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Determination of Groundwater Age in the Northeastern JIFARA Plain, LIBYA, Using Radiocarbon (C^{14})

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تحديد عمر المياه الجوفية في شمال شرق سهل الجفارة، ليبيا باستخدام نظير الكربون 14

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Abstract
Jifara basin is a wide triangular area in the NE of Libya. This study represents some isotopic characteristics of groundwater in the NE Jifara basin, Libya.
the results obtained from this study Were determination of age. geologic age, and the old climate in which the ground water had beer created by using the concentration of C14 in the samples.
the Row data in this study was provided by General Water Authority Libya.

Keywords: Groundwater, Jifara Plain, Radiocarbon (C14), Groundwater Dating.

الملخص
سهل الجفارة هي منطقة واسعة مثلثة الشكل تقع في الشمال الغربي من ليبيا. هذه الدراسة تعرض بعض الخواص الطبيعية والنظائرية للمياه الجوفية في شمال شرق سهل الجفارة.
من خلال هذه الدراسة تم تحديد عمر المياه الجوفية، العمر الجيولوجي والمناخ القديم الذي تكونت فيه هذه المياه (باستخدام نظير الكربون 14).
تم توفير العينات والبيانات الخاصة بها عن طريق الهيئة العامة للمياه، ليبيا.

الكلمات المفتاحية: المياه الجوفية، سهل الجفارة، الكربون المشع (C14)، تقدير عمر المياه.

Introduction

Groundwater resources are among the most important sources of fresh water in arid and semi-arid regions, such as the Jifara Basin in northeastern Libya, where they are heavily relied upon to meet agricultural, industrial, and domestic demands. With increasing pressure on these resources, it has become essential to understand their hydrogeological characteristics, particularly groundwater age, in order to assess their sustainability and manage them effectively. Isotopic techniques (Isotope Hydrology) are considered among the most important tools used in determining groundwater age. Among these, radiocarbon (C14) dating is one of the most effective methods for estimating the age of old groundwater, typically ranging from thousands to tens of thousands of years. This method is based on measuring the radioactive activity of carbon-14 present in dissolved inorganic carbon inground water, which decreases over time due to radioactive decay following an exponential decay law. Carbon-14 is naturally formed in the atmosphere through the interaction of cosmic rays with nitrogen atoms. It is then transferred into groundwater through the dissolution of carbon dioxide in rainwater and soil during the recharge process. Once groundwater becomes isolated from the atmosphere within the aquifer, the concentration of carbon-14 begins to decrease, allowing for the

estimation of the time elapsed since the water was last in contact with the atmosphere. This technique is commonly used to determine groundwater ages within a range of approximately 30,000 to 50,000 years, making it particularly useful for studying fossil groundwater. However, despite its importance, the application of this method in complex hydrogeological systems, such as the Jifara Basin, This study aims to investigate the age of groundwater in the northeastern part of the Jifara Basin using. the carbon-14 dating technique. It also obtained the old climate in which the groundwater had been created by using the concentration of carbon 14 in the samples.

1. Isotopes in Groundwater

Isotopes in groundwater give a direct insight into the movement and distribution processes within the aquifer.

Groundwater in its natural state contains environmental isotopes and conclusion may be drawn from their abundance variations.

The isotopes commonly employed in ground water investigations are the heavy stable isotopes of the water molecule, deuterium and oxygen-18 and the radioactive isotopes tritium and carbon-14.

The stable isotopes are excellent indicators of the circulation of water, while the radioactive isotopes are of special value in detecting the residence time.

The isotopic application in ground water can distinguish into three different types:

1- Stable and radioactive isotopes can be used as TRACER, marking a water body or a certain quantity of water. A nice example is the phenomenon that the rainwater during a heavy storm is often depleted in the heavy isotope (stable H2, deuterium, or stable 18O).

2- Often changes, undergoes so called ISOTOPE FRACTIONATION. conversely, observing differences in especially the stable isotopic concentration ratios informs us about certain geochemical or hydrological processes that took place.

3- Radiation decay offers the possibility to determination an age, provided certain conditions are met. Noteworthy in this respect is the frequent application of dating ground water. -i.e. determining the time elapsed since the infiltration of the water by comparing 14C or 3H (TRITIUM) activities in a ground water sample with that of the recharge water. Moreover, concentration differences of radioactive isotopes can also be used as a tracer.

1.2 Location of the area:

Jifara plain is a triangular area of about 20000 Km² (1% of Libya's total land surface). It is bounded on the north by Mediterranean Sea, on the south and east by Jabal Nafusah escarpment, and on the west by the Tunisian border. (fig.1)

The Jifara region is at the eastern end of a South Atlas lineament or Saharan flexure which defines a southern margin to the Atlas folds.

The flexure runs from morocco ENE to Tunisia where it branches to the ESE and apparently extends into NW Libya as the Jifara Axis.

This feature forms the southern margin of the pelagian platform and the jifara trough.

The jifara trends east-west and extends from the northwest of Libya into the southeast of Tunisia.

The Jifarah plain is a heavily populated area (More than 40% of the Libyan population lives in the area), mostly along the coast and contains the largest Libyan city, Tripoli. Economically, it is the most important part of the country. More than 50% of the agricultural production comes from this region.

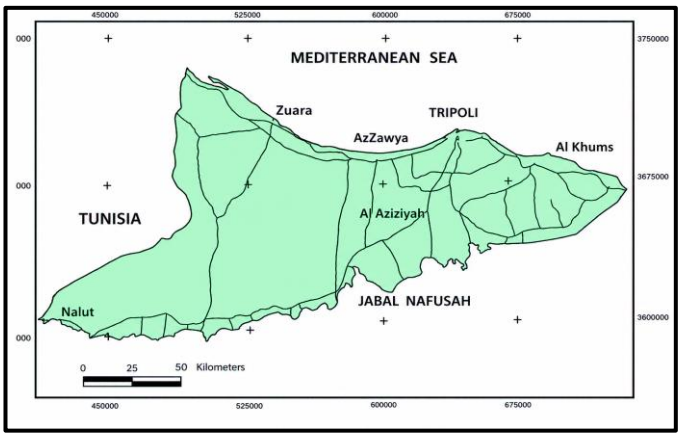

Fig. (1): Location Map.

1.3 Geology of the area

The Jifara plain is a low lying area, it rises gradually from sea level along the coast to 300 m above sea level at the foot of Jabal Nafusah escarpment.

The area is covered by rocks ranging in age from Triassic to Quaternary. Structurally, it is transversed by two major faults (coastal and Al Aziziyah faults) in east-west trend along with a number of smaller faults in the NW-SE trend. Al Aziziyah fault divides the Jifarah plain into two major geological areas. The northern area (north of Al Aziziyah fault) is defined by Miocene transgressive series which thickness increases towards the north. The total thickness of Mio-Quaternary formations can reach 600m along the coast. This sequence consists of thick sandy and calcareous beds with clay intercalation. The Miocene overlies Triassic Limestone and Jurassic evaporites in the west and Upper Triassic sandstone in the east.

The southern area lies between Al Aziziyah fault and Jabal Nafusah, where a thin Quaternary mantle covers Upper Jurassic alternating sandstone, clay and dolomites in the southern part, lower Jurassic evaporites in the meddle western part, Triassic dolomitic limestone in the central part and Upper Triassic sandstone in the eastern part.

Regional geophysical data suggests that the depth to the basement in the trough ranges from 6000 to 20000 f (General Water Authority).

Sedimentary infill of the trough is predominantly of carboniferous, Permian and Triassic age and its genesis is mainly related to tectonic movement associated with the Hercynian event.

There was also an extensional tectonic phase in the Middle to the Late Triassic and some younger tectonic activity led to re-juvination of old fault trends, Folding and associated volcanic activity.

1.4 Stratigraphy of the area

High resolution palynostratigraphy of Jifara Trough well sections has greater understanding of the bio-chrono and allowed a lithostratigraphic relationships.

A thick stratigraphical section of carboniferous, permain and Triassic age is preserved in the trough (fig. 2).

The deposition of these intervals is in a variety of paleoenvironments from terrestrial to fully marine. Although permain aged sediments reach in excess of 12000 f thick in the jifara Trough. these sediments were not deposited south of the Al- Azizayah Fault Zone.

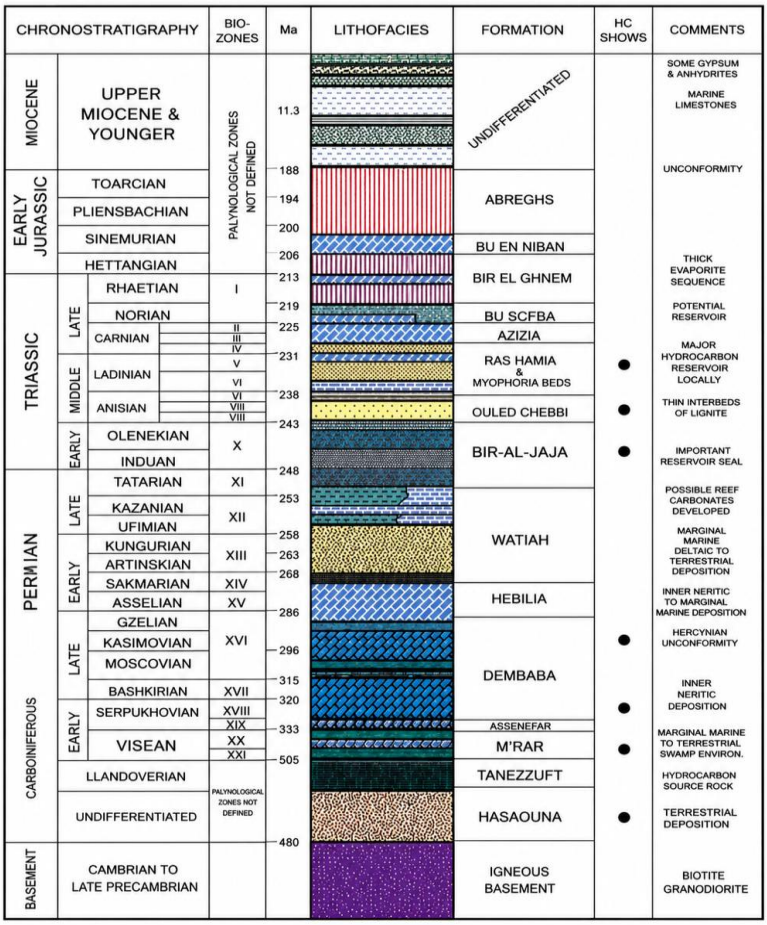

Fig. (2): Composite Stratigraphical Column of jifara trough.

1.5 Hydrology of the area

1.5.1 Groundwater Resources

Based on the geological formations developed in the Jifarah plain, the stratigraphic sequences penetrated in the area can be grouped into two main groundwater reservoirs. These reservoirs are consisting of different water bearing formations. The hydraulic characteristics of the different aquifers are given in Table (1).

1- First Reservoir

It is the most important source of groundwater (provides most of the irrigation and domestic supplies) in the Jifarah plain, it consists of shallow unconfined groundwater aquifers.

It is the Quaternary, Mio-Quaternary deposits in the north of Al Aziziyah fault (western Jifarah plain) and in the eastern Jifarah plain. Al Aziziyah dolomitic limestone in the central part of the Jifarah plain, south of Al Aziziyah fault forms the main unconfined groundwater aquifer, changes southwards to confined aquifer where it is underlying by Abu Shaybah sandstone unconfined aquifer.

2-Second Reservoir

It consists of deep confined aquifers. It is the Miocene deposits in the north of Al Aziziyah fault. This aquifer is in a hydraulic continuity with underlying Abu Shaybah sandstone aquifer in the western Jifara plain.

Abu Shaybah sandstone forms the main second reservoir in the eastern part of the Jifarah plain, where Kiklah sandstone is the main water bearing formation in the foot of Jabal Nafusah escarpment.

Table (1): Summary of the hydrogeological data of groundwater aquifers in jifarah plain

Aquifer	Thickness (m)	Water depth (m.b.g.s.)	Transmissivity (m2/Sec)	Average Storge Coefficient	Salinity (TDS) mg/l
Mio- Quaternary	10-90	10-80	1.2×10-2 - 1×10-1	6×10-2	500-1000
Upper Miocene	100-200	35-90	5×10-4	7×10-3	3000-4000
Lower Miocene	50-100	34-97	2×10-3 _2×10-2	1×10-4	2500-4500
Kiklah	130-200	15-65	1×10-4 _ 3×10-2	2×10-4	1000-2000
Takbal	60-180	32-40	4×10-4 _5×10-3	4×10-3	1500-3000
Abu Shaybah	150-400	10-145	2.6×10-5 _1×10-2	1×10-4	1000-2000
Al Aziziyah	150-350	165-176	7×10-3 _2×10-1	5×10-2	1500-2000

1.5.2 The Main Groundwater Aquifers

Quaternary Or Mio-Quaternary Aquifer

It is an unconfined aquifer at depths ranging from 30 to 160 m below ground surface. This aquifer rests on impermeable beds of blue plastic clays. It consists of sandstone and sandy limestone intercalated with limestone, clay, silt and marl. Its saturated thickness varies from 10m. to 90m and the depth to water level lies between 10 to 80m below ground surface. The wells penetrating the Quaternary aquifer yield 20 to 100m3/h. The aquifer's transmissivity is in the order of 1.2 x 10-3 to 1.0 x 10-1 m2/sec. The storage coefficient is estimated to be in the average of 2% to 15%.

Laboratory analyses of 2 core samples collected from 2 wells drilled in Tripoli area show that, the vertical permeability ranges from 105 to 766 MD, and horizontal from 107 to 957 MD.

Porosity ranges from 42% to 46%, (Table 2).

The water quality is generally good and its total dissolved solids do not exceed 1000 mg/l (Table1), but it deteriorates continuously due to sea water intrusion along the coastal belt.

Table (2): Core Analysis Results

Well No.	Core Sample Depth (m)	Lithology	Permeability MD(air)		Porosity (%)	Grain Density (g/cc)
			Vertical	Horizontal		
T/1/0650/0/88	61.15	Calcarenite	766.52	957.69	45.7	2.71
T/1/0653/0/88	62	Calcarenite	105.27	107.76	42.7	2.75

Miocene Aquifer

The Miocene aquifer is composed of intercalation of limestone, sandy limestone, dolomitic limestone, sandstone and clay forming a confined aquifer underlying the quaternary deposits in the north of Al Aziziyah fault. It consists of both Upper and Lower Miocene aquifers. The Upper Miocene is well developed in the western part of the Jifarah plain. It is penetrated at depths varying from 70 to 185m with an average transmissivity of 5 x 10-4 m²/sec and total dissolved solids concentration of 3000 to 4000 mg/l.

The lower Miocene occurs at greater depths varying from 250 to 500 m with a transmissivity of 2 x 10-3 to 2 x 10-2 m2/sec, storage coefficient is estimated to be in the order of 1 x 10-4 and total dissolved solids concentration (TDS) of 2500 to 4500 mg/l.

Kiklah Aquifer

The Khashm Az Zarzur member of Kiklah Formation is the mean water bearing formation in the southern part of western Jifarah plain (the area between Shakshuk and Tunisian border). The aquifer lies at a depth of 100 to 250m. it consists of sand and sandstone, and sometimes dolomite alternating with clay. It has a transmissivity of 1 x 10-4 1 to 3 x10-2 m2/sec. The aquifer yield and its water quality decreases from west to east, TDS ranging from 1000 to 2000 mg/l.

Takbal Aquifer

The aquifer is formed of limestone, marly limestone, marl, clay and intercalation of sand with gypsum at the base and thickness of 60 to 180m. It is exploited locally in Tiji village and Badr agricultural project.

The Takbal aquifer has a transmissivity of 4 x 10-4 to 5 x 10-3 m2/sec. The water quality is poor (TDS varies from 1500 to 3000mg/l) and becomes worse towards the bottom because of increasing gypsum contents.

Abu Shaybah Aquifer

Abu Shaybah formation of Upper Triassic outcrops only in small areas at the foot of Jabal Nafusah escarpment. It consists of thick layers of sand and sandstone intercalated with shale, clay, and silt overlies

Al Aziziyah aquifer in the central and eastern part of the Jifarah plain. It is a confined aquifer. Its depth varies from 300 to 700m with a thickness of 150 to 400 m.

The production wells penetrating this aquifer are pumped with a rate of 30 to 130m3/h. Depth to water level varies from 10 to 145 m depending on the topography of the area. TDS Varies from 1000 to 2000mg/l and The transmissivity ranges from 1×10-3 to 1×10-2 m2/sec.

In the Southern part of the study area (South of AL Azizyah fault), Abu Shayba formation is an unconfined aquifer. Its penetrated thickness varies from 140 to 210m.

The depth to Water level ranges from 50 to 90m below ground Surface. The discharge rate of the Wells penetrating this aquifer Varies from 4 to 27 m3/h. the transmissivity ranges from 2.6×10-5 to 2.5×10-4 m2/Sec due to reduced thickness and dominating clay beds.

AL Aziziyah Aquifer

AL Aziziyah formation of middle-Upper Triassic outcrops at places near the surface south of Al Aziziyah fault overlying by abu Shaybah formation at the Jabal Nafusah foot. Its thickness varies between 150 to 350 m. it is composed of highly fractured dolomitic limestone intercalated with limestone,dolomite, marl and clay.

Aziziyah aquifer well developed in the south central part and is exploited mainly for irrigation by local agricultural projects, such as wadi al hirah, wadi al hayy and abu shaybah.

Water Wells penetrating Al Aziziyah aquifer are drilled to Dephths Varying from 200 to 350 m With a yield of 50 to 90m3 /h. depth to water Varies from 165 to 176m below ground Surface and the transmissivity ranges from 7.0×10-3 to 2×10-1 m2 /sec.

A storage Coefficient is in the order of 5×10-2 . Totel dissolved Solids Concentration (TDS) of Water ranges from 1500 to 200 mg/l (Table.1)

North of Al Aziziyah fault the aquifer becomes less important due to higher depth, increasing salinity and reduced hydraulic properties.

It slopes down towards the north where it reaches a depth of about 900m near the coast with a TDS of more than 3000 mg/l.

2. AGE DATING USING CARBON-14

Carbon has three isotopes, two stable and one cosmogenic, carbon 14 a cosmogenic isotope with a half-life 5715 years, is useful for dating as well as for tracing hydrologic processes, such as groundwater flow and ocean circulation (Kamen et al, 1963).
(http://en.wikipedia.org/wiki/carbon-14).

Carbon -14 or radiocarbon, is a radioactive isotope of carbon with a nucleus containing 6 protons and 8 neutrons (Fig.3) its presence in organic materials is the basis of the radiocarbon dating method to date archaeological samples.
Carbon -14 was discovered on 27 february 1940, by Martin Kamen and Sam Rubin at the University of California Radiation Laboratory in Berkeley (Johston, Harold2003), although its existence had been suggested by Franz Kurie in 1934),
(http://web.sahra.arizona.edu/programs/isotopes/carbon-14.htm)
There are three naturally occurring isotopes of carbon on Earth: 99% of the carbon is carbon-12, 1% is carbon-13, and carbon -14 occur in trace amounts.
1 part per trillion (0.0000000001%) of the carbon in the atmosphere.
the different isotopes of carbon do not differ appreciably in their chemical properties. this is used in chemical research in a technique called carbon labeling: some carbon -12 atoms of a given compound are replaced with carbon -14 atoms (or some carbon-13 atoms) in order to trace them along chemical reactions involving the given compound.

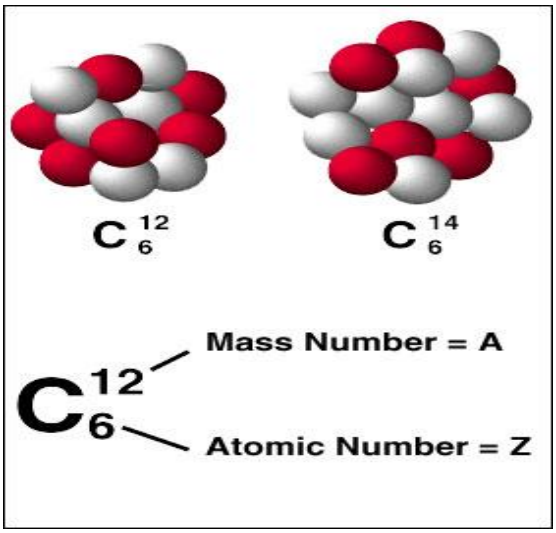

Fig. (3): Carbon Istope
After(www.Antonio-Education.Co.UK)

2.1 ORIGIN
14C is formed in two different ways:
1. Cosmogenic C-14
14C is created when cosmic rays in the earth's atmosphere cause some of the atoms in the upper atmosphere to fly apart into pieces (Fig.4).
Neutrons that come from these fragmented molecules run into other molecules, causing chemical reactions.
14N + neutron → 14C + proton
The highest rate of carbon -14 production takes place at altitudes of 9 to 15km and at high geomagnetic latitude, but the carbon -14 readily mixes and becomes evenly distributed throughout the atmosphere and reacts with oxygen to form radioactive carbon dioxide.
Carbon dioxide also dissolves in water and thus permeates the oceans. Carbon -14 can also be produced in ice by fast neutrons causing spallation reactions in oxygen.

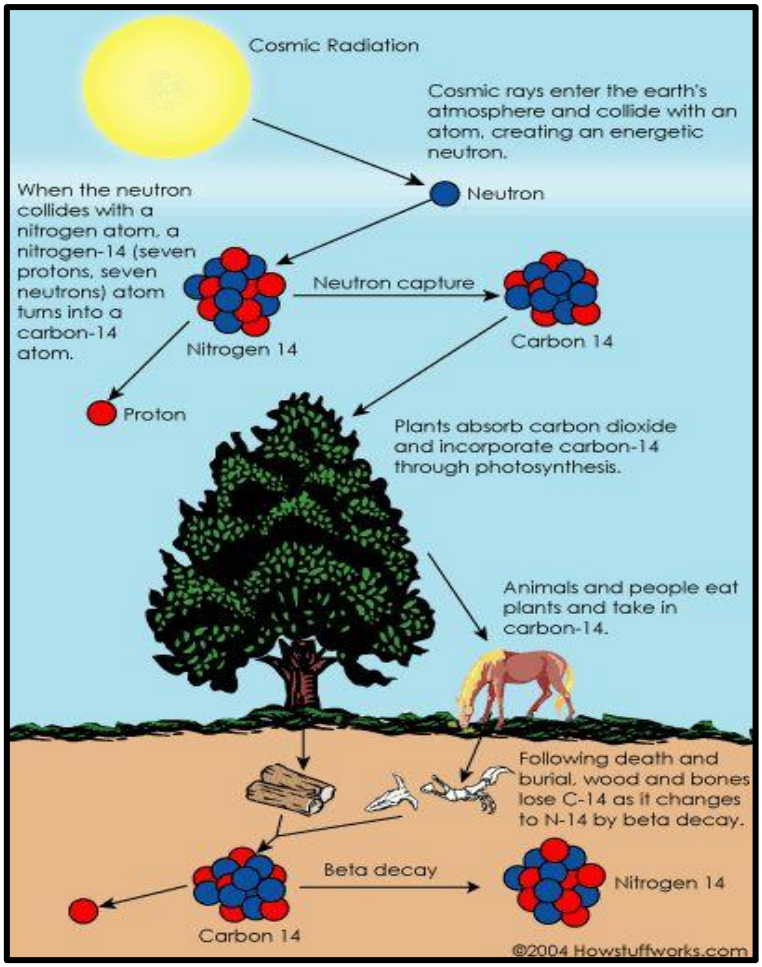

Fig. (4): Cosmogenic C-14 Producing
After(www.Science.Howstuffworks.Com)

2.Anthropogenic C-14

14C is also formed anthropogenically, or through man-made reactions. Much 14C has been added to the atmosphere due to the nuclear bomb tests.

2.2 Decay

Carbon -14 goes through radioactive beta decay, 14C decays according to $^{14}C \rightarrow {}^{14}N + \beta^-$

Decays into the stable (non-radioactive) isotope nitrogen -14, By emitting an electron and an electron antineutrino.

With maximum β^- energy of 165 KeV and a half-life of 5730±40 years (Figs 5 and 6).

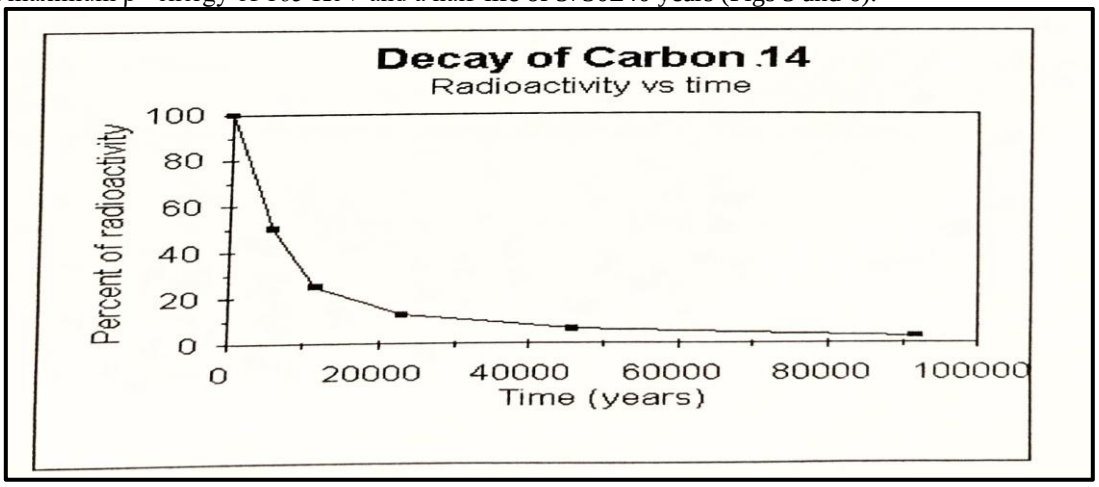

Fig. (5): Decay Curve of C-14
After(WWW.Chem.Csustan.Edu)

Originally the half-life was thought to be 5568 years, so that dating the first decade or two 14C age determinations were based on the wrong half-life. Later, when the better half-life became known, so many 14C ages were already published.
In order to avoid confusion, it was decided that the original half-life should continued to be used for reporting 14C ages. Moreover, it was meanwhile known that ages would still be error, even using the right half-life, because of the natural variations in the 14C content of atmosphereic CO2 during geologic times and deviating from the present These errors were even larger. Nowadays the 14C calbration, based on the known 14C content of tree rings with exactly known age, removes both errors at once.
The production and distribution of 14C in nature occurs through series of chemical and biological processes which has become stationary throughout much of geologic time.
As a consequence, the concentration of 14C in the atmosphere, oceans and biosphere reached a steady-state value which has been almost constant during a geologic period which is long compared to the life span of a 14C nucleus. this natural concentration, 14C/C, is equivalent to a specific activity of about 0.25Bq/Gc (disintegration per second per gram of carbon). However, nuclide data for C14 are given in Table (3).

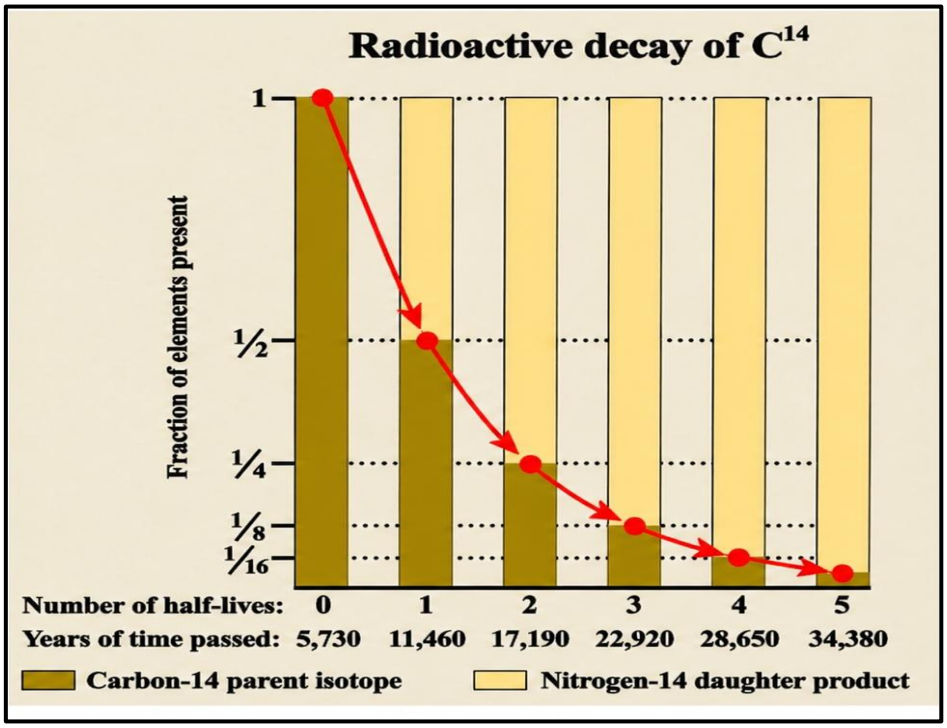

Fig. (6): Radioactive decay of c14
After (WWW. Williamsclass.Org)

Table (3): Nuclide data of Carbon-14

Carbon-14	
General	
Name, Symbol	Radiocarbon, 14C
Neutrons	8
Protons	6
Nuclide data	
Natural abundance	1 Part Per trillion
Half-Life	5,730±40 Years
Isotope-mass	14.003241 u
Decay mode	**Decay energy**
Beta	0.156476 Mev

2.3 Occurrence

Most man-made chemicals are made of fossil fuels, such as petroleum or coal, in which the carbon-14 should have long since decayed. However, such deposits often contain trace amounts of carbon -14 (varying significantly, but ranging from 1% the ratio found in living organisms to amounts comparable to an apparent age of 40,000 years for oil with the highest levels of carbon-14) this may indicate possible contamination by small amounts of bacteria, underground sources of radiation causing the 14N(n,p) 14C reaction, direct uranium decay (although reported measured ratios of 14C/U in uranium -bearing ores would imply roughly 1 uranium atom for every two carbon atoms in order to cause the 14C/12C ratio, measured to be on the order of 10-15) or other unknown secondary sources of carbon -14 production.

Presence of carbon -14 in the isotopic signature of a sample of carbonaceous material possibly indicates its contamination by biogenic sources or the decay of radioactive material in surrounding geologic strata. In connection with building the Borexino solar neutrino observatory, petroleum feedstock (for synthesizing the primary scintillant) was obtained with 14C content.

In the Borexino Counting Test Facility, a 14C /12C ratio of 1.49 × 10-18 was determined, reactions responsible for varied levels of 14C in different petroleum reservoirs, and the lower 14C levels in methane, have been discussed by Bonvicini et al.

2.4 Principles of carbon- 14 Dating

14C is produced in the atmosphere by a variety of nuclear reactions based generally on interactions of cosmic-ray produced neutrons with stable isotopes of nitrogen, oxygen, and carbon by far the most important of these is the reaction between slow cosmic-ray neutrons and the nucleus of stable 14N:

$10n + 147N \rightarrow 146C + 11H$

Where 1n is the neutron and 1H is the proton that is emitted by the product nucleus.

The atoms of 14C are then incorporated into carbon dioxide molecules by reactions with oxygen or by exchange reactions with stable carbon isotopes in molecules of CO or CO2

The molecules of 14CO2 mixed rabidly throughout the atmosphere and the hydrosphere and attain constant levels of concentration representing a steady-state equilibrium.

This equilibrium concentration is maintained by the production of 14C in the atmosphere in the one hand and by its continuous decay on the other.

The molecules of 14CO2 enter plant tissue as a result of photosynthesis and by absorption through the roots (Fig.7). the concentration of 14C in living green plants is maintained at a constant level by its continuous absorption from the atmosphere and its continuous decay. Animals that feed on plants or absorb carbon-bearing ions or molecules from the atmosphere or hydrosphere also acquire a constant level of radioactivity due to 14C. When the plant or animal dies, the absorption of 14C from the atmosphere stops and its activity due to 14C then declines as a result of radioactivity decay. If the activity of 14C in living tissue is known, the activity of 14C of dead plant tissue can be used to calculate the time elapsed since death. This is the "carbon-14 date " of the sample.

The decay 14C takes place by emission of a negative beta particle and leads to the formation of stable 14N:

$146C \rightarrow 147\ N + \beta^{-} + v + Q$

The end point energy (Q) is 0.156Mev. The decay is directly to the groundwater of 14N and no gamma ray is emitted. The radioactivity of a specimen of carbon extracted from plant or animal tissue that died t years ago is given by:

$A = A0\ \ e\text{-}\lambda t$

Where A is the measured activity due to 14C in units of disintegrations per minute per gram of carbon, and A0 is the activity of 14C in the same specimen at the time the plant or animal were alive.

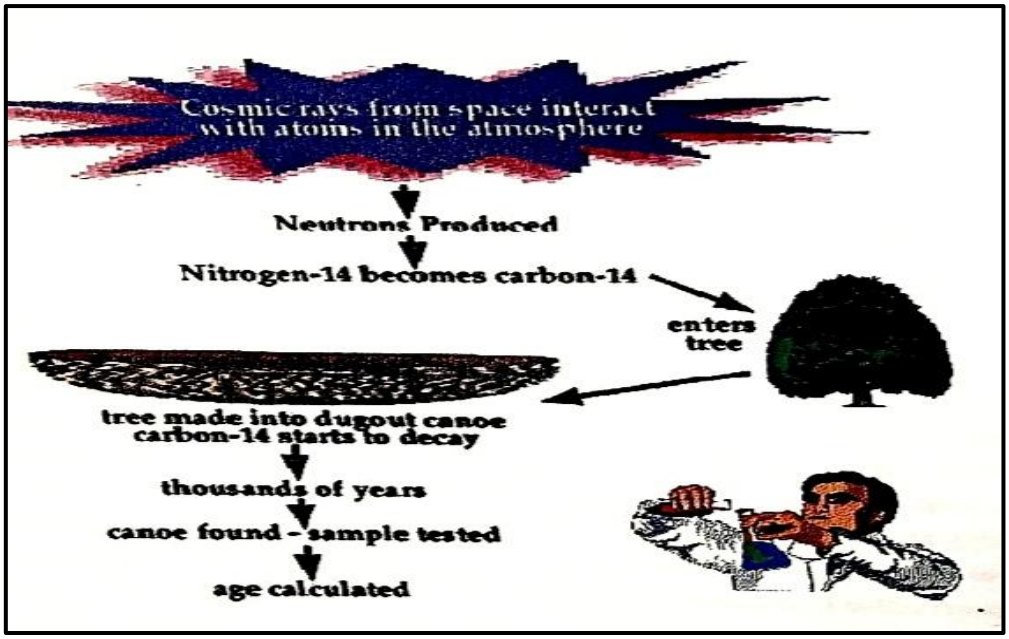

Fig. (7): Carbon-14 Dating
After(WWW.World-Faiths.Com)

The best estimate of the Specific activity of 14C in equilibrium With the atmosphere (A0) Is 13.56±0.07 dpm/g (Karlen et al, 1966)(http://creation wiki.org/carbon-14 dating)
The carbon -14 age of sample containing carbon that is no longer in equilibrium with the 14C of the atmosphere or hydrosphere is obtained by solving Equation for t:

$$\text{Ln}\left(\frac{A}{A0}\right) = -\lambda t$$

$$t = \frac{1}{\lambda}\ln\left(\frac{A}{A0}\right)$$

by changing to logarithms to the base 10 and by substitution of:

$$\lambda = \frac{0.693}{5730} = 1.209\times10\text{-}4\ \text{y-}1$$

we obtain the formula:

$$t = 19.035\times10^{3}\ \text{Log}\left(\frac{A0}{A}\right)\ \text{years}$$

it clear that the accuracy of the carbon-14 dating method depends critically on the validity of several important assumption regarding A and (A0) Its assumed that the initial activity of 14C in plant and animal tissues (A0) is a known constant that has been independènt of time during the past 70,000 years and that its value is also independent of geographic location and does not depend on the species of plant or animal whose dead tissue are being dated has not been contaminated with modern 14C and that the observed activity is not affected by radioactive impurities in the sample.

2.5 Results and Discussion

In this study, seven samples have been collected from seven different wells, four of which are from Miocene aquifer and three are from Quaternary aquifer, the samples have been analyzed, and determine the percentage of the carbon-14 that is available in those samples are determined by using a computer program called (C-14 calculator) The results are given in Table (4).

Table (4): Results of Calculator

Sample	Sample site	Latitude	lonigtude	aquifer	C14	Age
J1	Libda	32.5975	14.24753	Miocene	12.7	17059±10
J2	Suk Kamis	32.52358	14.38914	Quaternary	23	12150±10
J3	Wadi kaam	32.46672	14.41414	Miocene	12.1	17450±10
J4	Zliten	32.46192	14.61789	Quaternary	25.2	11400±10
J5	Skit	32.29561	15.00353	Miocene	4	26600±50
J6	Khoms	32.57367	14.33167	Miocene	14.6	15900±10
J7	Selen-Kho	32.67744	14.22694	Quaternary	44.5	6700±10

It shows from the previous results that the samples taken from Miocene aquifer which are J1,J3,J5,J6 are older and their ages vary between 15900 to 26600 year old, whereas the samples taken from

Quaternary aquifer which are J2,J4,J7 are younger and their ages vary between 6700 to 12150 year old, which means that the groundwater of the Miocene aquifer are older and was there before the Quaternary aquifer.

And to know the geologic age of the samples, and by going to the geologic time scale conclude that all the samples fall in the range of Quaternary time, which is divided into two important periods: The Pleistocene and the Holocene, the samples from J1to J6 falls in the late Pleistocene and only one sample J7 falls in the Holocene.

Looking back to the climate classification to determine the old climate in which the groundwater had been created, all the samples have been formed during the ice age which divided into the periods **(Table. 5).**

Table (5): The Ice Age Periods

10,000BP	Beginning of Holocene. Large mammals including saber-toothed cats, mammoths, and mastodons become extinct. Neolithic period with beginning of agriculture and end of Ice Ages. An estimated 5 million Homo sapiens inhabit planet Earth. Image of Woolly Mammoth from Tulane University Museum of Natural History.
20,000BP	Abrupt cooling about 15,000 years ago gives way to abrupt warming at the end of the Younger Dryas period some 11,600 years ago, with a climatic ripple effect impacting habitats around the world. Gray wolves in East Asia become domesticated about 15,000 years ago, with all modern dogs evolving from them. (Savolainen, Leonard, 2002). 20,000 years ago, global mean temperature 4 degrees C cooler than today, although the North Atlantic was 14 degrees C cooler. Lower sea level allows large-scale migrations of people into the Americas.
30,000BP	Homo sapiens thrive in cold European climate. Homo neanderthalensis become extinct, with last fossil evidence dated 28,000 years ago in Portugal.

Modified from (http://en.wikipedia.org/wiki/Little-Ice-Age)

conclusion

The results indicate the presence of two main groundwater groups within the study area.

Shallow aquifers are generally characterized by relatively young waters, with ages ranging from modern to a few thousand years, reflecting recent recharge from precipitation and local infiltration. In contrast, deeper aquifers contain significantly older groundwater, with ages spanning from the late Holocene to the Pleistocene (approximately 5,000 to over 30,000 years), suggesting recharge under past humid climatic conditions.

Furthermore, the findings reveal that groundwater flow velocities are relatively low, indicating limited natural replenishment. This highlights that a substantial portion of the groundwater resources in the northeastern Jifara Plain can be classified as fossil water, with minimal modern recharge.

In conclusion, radiocarbon dating provides valuable insights into the origin, movement, and renewal capacity of groundwater in the study area. The predominance of old groundwater emphasizes the need for careful and sustainable management strategies, as these resources are largely non-renewable on human timescales.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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