PALAEOCLIMATOLOGY AND PALAEOHYDROLOGY OF LATE PLEISTOCENE PALAEOLAKE AT QA'A SELMA (JORDANIAN BADIA)

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Abstract

Qa'a Selma (as a playa) is located on the northern basaltic flow of northeast Jordan, about 35 km northeast of the Safawi town. The present climate of the region is characterized by seasonal rain (during winter) and it has mild winter and temperate dry summer. Late Pleistocene palaeoclimatic and palaeohydrologic conditions of Qa'a Selma are deduced based on lake level changes. One palaeoshoreline was delineated at 745m a.s.l. and 4m above the present one (1m above the bottom of Qa'a). The Qa'a is located at 740m a.s.l. The present Qa'a area is calculated to equal 18 km^2, where its area has increased during the Late Pleistocene pluvial period and calculated to reach 36 km^2. The Drainage basin area is calculated as well to equal 15000 km^2.

The present hydrological balance is calculated. The present potential evaporation P_E and actual evaporation A_E over the catchment area are calculated to equal 835 mm/ year and 69.01 mm/ year respectively.

Free surface evaporation from the lake surface is calculated to be 1643 mm/ year. Two climatic models are proposed, with the assumed mean annual palaeotemperature 4˚C and 8˚C less than present one (18.9˚C), for the first and second climatic models respectively.

For the first climatic model (mean annual palaeotemperature is 14.9˚C, 4˚C less than present and mean annual palaeoprecipitation 450 mm/ year, ~380mm greater than present), the potential evapotranspiration and the actual evaporation are calculated to be 816 mm/ year and 436 mm/ year respectively.

The free surface evaporation from the lake surface E_L is calculated to equal 1392.6 mm/ year. The palaeorunoff under these condition is calculated as well to equal 14mm/ year, as water volumes required to form and maintain the palaeolake, equal to 210 x10^6 m^3/ year.

Whereas under the proposed climatic conditions of the second model (mean annual palaeotemprature equal to 10.9˚C, 8˚C less than present and mean annual palaeoprecipitation 380mm/ year, or 310 mm/ year greater than presents).

Potential evapotranspiration and the actual evaporation are calculated, as 658 mm/year and 368 mm/ year respectively. The free surface evaporation E_L is calculated as well, and equal 1111mm/ year. The Estimated palaeorunoff is 12mm/ year and as volume of water equal to 180x 10^6 m^3/ year. This amount of water that is needed to form and maintain the palaeolake at the Qa'a area.

So that most probably climatic conditions similar to those of the first and second models might prevailed in the northeast Jordanian Badin throughout Late Pleistocene pluvial periods (37-32 ka BP) and (15.5-13.9 ka BP), which led to form and maintain the palaeolake at the Qa'a area.

مناخ وهيدرولوجية بحيرة قاع سلمى لنهاية البلايستوسين
(البادية الاردنية)

الخلاصة

قاع سلمى كبلايا تقع عند مسار البازلت الشمالي لشمال شرق الاردن، وبما يقارب 35 كيلومتر شمال شرق مدينة الصفاوي. يتميز المناخ الحالي للمنطقة بالامطار الموسمية (خلال فصل الشتاء فقط) وتتميز بشتاء دافئ نوعاً ما، وصيف معتدل الحرارة وجاف. ويبلغ معدل الحرارة السنوي للمنطقة 18.9مْ ومعدل الامطار السنوي 69.4 ملم/ السنة. تم استنتاج الظروف المناخية والهيدرولوجية القديمة لنهاية البلايستوسين لقاع سلمى معتمدين على التغير في مستوى مياه البحيرة. تم تحديد خط ساحل قديم على ارتفاع 745 م عن مستوى سطح البحر الحالي وعلى ارتفاع 4 م اعلى من خط الساحل الحالي للبحيرة الذي يرتفع بمعدل 1م عن قاع البحيرة، الذي بدوره يرتفع 740م عن مستوى سطح البحر. تم حساب المساحة الحالية للبحيرة التي بلغت 18 كم^2، في حين كانت مساحة البحيرة متسعة خلال الفترات المطيرة لنهاية البلايستوسين وقد وصلت مساحتها الى 36 كم^2 اما حوض التصريف للبحيرة وبلغت مساحته 15000 كم^2.

تم حساب الموازنة الهيدرولوجية الحالية، التبخرالكامل الحالي P_E والتبخر الحقيقي A_E فوق مساحة حوض التصريف للبحيرة وكانت مساوية الى 835ملم/ سنة و 69.01 ملم/ سنة على التوالي. كما تم حساب التبخر الحر عن سطح البحيرة ليصل الى 1643 ملم/ سنة.

تم افتراض موديلين مناخيين وبافتراض ان المعدل السنوي لدرجة الحرارة اقل بـ4 ْم و 8 ْم اقل من الوقت الحاضر للموديل المناخي الاول والثاني وعلى التوالي.

المعدل السنوي لدرجات الحرارة للموديل المناخي الاول 14.9ْم، (4 ْم اقل من الوقت الحاضر) والمعدل السنوي للامطار 450 ملم/ السنة (أي ما يقارب 380 ملم/ سنة اكثر من الوقت الحاضر). تم حساب التبخر الكامن والتبخر الحقيقي وكانا 816 ملم/ السنة و 436 ملم/ السنة على التوالي. وحسب التبخر الحر من سطح البحيرة عند هذه الظروف المناخية للموديل الاول وكان 1392.6 ملم/ السنة.

اما الجريان السطحي لهذه الظروف فكان 14 ملم/ السنة وكحجم مياه مطلوبة لملئ وأدامة البحيرة كان 210x10^{6}م^3/ سنة.

اما الظروف المناخية المفترضة للموديل الثاني فكانت (بمعدل سنوي لدرجات الحرارة 10.9ْم أي 8ْم اقل من الحاضر، وبمعدل امطار سنوي 380 ملم/ سنة أي بما يقارب 310 ملم، سنة اكثر من الوقت الحاضر). تم حساب كلا من P_E و A_E التبخر الكامن والتبخر الحقيقي 658 ملم/ سنة و 368 ملم/ سنة على التوالي. كما ان E_L التبخر الحر من سطح البحيرة تم حسابه وقد بلغ 111 ملم/ السنة. تقديرات الجرياني السطحي R عند هذه الظروف المناخية كانت 12ملم/ سنة وكحجوم للمياه المطلوب لملئ البحيرة وادامتها مقاربة الى 180x10^{6}م^3/ السنة.

لذا فانه البحيرة قد تعرضت على الارجح الى ظروف مناخية مشابه او مقاربة لتلك التي وردت في الموديلين المناخيين الاول والثاني والتي تكون قد سادت في منطقة البادية الشمالية الشرقية الاردنية خلال الفترات المطيرة من نهاية البلايستوسين (37-32ka BP) و (15.5-13.9 kaBP) والتي ادت الى تكوين وادامة البحيرة القديمة عند القاع.

Introduction

It has been recognized for more than two decades that many lakes fluctuate in level in response to changes in climate. Most sensitive in this respect are closed basin lakes, which lack surface outlets. Their fluctuating in depth and area is often clearly apparent from abandoned shorelines and other morphological evidence or from abrupt changes of facies in sedimentary sections. Variation in water volumes resulting from climatic change. In general, the spatial consistency of evidence in many areas has been sufficient to exclude the non-climatic factors, at least for the later part of the Quaternary, and in the great majority of cases, lake-level fluctuations can be seen as a direct expression of surface water balance [1]. Where these changes in water level are a reflection of increased precipitation (in the other words pluvial phase) or reduced evaporation losses [2,3]. In most regions of the world where there is evidence of fluctuating lake-level, it is still generally accepted that periods of maximum lake expansion probably reflect both reduced evaporation and increased precipitation [4].

The most suitable lake to choose for a study of water-level fluctuations are closed lakes occupying volcanic meteoritic or fault-bounded basins with moderate relief [5].

Qa'a Selma is one of the playas that had spread in north eastern Jordanian Badia [6] has been chosen for this study in an attempt to detect palaeoclimatic and palaeohydrological changes that occurred during Late Quaternary which, in turn, led to the repeated horizontal expansion and contraction of the palaeolake at the Qa'a.

This example does, however, illustrate the tendency of lakes to form under suitable hydrological conditions even where no preexisting topographic barrier.

The present climate is represented by mean annual rainfall equal to 69.4 mm/ year and mean annual temperature equal to 18.9˚C. Climatological, hydrological and geomorphological data are used here to deduce the nature of major climatic fluctuation that have governed the long-term behavior of the palaeolake that has had occupied the current Qa'a.

Environmental Setting:

Qa'a Selma is located on the northern basaltic flow of northeast Jordan, about 35km northeast of the Safawi (Figure 1). The Qa'a lies at 32˚ 24′ N and 37˚ 22′ E, it has an E-W trend.

The present climate of the area is characterized as being a transition zone between the Mediterranean environment of the Jordan Valley and the western highlands and the arid interior of far eastern Jordanian. Like other transition zones, this region is very sensitive to natural climatic changes such as temperature and the amount of rainfall [7].

Rainfall is subjected to the drastic fluctuation in place and season. Mean annual rainfall in Jordan ranges from less than 50mm at eastern Jordan to over 600mm at Ajlun mountains. The mean annual rainfall at Qa'a selma is about 70mm. The mean annual temperature is 18.9˚C ranging from 8˚C in January to 28.9˚C in July [8,9].

Geomorphology of Qa'a Selma

A detailed geomorphological map for Qa'a Selma shown in (Fig.2). The area can be divided into three landforms, which are represented in the geomorphic map (Fig.2): (a) Basalt, (b) silty clay-loam present at the Qa'a itself and (c) fan debris flows, which are presented in the wadis that feed the Qa'a. Several wadis flow into the Qa'a from all direction.

Alluvial fans-flood plains are highly susceptible to environmental changes. Hill slopes having relatively small catchments areas that are acted upon by relatively low energy, may serve as a key to major climatic changes. Under arid conditions, mountainous hillslopes and escarpments may undergo slope wash and gullying. In such terrians, evidence of short, mild to semi-arid climatic regimes do not survive. Only relatively long periods of stable wet climatic regimes may shift the landscape into different mode of geomorphic activity [7], this in turn require an accurate surveying and description of the landform within the drainage basin and the shore lines of the lake.

Qa'a Selma was surveyed along its present margin and further more towards the wadies, in an attempt to delineate the palaeoshorelines which reflect the lake expansion and contraction throughout Late Quaternary.

Shorelines were not evident except discontinuous old shoreline at 745m above sea level (4m above the present one) which has reflected the expansion of the palaeolake and increasing its surface area, to reach 36km^2 instead of 18km^2, the present area. The bottom of the Qa'a is at 740m above sea level. The area of drainage basin is calculated as well to be equal to 15000 km^2.

Palaeohydrology

- Water-balance models

In case which the areas of a palaeolake and its catchment can be accurately deduced from geomorphological data, it is possible to calculate the change in water balance parameters necessary to maintain a closed lake in equilibrium at a given size. The variable most commonly estimated in this approach is palaeoprecipitation [5].

A simple hydrological approach is presented here and based on the following equations,

$$R = A_L (E_L - P_L) \quad (1)$$

(Under equilibrium condition assuming that groundwater transfer are negligible) if it is further assumed that the runoff from the drainage basin can be represented.

$$R = A_B (P_B - E_B) \quad (2)$$

and

$$Z = \frac{A_L}{A_B} = \frac{P_B - E_B}{E_L - P_L} \quad (3)$$

where

R is the runoff from the catchment,

A_B is the area of the catchment

P_B, P_L are precipitation over the catchment and the lake respectively.

and

E_B is the evapotranspiration over drainage basin

E_L is the free surface evaporation over the lake.

Where Z is the lake area to catchment area ratio. This simple expression shows that the equilibrium area of a closed lake under natural conditions is strictly dependent on the precipitation and evaporation over its catchment and water surface. Equation (3) has been verified empirically by Bowler (a) in [5]. In arid areas, (P_B-E_B) is small and (E_L-P_L) is large. The reverse is true under humid conditions [5].

Palaeoprecipitation can be estimated from equation (3) provided that the former evaporation rate from open water, EL, and either palaeorunoff, R, or the former evapotranspiration rate from the catchment, E_B, can be estimated using Thornthwaite method [10]. E_L can be calculated by using Penman equation [11].

Palaeoclimatic and Palaeohydrologic Models

The climatological basis for using Late Quaternary lake level patterns to reconstruct past states of the general atmospheric circulation is the modern relationship between the global distribution of lakes and major features of the mean annual circulation [12].

For the purpose of reconstructing palaeoclimatological and palaeohydrological conditions that had led to the palaeolake formation at Qa'a Selma, two climatic models are proposed, with assumed mean annual palaeotemperatures 4˚C and 8˚C less than present (for the first and second model respectively).

The choice of palaeotemperature 4˚C and 8˚C less than present (18.9˚C) is based on the previous studies which imply that throughout Late Quaternary, East Mediterranean regions experienced wetter and cooler conditions than present [13]. Temperature in Arabian regions ranging between 4˚C-5˚C less than present and ~6˚C less than present in the Levants region [14], [15].

Estimated values of the mean annual palaeoprecipitation are assumed as well for each model. Both estimated values for palaeotemperatures and palaeoprecipitation are based on their present distribution through the year.

Data from the department of meteorology for 16 years (1981-1997) were used to calculate the present mean annual precipitation (69.4mm/ year) and mean annual temperature (18.9˚C) at the Qa'a area. Where they are 69.4mm and 18.9˚C respectively.

Table-1 shows the present distribution of mean monthly temperature and precipitation. The present potential evapotranspiration P_E and actual evaporation A_E over the catchment are calculated by using Thornthwait method [10] to be ~835.03 mm/ year and 69.01mm/ year respectively (Table-1). The great difference in value between P_E and A_E related to the low present mean annual precipitation which is equal to 69.4mm/year. Free surface evaporation from the lake surface is calculated using Penman equation [11] to be equal to 1643 mm/ year (Table-2). The presents surface runoff is zero. This mean that the current climatic condition obviously are not favorable to maintain a lake of the same size as the palaeolake at the Qa'a area.

From the proposed climatic conditions of the first climatic model (mean annual palaeo-temperature 14.9˚C, 4˚C less than present and mean annual palaeoprecipitation of 450 mm/ year, ~ 380 mm/ year greater than present), the potential evapotranspiration and actual evaporation, P_E and A_E are calculated to be 816 mm/year and 436 mm/ year respectively (Table-3). Free surface evaporation from the lake surface E_L is calculated as well to be equal 1392.6 mm/ year (Table-4).

The palaeorunoff value under these circumstances is calculated to be 14mm/ year, using equation (2) as runoff for the drainage basin to be equal to 210 x 10^6 m^3 this volume of water seems to be little more than the volume which is needed to form and maintain the

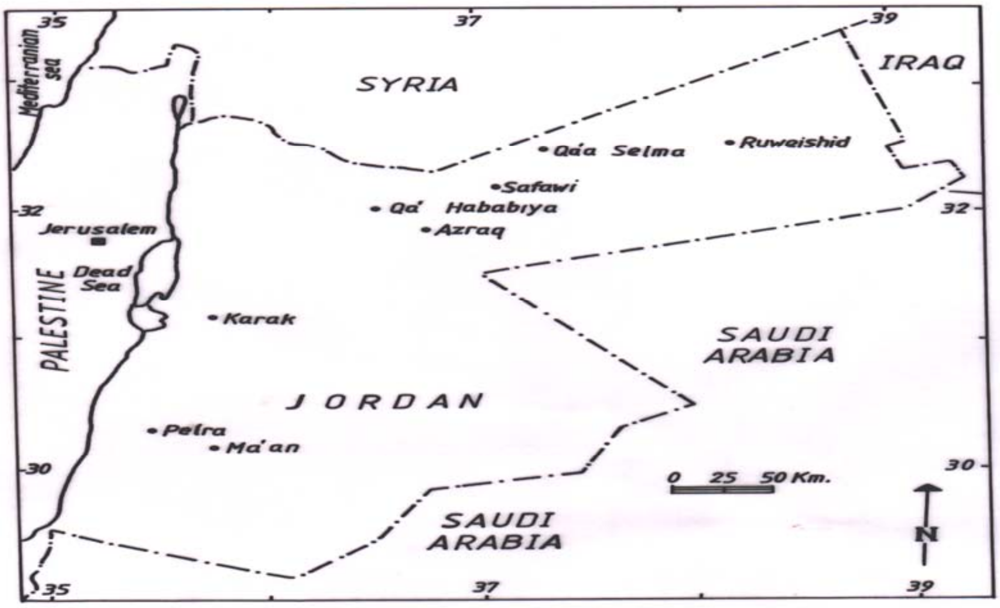

Figure (1): Location map of Qa'a Selma

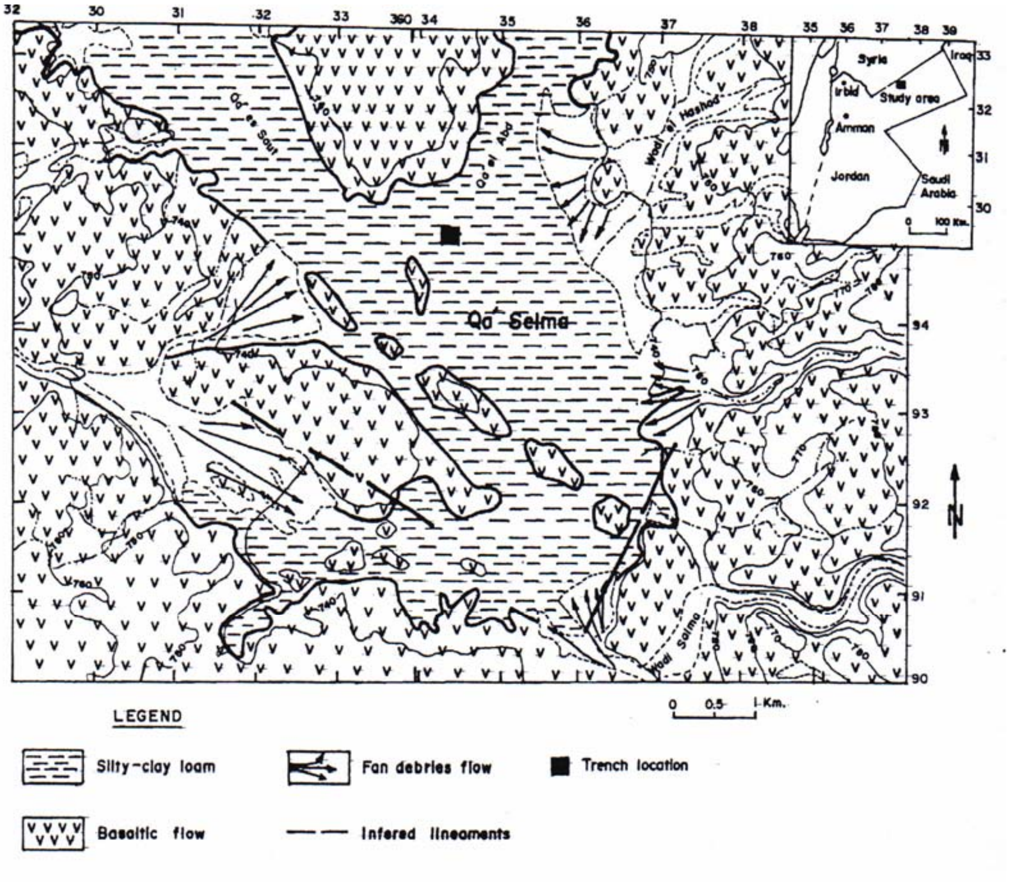

Figure (2): Geomorphological map of Qa'a Selma

Table (1): Potential evapotranspiration (P_E) and surface runoff (R) from the Qa'a Selma drainage basin under present climatic conditions, T: 18.9˚C and P: 68.4mm by using Thornthwait method.

	Jan.	**Feb.**	**Mar.**	**Apr.**	**Ma.**	**J.**	**Jl.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
T˚C	8	9.9	13.2	17.7	22.8	26.5	28.3	28.1	26.4	21.3	14.7	9.4
P_E	6.18	10.71	21.17	43.13	99.77	136.73	157.78	147.97	113.07	63.67	25.53	9.32
P	11.8	12.2	10.4	6.5	2.3	-	-	-	0.1	3.9	10.6	11.6
$P-P_E$	5.63	1.49	-10.77	-36.63	-97.47	-136.7	-157.78	-147.97	-113	-59.77	-14.93	2.28
Acc.Pot.W.L	-	(-1000)	-1010.77	-1047.4	-1144.87	1281.6	-1439.38	-1587.35	-1700.35	-1760.12	-1775.05	
ST	8.91	10	10	9	6	4	2	1	1	1	1	3.28
ΔST	5.63	1.49	0	-1	-3	-2	-2	-1	0	0	0	2.28
A_E	6.18	10.71	10.4	7.5	5.3	2	2	1	0.1	3.9	10.6	9.32
D	0	0	10.77	35.63	94.47	134.73	155.78	146.97	112.97	59.77	14.93	0
S	0	0	0	0	0	0	0	0	0	0	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0

Where: P_E: potential evapotranspiration (mm). T˚C: temperature, P: precipitation (mm), Acc. Pot. W.L., Accumulated potential Water Loss, ST: storage, ΔST: change in soil moisture, A_E: Actual evapotranspiration, D: moisture deficit, S: moisture surplus, R: surface runoff.

Table (2): Mean free surface evaporation E_L of Qa'a Selma under present climatic conditions, T°C: 18.9°C, using Penman method

	Jan.	Feb.	Mar.	Apr.	Ma.	J.	Jl.	Aug.	Sept.	Oct.	Nov.	Dec.
T°C	8	9.9	13.2	17.7	22.3	26.5	28.3	28.1	26.4	21.3	14.7	9.4
E_1	-2.1	-2.5	-3.1	-3.9	-5.1	-5.6	-5.9	-5.9	-5.65	-4.58	-3.2	-2.41
E_2	2.03	3.12	4.0	5.8	7.1	7.9	7.7	7.2	6.3	4.65	3.0	2.09
E_3	0.76	0.91	1.19	1.58	2.2	2.6	3.0	3.0	2.78	2.01	1.35	0.88
E_4	0.78	0.9	1.26	2.0	2.25	2.7	2.9	2.6	2.15	1.59	1.08	0.69
Eo mm/day	1.47	2.43	3.35	5.28	6.45	7.6	7.7	6.9	5.58	3.67	2.23	1.25
Eo mm/month	45.6	68.04	103.85	158.4	199.95	228	238.7	213.9	167.4	113.77	66.9	38.75

$\sum$ Eo = 1643 mm/ year

Table (3): Potential evapotranspiration (P_E) and surface runoff (R) from the drainage basin under the condition of first climate model: T°C: 14.9°C (4°C less than present) and P: 450mm/year (~380 mm/ year 450>present)

	Jan.	Feb.	Mar.	Apr.	Ma.	J.	Jl.	Aug.	Sept.	Oct.	Nov.	Dec.
T°C	4	5.9	9.2	13.7	18.8	22.5	24.3	24.1	22.4	17.3	10.7	5.4
P_E	6	11	26	52	95	125	145	135	113	70	29	9
P	76	79	68	42	15	-	-	-	2	25	68	75
$P-P_E$	70	68	42	-10	-80	-125	-145	-135	-111	-45	+39	+66

Table (3): Continued

Acc.Pot.W.L			0	-10	-90	-215	-360	-495	-606	650		
ST	209	277	300	290	222	146	84	57	39	34	73	139
ΔST	70	68	23	-10	-68	-76	-62	-32	-18	-5	-39	+66
A_E	6	11	26	52	83	76	62	32	20	30	29	9
D	0	0	0	0	12	49	83	103	93	40	0	0
S	0	0	19	0	0	0	0	0	0	0	0	0
R	0	0	19	0	0	0	0	0	0	0	0	0

Table (4): Mean annual free surface evaporation E_L under climatic condition of T˚C: 14.9˚C (4˚C less than present), by using Penman method

	Jan.	**Feb.**	**Mar.**	**Apr.**	**Ma.**	**J.**	**Jl.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
T˚C	4	5.9	9.2	13.7	18.8	22.5	24.3	24.1	22.4	17.3	10.7	5.4
E_1	-1.53	-1.95	-2.4	-3.15	-4.2	-4.7	-5.0	-4.9	-4.6	-3.6	-.2.3	-1.8
E_2	1.71	2.6	3.4	4.91	6.2	7.0	6.8	6.4	5.6	3.8	2.35	1.7
E_3	0.6	0.75	0.9	1.3	1.85	2.1	2.5	2.5	2.6	1.6	0.94	0.7
E_4	0.31	0.54	0.9	1.45	1.4	2.0	2.0	2.0	1.55	1.15	0.72	0.35
Eo mm/day	1.27	1.94	2.8	4.51	5.75	6.4	6.3	6	5.15	2.95	1.71	0.95
Eo mm/ month	39.37	54.32	86.6	139.81	172.5	192	195.3	186	154.5	91.45	51.3	29.45

$\sum$ Eo = 1392.6 mm/ year

Table (5): Potential evapotranspiration (P_E) and surface runoff (R) from the drainage basin under the climatic conditions, T˚C: 10.4˚C (8˚C less than present), and P: 380mm/year (~310 mm/year greater than present), by using Thornthwait method

	Jan.	Feb.	Mar.	Apr.	Ma.	J.	Jl.	Aug.	Sept.	Oct.	Nov.	Dec.
T˚C	0	1.9	5.2	11.7	14.8	18.5	20.3	20.1	18.4	13.3	6.7	1.4
P_E	0	5	19	43	80	107	121	111	91	57	21	3
P	64	66	58	35	13	-	-	-	2	22	57	63
$P-P_E$	64	61	39	-8	-67	-107	-121	-111	-89	-35	+36	60
Acc.Pot.W.L			0	8	76	183	304	415	504	539		
ST	210	271	300	292	232	162	108	74	55	50	86	146
ΔST	64	61	39	-8	-59	-70	-54	-34	-19	-7	+35	+59
AE	0	5	19	43	71	70	54	34	20	28	21	3
D	0	0	0	0	9	37	67	77	71	29	0	0
S	0	0	10	0	0	0	0	0	0	0	0	0
R	0	0	10	0	0	0	0	0	0	0	0	0

Table (6): Mean annual free surface evaporation E_L under climatic condition, T°C: 10.9°C (8°C less than present), using penman method

	Jan.	**Feb.**	**Mar.**	**Apr.**	**Ma.**	**J.**	**Jl.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
T°C	0	1.9	5.2	9.7	14.8	18.5	20.3	20.1	18.4	13.3	6.7	1.4
E_1	-1.09	-1.54	-1.75	-2.4	-3.3	-3.79	-4.01	-4.0	-3.75	-2.8	-1.74	-1.3
E_2	1.25	2.1	2.7	3.69	5.25	6.15	6.35	5.7	4.86	3.2	1.87	1.35
E_3	0.38	0.53	0.66	1.0	1.5	1.85	2.15	2.15	2.05	1.3	0.69	0.45
E_4	0.015	0.18	0.45	0.92	1.4	1.6	1.5	1.32	0.49	0.6	0.32	0.025
Eomm/day	0.55	1.26	2.06	3.21	4.85	5.81	5.99	5.0	3.77	2.23	1.14	0.52
Eo mm/month	17.2	35.5	63.86	96.3	150.35	174.3	185.69	155.1	113.15	69	34.2	16.275

$\sum E_o$ = 1111 mm/ year

palaeolake at the Qa'a.

Whereas under the proposed climatic conditions of the second model (mean annual palaeotemperature 10˚C, 8˚C less than present and mean annual palaeoprecipitation 380mm/ year, or 310 mm greater than present) P_E and A_E the potential evapotranspiration and the actual evaporation are calculated, as 658 mm/ year and 368 mm/ year respectively (Table-5). Where the free surface evaporation E_L is calculated as well to equal 1111mm/ year (Table-6). The palaeorunoff approximately equal to 12mm/ year or about 180x 10^6 m^3, means that the volume of water is enough to form and maintain the palaeolake that occupied the Qa'a area.

It is obvious that the existence of the palaeolake at the Qa'a require vast climatic changes from those of present. With first model (Palaeotemperature 14.9˚C and palaeoprecipitation 450 mm/year) and / or of the second model (palaeotemperature 10.9˚C and palaeoprecipitation 380mm/year), might produced adequate surface palaeorunoff to form and maintain palaeolake. That means throughout Late Quaternary wet periods, the climatic conditions were probably similar to those of the first and/ or second model led to a surpluse moisture, which in turn has produced adequate palaeorunoff to form and maintain the palaeolake within the Qa'a area at that time.

The results show a good agreement with other works in the neighboring areas, at Qa'a Al-Hababyya northeast of Jordan the estimation of palaeoprecipitation ranging between 300-420 mm/ year, greater than present one (~64mm/ year) [16].Where [17] deduced that the estimated palaeoprecipitation were 430-480mm/ year over the Razzaza drainage basin and 440-510mm/year over the Tharthar drainage basin, where the proposed temperature was 15.5˚C, 5˚C less than present (20.5˚C), and at temperature 10.5˚C (10˚C less than present) the estimated palaeoprecipitation over Razzaza and Tharthar drainage basins were, 330-380mm/ year and 350-400mm/year respectively are required to form and maintain the various level of palaeolakes. So that both P and (P-E) results are in a good accord with the palaeoclimate estimates (ΔP= 130-505mm/ year) [18, 19].

Conclusion and Discussion:

Because of the very close relationships that appear between pluvial lakes, precipitation and evaporation, fluctuations in water levels in closed-basin lakes are potentially useful indicators of continental palaeoclimate. The estimation of the climatic conditions during periods of greater moisture throughout Late Pleistocene by using hydrological models reveal interesting insights. The estimated values of mean annual precipitation and temperature that are required for forming and maintaining the palaeolake at the Qa'a area during Late Pleistocene pluvial periods (32-37 ka BP) and (15.5-13.9 ka BP) [6], are either 450mm/year [380mm/year greater than present] with the temperature equal to 14.9˚C [4˚C less than present] and/ or 380mm/ year [310mm/ year greater than present] with temperature 10.9˚C [8˚C less than present]. These results for palaeoprecipitation and palaeotemperature, are in a good agreement with palaeoclimatic estimates [ΔP: 130-505mm/ year] [18, 19] and [ΔT: 4-10˚C] [13, 14, 20].

The palaeorunoff values under such circumstances have been calculated to be 14mm/year under the first climatic model condition, and by volumes equal to 210x10^6 m^3/year. Such amount it seems little more than the volume of water that is needed to form and maintain the palaeolake at the Qa'a area. Whereas the palaeorunoff under the second climatic model conditions is 12mm/ year and by volume 180x10^6 m^3/year, which is adequate to form and maintain a shallow palaeolake at the Qa'a, of 36km^2 surface area and 5 meter depth. This mean that the existing of palaeolake at Qa'a Selma require a vast climatic and hydrologic changes, from those of present. A climatic conditions similar to those of the first and/ or second models might have prevailed in the area during Late Pleistocene pluvial periods. The palaeolake that occupied the Qa'a might reached its maximum extent during the two wet episodes (32-37 Ka BP) and (15.5-13.9 Ka BP).

The suggested Late Pleistocene time intervals for the occurrence; expansion and contraction of the Palaeolake at Qa'a Selma showed a good agreement with results from other works in the neighboring areas such as the evidence of invasion of Lake Lisan, the Late Pleistocene precursor of the Dead Sea, is revealed within the valley of lower Nahal zin that runs down to the Dead sea from the Negev Highlands. The main proof of the invasion is presence of lacustrine sediments that are followed continuously along the lower zin valley for a distance of 25km from the coast of the Dead sea. TL dating has demonstrated that ages of the lacustrine sediments is of about 30 ka [21].

Similar results deduced from a study on lake Huleh near Ain Mallah at the western edge of the upper Jordan valley, in term of vegetation history by Uri Barnch and sytze Bottema [22]. A pollen diagram indicates that oak parkland some what denser than its modern counterpart covered the surrounding hills between about, 15000 and 12000 year ago. The existence of a large and deeper lake is confirmed by the presence of shoreline gravels [23]. Like Huleh, the konya basin (Turkey) was occupied by a lake during the Late Pleistocene. ^{14}C dating of the shoreline around the basin shows that the main lake phase drew to a close about 20,000 cal. Year. BP., but that smaller residual lakes existed north and east of Catalhoyuk as late as 13000 cal. Year, BP. [23]. Where as, Al-Rawi et al [24] in their study of Lake Razzaza, western Iraq, deduced Late Pleistocen pluvial period occurred at 36-31 ka BP, the sediment reflect a higher water level for the lake, the palynomorphs content of this period to suggest a warm and wet climate.

Due to the aridity that prevailed the region (Qa'a Selma) during the dry episodes (32-15.5 ka BP) and (13.9-13.4 ka BP) [6], most probably such climatic conditions led to the contraction and even to palaeolake disappearance. Such Late Quaternary aridity confirmed by other workers [5], that the 13000 year BP was the most arid period in the Late Quaternary throughout Africa and western Eurasia. The minimum of atmospheric convergence and runoff over Africa, western Eurasia and tropical Australia at 13000 year BP is one of the most intriguing features of the whole Late Quaternary record. It implies a strong suppression of monsoonal air flows and hence a radically different state of Asian/ Indian ocean monsoon system from the present day [12]. Lake level fluctuation in Africa for the time period 30.000 year BP up to present [1] show high lake level prior to 21000 year BP, and falling lake level to 12.500 year BP with the phase of maximum aridity being experienced around 13000 year. BP. These changes are interpreted as reflecting major shifts in precipitation regimes and when combined with the palaeotemperature estimates derived from other data [25, 4] allow inferences to be made about past rainfall during the inter pluvial 21000-12.500 year BP, for example, maximum precipitation estimated range from 54-90 per cent of present day levels (drier than present), while for the Sahel, the figures may have been as low as 15-20 per cent [4].

It is obvious that Late Quaternary witnessed vast climatic changes on global and regional scales, which led to many geomorphological features formation. Among them the pluvial lakes and their shorelines and the playas, which are considered as an excellent indicator for palaeo-precipitation and palaeoevaporation.

References

1. Street, F.A. and Grove, A.T. **1979**, *Global maps of lake-level fluctuations since 30,000 year BP*, Quaternary Research, 12. 83-118.
2. Morrison,R. **1968**, *Pluvial lakes, In R. W. Fairbridge (ed)* Encyclopedia of Geomorphology, Reihold, New Yerk, 873-83.
3. Galloway, **1970**, *The fullglacial climate in southwestern united States*. Annals of the Association of American Geographers, Vol. 60, 245-256.
4. Lowe, J.J. and walker, M. J. C. **1984**, *Reconsturcting Quaternary Environment*, Longman Group, England, 399P.
5. Street-Perrott, F.A. and Harrison, P.S., **1985**, *Lake level fluctuations*. In A. Hecht (Editor). Palaeoclimate analysis and Modeling; Wiley. New York. 291-340p.
6. Al-Tawash, B., **2007***, Carbon-14 and stable isotopes of carbonates of Late Pleistocene lacaustrine sediment in Qa'a Selma (Jordanian Badia)*. Iraqi Journal of Science, Vol. 48, No., 1, 2007, 155-165pp.
7. Ali, A.J., Abu-Jaber, N., Awawdeh, M., Al-Qudah, K. and Al-Tawash, B. **1999**, *Climatic change and hydrological balances in the Jordanian Badia, Jordan*, UNESCO CHAIR, Research project, report (Unpub.), Yarmouk University, 62P.
8. Meteorological Department, Jordan. **1987**, Meteorology National Atlas. Met. Dept., Jordan.
9. Meteorological Department, Jordan, **1988**, Jordan climatological Dara Handbook., Met. Dep., Jordan, 104P.
10. Thornthwait, W.C. and Mather, R.J.**1955**, *The water balance publications in climatology*, III, 1. Centerton, New Jersy. 1o4P.
11. Wilson, E.M. **1990**, *Engineering hydrology* (Fourth edition), Macmillian Education Ltd, UK, 348P.
12. Street-Perrott, F.A. and Roberts, N. **1983**, *Fluctuations in closed basin lakes as an indicator of past atmospheric circulation patterns*, in A. Street-perrott, M., Beran and

R.Ratcliffe (eds.), Vara-tions in the global water budget. Dordrecht: Reidel, pp. 331-45.

13. Walter, H., **1971**, *Ecology of Tropical and Sub-tropical vegetation (Translated by D. Muellar-Dombois).* Oliver and Boyd, Edinburgh.
14. Nutzle, Werner, **1974**, *Climate of the Mesopotamia and bordering areas 14000 to 12000 BC.* Sumer, 20. Directorate General of Archaeology. PP:11-24.
15. Bar-Mathews, M., Ayalon, A. and koufman, A., **1997**, *Late Quaternary Palaeoclimate in the Eastern Mediterranean region from stable isotope analysis of spleothems at Soreq Cave, (Palestine).* Quaternary Research, Vol. 47. 155-168.
16. Awawdeh, M. M., **1998**, *Reconstructing The Quarternary Sedimentary Environment of Qa'a Al-Hababyya, Northeast of Jordan,* M. Sc. Thesis, University of Yarmouk (Unpublished) 80p.
17. Al-Tawash, B.S., **1996**, (In Arabic). *The Pleistocene History of the Razzaza and Tharthar Depressions in Central Iraq,* Ph.D. Thesis, University of Baghdad, 124P.
18. Street, F.A., **1979**, *Late Quaternary precipitation estimates for the Ziway-shala Basin, southern Ethiopia,* Palaeoecology of Africa, 11: 135-143.
19. Kutzbach, J.E., **1983**, *Monsoon rains of the Late Pleistocene and Early Holocene: Patterns, intensity and possible causes of changes*, In: F.A. Street-Perrott, M.Beran and R.A.S. Ratcliffe (Editors), Variation in the global water Budget. Dordrecht: Reidel, 371-89.
20. Shumm, A.S., **1965**, *Quaternary Palaeohydrology*, 783-795 in H.E. Wright and D.G. Frey. (eds.): The Quaternary of the United States, Princton Univ. press.
21. Sheinkman, V., **2002**, *Late Pleistocene invasion of Palaeo-Dead Sea into the lower Zin Valley, the Negev Highlands, Isreal.* European Geoscinces Union Stephen Muller Special Publication Series, 2, 113-122, 2002.
22. Baruch, U. and Bottema, S. **1991**, *Palynological evidence for climatic changes in the Levant ca 17000-9000 B.P.,* In O. Bar-Yosef and F.R. V. alla (eds.), The Natufian culture in the Levant. Ann Arbor, Michigan: International Monographs in Prehistory, 11-20.
23. Roberts, N., **1998**, *The Holocene, an Environmental History.* Blackwell publishers. 315.
24. Al-Rawi, Y.T., Al-Tawash, B.S., and Al-Ameri, T.K., **2005**, *Pollen evidence of Late Quaternary vegetation and inferred climatic changes of Lake Razzaza, Western Iraqi Desert,* Iraqi Bulletin of Geology and Mining, Vol., 1, No.2:1-13.
25. Butzer, K. W., lsaac, G. L., Richardson, J. L. and Washbourn-Kamau, C.K., **1972**, *Radiocarbon dating of East African lake levels,* Science. 175, 1069-76.