out of nine isotopically different water molecules, only three occur in nature in easily detectable concentrations: (H$_2$ $^{16}$O, H$_2$ $^{18}$O and $^1$H$^2$H $^{16}$O) (Rozanski, *et al.*, 2001). The isotopic concentration or abundance ratios are generally referred to those of a specifically chosen standard. The internationally accepted standard for reporting the hydrogen and oxygen isotopic ratios of water is Vienna Standard Mean Ocean Water, V-SMOW (IAEA, 2007).

The absolute isotopic ratios 2H/1H and 18O/16O of V-SMOW were found to be equal to (De Wit, *et al.*, 1980; Baertschi, 1976):

$$^2\text{H}/^1\text{H} = (155.95 \pm 0.08) \times 10^{-6} \quad \ldots\ldots(1)$$
$$^{18}\text{O}/^{16}\text{O} = (2005.20 \pm 0.45) \times 10^{-6} \quad \ldots(2)$$

These values are close to the average isotopic composition of ocean water given by Craig (Craig, 1961a; Craig, 1961b). Since the ocean represents about 97% of the total water inventory on the earth's surface and the observed variations of $^2$H/$^1$H and $^{18}$O/$^{16}$O within the water cycle are relatively small, the heavy isotope content of water samples is usually expressed in delta (δ) values defined as the relative deviation

from the adopted standard representing mean isotopic composition of the global ocean:

$$\delta[‰] = \left(\frac{R_{Sample}}{R_{Reference}} - 1\right) * 1000 \quad ...(3)$$

where $R_{Sample}$ and $R_{Reference}$ stands for the isotope ratio ($^2R = {^2H}/{^1H}$ and $^{18}R = {^{18}O}/{^{16}O}$) in the sample and the reference material (standard), respectively (Rozanski *et al* ., 2001). Positive δ values indicate that the water sample is enriched in its isotopic concentration, while negative values refer to depleted water samples.

$^2H$ and $^{18}O$ isotopic compositions of meteoric waters (precipitation, atmospheric water vapor) are strongly correlated. If $\delta^2H$ is plotted versus $\delta^{18}O$, the data cluster along a straight line:

$$\delta^2H = 8 . \delta^{18}O + 10 \qquad ……. (4)$$

This is a famous line in environmental isotopes studies, and it is referred to as the Global Meteoric Water Line (GMWL) (Craig, 1961).

The use of isotope technique to monitor rivers was used by several researchers all over the world (Winston, *et al.*, 2003, Aggarwal, *et al.*, 2005). Application of the technology extended to other applications, such as studying oil-field water (Clayton, *et al.*, 1966), imaging of a dynamic groundwater system (Davisson, *et al.*, 1993), and Migration pathways at landfill sites (Mohr, *et al.*, 1992).

In the Middle East, the isotope technique was used by several researchers. Gat and Carmi (GAT, *et al.*, 1970) was one of the first published papers about the Isotopic Composition of Atmospheric Waters in the Mediterranean Sea Area.

furthermore(Kattan (2008). published a study to estimate the evaporation and irrigation return flow in Euphrates River. In Iraq, the application of the technique is very limited. (Bowen *et al.* , 2005) examined bottle water around the world (including bottles purchased from Baghdad). Samples were obtained from a military camp in Baghdad, Iraq. The measured isotope ratios for these samples span a large range (-75‰ for $\delta^2H$, -9.7‰ for $\delta^{18}O$), and give average values (-45‰, -7.0‰) that were somewhat lighter than those estimated for Baghdad precipitation (-22‰, -4.8‰). Source locations were available for these samples, and suggest that none of the bottled water originated within Iraq. The relatively low average isotope ratios for bottled waters reflect the fact that half the water samples were of European origin. The research aims to start an evaluation for water sample isotope concentrations and evaluate the validity of the instruments and procedures implemented in the environmental isotope analysis laboratory in the Ministry of Science and Technology in Baghdad. Moreover, data can be exploited in future researches to find hydrological relations between various water resources (surface and groundwater) in Baghdad or any area around it. Finally, conducting this research locally will make us, for the first time, able to contribute in the international efforts to gather isotopic information of rivers in the world through an international information network that was established by International Atomic Energy Agency (IAEA) (i.e., Global Network for Isotope in Precipitation, GNIP).

**Materials and Methods**

Figure (1) represents the area of the study with the locations of rain water

sampling points in Baghdad. Precipitations were collected from seven sites for four months (December, 2010 to March, 2011) which covers the rain season in Baghdad. Water samples from each site were stored at 4 $^{\circ}$C till being examined for stable isotopes in the environmental isotopes laboratory, in the Environment and Water Directorate in the Ministry of Science and Technology, Baghdad/Iraq.

Stable isotopes ratios ($^2$H/$^1$H and $^{18}$O/$^{16}$O) were measured using Liquid Water Isotope Analyzer (LWIA) instrument from LGR Company-USA. The instrument uses laser technique to determine these ratios.

Standardization was implemented using two sets of standard samples; the first was provided by the instrument supplier, while the second was our internal standard water samples prepared and measured at the laboratories of the IAEA in Vienna. Table (1) show the values measured for three internal standard samples in the IAEA laboratories for both $\delta^2$H and $\delta^{18}$O.

**Table (1) Standardization Table for $\delta^2$H and $\delta^{18}$O**

| Sample Identification | $\delta^2$H (‰) | $\delta^{18}$O (‰) |
|---|---|---|
| South of Iraq | -15.48 ±0.46 | - 3.07 ±0.04 |
| North of Iraq | -62.59 ±0.35 | -10.86 ±0.04 |
| Middle of Iraq | -40.31 ±0.4 | -6.58 ±0.03 |

The measure values for $\delta^2$H and $\delta^{18}$O will be corrected using these standards and plotted against each other to produce the local meteoric water line in Baghdad.

**Results and Discussion**

Precipitation water samples were analyzed for their stable isotope abundance. The results are shown in Table-2. Some of the isotopes values in the precipitation were positive, which reflects enriched samples. This may be due to the partial evaporation from droplets during their fall causing the enrichment of heavy isotopes in the rain

water (Gat, *et al*., 1970), or the sampling process was not accurate and samples were evaporated after been collected.

Obtaining the local meteoric water line (LMWL) was very important, because it will be used in several hydrological studies and to understand relation between water points, recharge points, and surface water relationships. The combined measurement of $^{18}$O and $^2$H can be used to quantify the evaporation effect and to study mixing processes between river water and adjacent groundwater (Rozanski *et al.*, 2001). The above isotopic results were used to obtain the LMWL and compare it with the Global meteoric water line. Figure (3) illustrated the LMWL obtained from the regression of the data to best fit a straight line, when the slop was fixed to 8. This line yielded a y-intercept, or deuterium excess of +15.16, which was consistent with precipitation observed regionally (Nir, 1967; Kattan, 1997).

Hence the local meteoric water line for the city of Baghdad was estimated according to this study to follow a straight line, as follows:

$\delta^2$H = 8 $\delta^{18}$O + 15.16 ……..(5)

It was worth noting that Nir. (1976) showed that the deuterium excess was +22 for the Mediterranean area. However, for a region like Baghdad with less

humidity, higher temperature than the Mediterranean area, and differing moisture sources, the +15.16 value appears logical, especially when compared with Kattan results(Kattan, 1997) who showed a somewhat similar value for Syria.

In brief, the final conclusions of this work are:

1. The LMWL for the city of Baghdad was produced for the first time ($\delta^2$H= 8 $\delta^{18}$O + 15.16). The deuterium excess was higher due to the same effect observed in the precipitation from Mediterranean origin.

2. Deuterium excess in this equation (15.16) was lower than the Mediterranean meteoric water line (22)

due to the continental effect that characterize Baghdad with less humidity and higher temperature than the Mediterranean area.



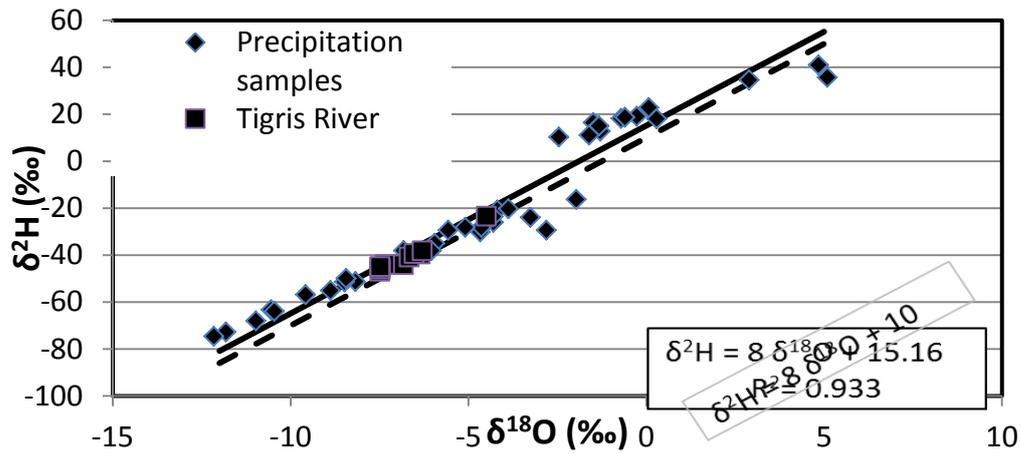**Figure (1) Baghdad Area and the Location of the Sampling Points**

$$\delta^2H = 8\ \delta^{18}O + 15.16$$
$$R^2 = 0.933$$

**Figure (2) Relation between $\delta^2H$ and $\delta^{18}O$ to obtain LMWL**

**Table (2) Measured Values for $\delta^2H$ and $\delta^{18}O$ for Precipitation Water Samples in Baghdad**

| Month | Location | Average $\delta^2H$ (‰) | Std. Err. Dev. | Average $\delta^{18}O$ (‰) | Std. Err. Dev. |
|---|---|---|---|---|---|
| December, 2010 | Zaafaraniya | -56.86 | 0.40 | -9.58 | 0.14 |
| | Kadhimiya | -38.09 | 0.17 | -6.82 | 0.07 |
| | Obaidi | -51.24 | 0.19 | -8.18 | 0.05 |
| | Husainiya | 19.09 | 0.21 | -0.27 | 0.25 |
| | Binok | 12.8 | 0.35 | -1.29 | 0.03 |
| | Dora | -51.39 | 0.17 | -8.48 | 0.02 |
| | Karrada | -49.91 | 0.27 | -8.44 | 0.03 |
| January, 2011 | Zaafaraniya | 16.48 | 0.19 | -1.49 | 0.06 |
| | Obaidi | -26.06 | 0.20 | -4.30 | 0.10 |
| | Husainiya | 15.03 | 0.46 | -1.33 | 0.25 |
| | Binok | -35.00 | 0.40 | -5.95 | 0.10 |
| | Dora | -28.17 | 0.15 | -4.64 | 0.05 |
| | Karrada | -23.58 | 0.53 | -4.31 | 0.16 |
| | Palestine St | -28.15 | 0.13 | -5.09 | 0.03 |
| February, 2011 | Zaafaraniya | -20.27 | 0.29 | -3.88 | 0.03 |
| | Obaidi | -72.75 | 0.48 | -11.82 | 0.07 |
| | Binok | -55.08 | 0.04 | -8.88 | 0.04 |
| | Dora | -63.88 | 0.04 | -10.46 | 0.04 |
| | Karrada | -40.88 | 0.03 | -6.68 | 0.02 |
| | Palestine St | -41.37 | 0.68 | -6.61 | 0.03 |
| March, 2011 | Obaidi | -16.25 | 0.68 | -1.97 | 0.05 |
| | Binok | -29.34 | 0.36 | -2.81 | 0.09 |
| | Dora | -23.92 | 0.27 | -3.26 | 0.04 |
| | Palestine St | 35.72 | 0.25 | 5.09 | 0.02 |

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