International Journal of Science Academic Research
Vol. 02, Issue 02, pp.1028-1033, February, 2021
Available online at http://www.scienceijsar.com

ISSN: 2582-6425

Research Article

MODELING THE TIME TRENDS OF SOME DYNAMIC FACTORS RESPONSIBLE OF THE WATER DRYNESS IN LAKE CHAD

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Received 20th December 2020; **Accepted** 18th January 2021; **Published online** 15th February 2021

Abstract

This study investigates the contribution of some dynamic factors to the dryness process of Lake Chad. It clearly indicates that natural factors were not the main causes of this process as their contributions could be neglected. The principal causes were the social factors. To slowdown this phenomenon, the education of the populations to a rational use of water like it has been already going on in other countries is strongly recommended.

Keywords: Modeling, time trends, dynamic factors, water dryness, water fluxes, air relative humidity, air temperature, rainfall, clouds of experimental points, functional relationship, regression line, least square method.

INTRODUCTION

Lake Chad is the biggest one in Central Africa. It is bordered by the following countries: Chad, Niger, Nigeria and Cameroon. Fishing, agriculture, livestock and trade are the main activities of inhabitants surrounding that area. It considerably influences the climate of the sub region. Till year 1960, the territory occupied by its water was estimated to 25000 km^2. It has been reduced to less than 2000 km^2 within 50 years, meaning that at least 90% of its territory has been disappeared. Certainly that this dryness is still going on today. Thus, Lake Chad should be under permanent observations. Investigations should be carried out to identify and manage the factors responsible of this catastrophic degradation. In 1928, questions on the disappearance of Chad have been set up, (Tilho, 1928). Possible full dryness of Lake Chad has been investigated, (Pouyaud *et al.,* 1989). Impacts of some atmospheric factors were studied, between others, the role of the rainfall and temperature on Lake Chad, (Maley, 1973). The relation between the demograqphy and the water dryness of Lake Chad was investigated, (Lemoalle *et al.,* 2012; Harris *et al.,* 2014; Guengant, 2018). It was proved that evapotranspiration alone could not lead to such a water dryness of Lake Chad within that period, (Njipouakouyou *et al.,* 2019). Thus, the ongoing process of dryness of Lake Chad has a complex character and could be explained considering the contribution of many factors, what some researchers have tried to do, unfortunately letting away some social factors (Abdoulaye *et al.,* 2017). This study is based on two groups of factors: natural and social ones. In the natural factors are included the water fluxes in the river Chari-Logone whose water feeds the lake, the rainfall which brings new quantities of water to the lake, the air temperature which stimulates water losses from the lake through evaporation, the relative humidity of the air which indicates whether the atmosphere could receive or not new quantities of water vapor from the earth surface. In the social factors are the populations with their water consumption for their daily activities.

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Thus, our study is more complete than the previous ones and its results should be given great considerations. In particular, great attention was given to the impacts of the time variations of these factors on the process of dryness of Lake Chad knowing that if the water fluxes decrease with time, less water will be carried to the lake and its territory will decrease; if the rainfall decreases, less water will be drained to the lake and its territory will also decrease; if the air temperature increases, evaporation will be intense causing more lost of water, the reduction of the water fluxes of the river and the diminution of the water surface of Lake Chad; at last if the air humidity decreases, the air will be dry with high capacity to receive more quantities of water vapor. This study has a statistical approach, notably the analysis of clouds of experimental points in coordinates systems to find fitting functional relationships between variables and their corresponding analytic expressions by the least square method. This work has five sections. The first and present one is the introduction to the problem to be solved. The second exposes the data and methodology. The results and analysis are in the third section. In the fourth are the conclusion, recommendations and acknowledgements. At last the references in alphabetic order are presented in the fifth section.

DATA AND METHODOLOGY

Data

The data is divided into two groups. The first one, physical factors, contains: water fluxes, pluviometry, temperature and relative humidity of the air. Almost all these factors were observed in Ndjamena and one - in Bol, a locality situated some 200-300 kilometers away from Ndjamena on the bank of Lake Chad. The data is regular over periods from 1934 to 2015 for water fluxes in Ndjamena, and from 1950/1951 to 2009/2010 for the remaining factors. Stationnary pluviometer, thermometer and hygrometer were used for the observations. All the data is kept in tabular forms at the National Meteorological Service and National Service of Water in Ndjamena. The data of the second group concerns the populations growth in Chad in general, and the estimated ones on the two banks of the river which provides water to Lake Chad, namely Logone-Chari. In 1960 and 2018, the populations of Chad were estimated to 3 and 15.5 millions and their rates of growth were 2.94%, 3.86% and 3.02% in 1986, 2002 and 2018 respectively, (Guengant, 2018). Averagely, the yearly rate of the populations growth in Chad could be estimated to 3%. Many of them on the banks of the river and around Lake Chad are farmers with agro-pastoral activities.

Methodology

To avoid big numbers, fictive variables were introduced. Thus, the years were replaced by the variable t such that t=0 for 1974.

The amplitude A_Φ of the water fluxes in Ndjamena over the whole period of study was determined by the formula:

$$A_\Phi = \Phi_{max} - \Phi_{min}, \quad (1)$$

Φ_{max} and Φ_{min} been respectively the absolute maximum and minimum values of the water fluxes. Then, the relative deviations of tabulated (experimental) values, Φ_{exp}, from A_Φ were calculated by the formula:

$$d_{exp} = (\Phi_{exp} - A_\Phi)/100. \quad (2)$$

Analyzing the cloud of experimental points $M(t,d_{exp})$ in a coordinates system has permitted to find the functional relationship d = d(t) and the least square method has given its analytic expression to be used to calculate the theoretical values of the deviations, d_{th}, and the theoretical values of the water fluxes, Φ_{th}, by the formula:

$$\Phi_{th} = A_\Phi + 100d_{th}. \quad (3)$$

At last, the degree of fitness of the obtained model was calculated by the formula:

$$\delta = \Phi_{exp} - \Phi_{th}. \quad (4)$$

The values of the water fluxes in Bol were replaced by their corresponding relative ones calculated by the formula:

$$\varphi_{exp} = \Phi_{exp}/100. \quad (5)$$

Also analyzing the cloud of experimental points $M(t,\varphi_{exp})$ in a coordinates system has given a functional relationship $\varphi_{exp} = \varphi_{exp}(t)$ and its analytic expression was obtained by the least square method. The theoretical values of the water fluxes in Bol, Φ_{th}, were calculated by the formula:

$$\Phi_{th} = 100\varphi_{th}, \quad (6)$$

and the degree of fitness of the model by formula (4).

The pluviometry was treated similarly to the water fluxes in Ndjamena, the only difference been that instead of dividing and multiplying (2) and (3) by 100, these operations were done by 1000. The temperature and relative humidity of the air were treated without modification, analyzing their clouds of experimental points, finding the functional relationships between corresponding variables and their analytic expressions by the least square method.

RESULTS AND ANALYSIS

Yearly water fluxes in the river Chari-Logone in Ndjamena and Bol

The results of simulation are presented respectively in Tables 1 and 2. They show that minimal and maximal yearly values of water fluxes in Ndjamena and Bol were respectively 234.5 and 1678.8, 62.0 and 699.5 m^3. The formers were one or two orders superior their corresponding values in Bol, particularly during the first half period, from 1951 to 1970 when they were generally two orders greater. In Ndjamena they were at least twice their corresponding values in Bol particularly during the second period, from 1971 to 2010. Thus, along its way to Lake Chad, quantities of water were disappeared, certainly because of increasing human activities on the banks of the river. Analysis of clouds of experimental points $M(t,d_{exp})$ and $M(t,\varphi_{exp})$ has led to linear functional relationships d(t) and φ(t). Their analytic expressions were respectively:

For Ndjamena: $d(t) = -0.1t - 4.9. \quad (7)$

For Bol: $\varphi(t) = -0.02t + 2.9. \quad (8)$

In both localities, the coefficients of the regression lines were negative, indicating that during the considered periods the water fluxes of the river Chari-Logone were decreasing. Thus, the quantities of water to Lake Chad were decreasing following by its territory.

Yearly pluviometry in Ndjamena from 1950 to 2010

The results of its simulation presented in Table 3 show that during that period, the yearly pluviometry has varied from 2261 mm in 1984 to 9901 mm in 1959 for amplitude of 7640 mm. From 1950 to 1974, its values were higher than during the remaining period when it was decreasing, reducing the quantities of water in Lake Chad, whence its dryness. Put r_{exp} the relative deviation of pluviometry from its amplitude. Analyzing the cloud of experimental points $M(t,r_{exp})$ has given a linear relationship between the variables and the least square method has permitted to obtain its analytic expression:

$$r(t) = -0.02t - 1.77, \quad (9)$$

which was used to calculate the theoretical deviation, r_{th}, and the theoretical values of the pluviometry, R_{th}, by the formula:

$$R_{th} = 7640 + 1000r_{th}. \quad (10)$$

The negative coefficient of the regression line confirms that the pluviometry was decreasing over the period, reducing the quantities of water and the territory of Lake Chad.

Yearly temperature of the air in Ndjamena (θ, in °C) from 1950 to 2009

Its simulation in Table 4 indicates its variation from 27.3°C in 1959 to 29.5°C in 2004, 2006 and 2008, giving amplitude of 2.2°C. From 1950 to 1974, the values of the air temperature were less than during the remaining period. So, this factor was increasing with time over the period. Analyzing the cloud of experimental points $M(t,\theta_{exp})$ has led to a linear relationship between the two variables and the least square method has given its analytic expression:

Table 1. Simulation of the yearly water fluxes (in m^3/year) in the river Chari-Logone in Ndjamena from 1934 to 2015

Years	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
t	-40	-39	-38	-37	-36	-35	-34	-33	-32	-31	-30	-29
Φ_{exp}	1545.7	1248.3	1556.9	995.3	1370.8	1156.8	893.6	750.5	996.8	1144.2	1033.8	1111.4
d_{exp}	1	-2	1	-4	-7	-3	-6	-7	-4	-3	-4	-3
d_{th}	-0.9	-1.0	-1.1	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8	-19	-2.0
Φ_{th}	1354.3	1344.3	1334.3	1324.3	1314.3	1304.3	1294.3	1284.3	1274.3	1264.3	1254.3	1244.3
δ	191.4	96.0	222.6	-329.0	56.5	-147.5	-400.7	-533.8	-277.5	-120.1	-220.5	-132.9

1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
-28	-27	-26	-25	-24	-23	-22	-21	-20	-19	-18	-17	-16
1523.9	-	-	-	-	-	-	-	1508.6	1678.5	1582.8	1157.9	1110.0
1	-	-	-	-	-	-	-	6	2	1	-3	-3
-2.1	-2.2	-2.3	-2.4	-2.5	-2.6	-2.7	-2.8	-2.9	-3.0	-3.1	-3.2	-3.3
1234.3	12243	1214.3	1204.3	1194.3	1184.3	1174.3	1164.3	1154.3	1144.3	1134.3	1124.3	1114.3
289.6	-	-	-	-	-	-	-	354.3	534.2	448.5	33.6	-4.3

1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3
1251.9	1349.0	1678.8	1598.6	1446.2	1370.4	1012.2	1044.1	1334.0	1039.8	1061.0	1187.6	994.7
-2	-1	2	1	0	-7	-4	-4	-1	-4	-4	-3	-4
-3.4	-3.5	-3.6	-3.7	-3.8	-3.9	-4.0	-4.1	-4.2	-4.3	-4.4	-4.5	-4.6
1104.3	1094.3	1084.3	1074.3	1064.3	1054.3	1044.3	1034.3	1024.3	1014.3	1004.3	994.3	984.3
147.6	254.7	594.5	524.3	381.9	316.1	-32.1	9.8	309.7	25.5	56.7	193.3	10.4
1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
-2	-1	0	1	2	3	4	5	6	7	8	9	10
579.7	576.7	924.6	1123.5	928.8	814.9	931.2	648.7	-	-	-	541.4	234.5
-9	-9	-5	-3	-6	-6	-5	-8	-	-	-	-9	-12
-4.7	-4.8	-4.9	-5.0	-5.1	-5.2	-5.3	-5.4	5.5	-5.6	-5.7	-5.8	-5.9
974.3	964.3	954.3	944.3	934.3	924.3	914.3	904.3	894.3	884.3	874.3	864.3	854.3
-394.6	-387.6	-29.7	179.2	-5.5	-109.4	16.9	-255.6	-	-	-	-322.9	-619.8

1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
11	12	13	14	15	16	17	18	19	20	21	22	23
521.2	480.4	310.6	857.5	515.9	386.1	607.2	647.4	487.7	658.6	708.5	804.8	585.1
-9	-10	-11	-6	-9	-11	-8	-8	-10	-8	-7	-6	-9
-6.0	-6.1	-6.2	-6.3	-6.4	-6.5	-6.6	-6.7	-6.8	-6.9	-7.0	-7.1	-7.2
844.3	834.3	824.3	814.3	804.3	794.3	784.3	774.3	764.3	754.3	744.3	734.3	724.3
- 323.1	-353.9	-513.7	43.2	-288.4	-408.2	-177.1	-126.9	-276.6	-95.7	-35.8	70.5	-139.2

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
24	25	26	27	28	29	30	31	32	33	34	35	36
994.9	976.8	699.8	878.6	532.4	876.3	577.3	754.0	628.1	739.3	661.5	532.7	855.9
-4	-5	-7	-6	-9	-6	-9	-7	-8	-7	-8	-9	-6
-7.3	-7.4	-7.5	-7.6	-7.7	-7.8	-7.9	-8.0	-8.1	-8.2	-8.3	-8.4	-8.5
714.3	704.3	694.3	684.3	674.3	664.3	654.3	644.3	634.3	624.3	614.3	604.3	594.3
280.6	272.5	5.5	194.3	-141.9	212.0	-77.0	109.7	-6.2	115.0	47.2	-71.6	261.6

2011	2012	2013	2014	2015
37	38	39	40	41
739.5	1026.3	802.9	854.4	597.6
-7	-4	-6	-6	-8
-8.6	-8.7	-8.8	-8.9	-9.0
584.3	574.3	564.3	554.3	544.3
155.2	452.0	238.6	300.1	53.3

$$\theta(t) = 0.03t + 28.3, \qquad (11)$$

which was used to calculate the theoretical values , θ_{th}, of the temperature.

The positive coefficient of (11) tells that θ was increasing during that period. Thus, the temperature of the water in the river Chari-Logone was also increasing, intensifying the process of evaporation, following by a progressive lost of its water and the diminution of the water fluxes, whence the reduction of the water surface of Lake Chad.

Yearly relative humidity of the air in Ndjamena (f, in%) from 1950 to 2010

Its simulation in Table 5 indicates its variation from 35% in 1985 to 53% in 1957. From 1950 to 1974, its values were higher than during the remaining period, indicating that the air was progressively dry, increasing its possibility to receive more quantities of water vapor. Thus, the evaporation from the river Chari-Logone should progressively increase, reducing its water fluxes and the quantities of water to Lake Chad, whence the diminution of its surface.

Table 2. Simulation of the yearly water fluxes (in m^3/year) in the river Chari-Logone in Bol from 1951 to 2010

Years	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
t	-23	-22	-21	-20	-19	-18	-17	-16	-15	-14	-13	-12
Φ_{exp}	230.3	383.5	313.5	699.5	295.6	481.7	319.8	319.3	520.6	258.2	504.4	269.8
φ_{exp}	2.3	3.8	3.1	7.0	3.0	4.8	3.2	3.2	5.2	2.6	5.0	2.7
φ_{th}	3.38	3.36	3.34	3.32	3.30	3.28	3.26	3.24	3.22	3.20	3.18	3.16
Φ_{th}	338.0	336.0	334.0	332.0	330.0	328.0	326.0	324.0	322.0	320.0	318.0	316.0
δ	-107.7	47.5	-20.5	367.5	-34.4	153.7	-6.2	-4.7	198.6	-61.8	186.4	-46.2

1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1
291.3	327.1	311.5	295.4	355.0	194.8	285.7	362.6	203.9	62.0	148.1	420.6	242.6
2.9	3.3	3.1	3.0	3.6	1.9	2.9	3.6	2.0	0.6	1.5	4.2	2.4
3.14	3.12	3.10	3.08	3.O6	3.04	3.02	3.00	2.98	2.96	2.94	2.92	2.90
314.0	312.0	310.0	308.0	306.0	304.0	302.0	300.0	298.0	296.0	294.0	292.0	290.0
-22.7	15.1	1.5	-12.2	49.0	-109.2	-16.3	62.6	-94.1	-234.0	-145.9	128.6	-47.4

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
2	3	4	5	6	7	8	9	10	11	12	13	14
223.3	225.1	344.9	340.3	183.2	260.6	113.4	183.2	339.3	306.6	261.3	102.8	346.6
2.2	2.3	3.5	3.4	1.8	2.6	1.1	1.8	3.4	3.1	2.6	1.0	3.5
2.88	2.86	2.84	2.82	2.80	2.78	2.76	2.74	2.72	2.70	2.68	2.66	2.64
288.0	286.0	284.0	282.0	280.0	278.0	276.0	274.0	272.0	270.0	268.0	266.0	264.0
-64.7	-60.9	60.9	58.3	-96.8	-17.4	-162.6	-90.8	67.3	36.6	-6.7	-163.2	82.6
1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
15	16	17	18	19	20	21	22	23	24	25	26	27
138.4	179.9	149.8	173.6	267.7	452.2	167.6	154.6	181.3	116.9	414.8	193.4	174.6
1.4	1.8	1.5	1.7	2.7	4.5	1.7	1.5	1.8	1.2	4.1	1.9	1.7
2.62	2.60	2.58	2.56	2.54	2.52	2.50	2.48	2.46	2.44	2.42	2.40	2.38
262.0	260.0	258.0	256.0	254.0	252.0	250.0	248.0	246.0	244.0	242.0	240.0	238.0
-123.6	-80.1	-108.2	-82.4	13.7	200.2	-82.4	-93.4	-64.7	-127.1	172.8	-46.6	-63.4

2002	2003	2004	2005	2006	2007	2008	2009	2010
28	29	30	31	32	33	34	35	36
238.5	202.6	324.3	364.1	321.2	363.3	281.1	206.4	324.3
2.4	2.0	3.2	3.6	3.2	3.6	2.8	2.1	3.2
2.36	2.34	2.32	2.30	2.28	2.26	2.24	2.22	2.20
236.0	234.0	232.0	230.0	228.0	226.0	224.0	222.0	220.0
2.5	-31.4	92.3	134.1	93.2	137.3	57.1	-15.6	104.3

Table 3.3 Simulation of the yearly pluviometry (in mm/year) in Ndjamena from 1950 to 2010

Years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
t	-24	-23	-22	-21	-20	-19	-18	-17	-16	-15	-14	-13
R_{exp}	9519	5499	7592	6426	7785	7351	6075	7400	5374	9901	5333	7801
r_{exp}	2	-2	0	-1	0	0	-2	0	-2	2	-2	0
r_{th}	-1.29	-1.31	-1.33	-1.35	-1.37	-1.39	-1.41	-1.43	-1.45	-1.47	-1.49	-1.51
R_{th}	6350	6330	6310	6290	6270	6250	6230	6210	6190	6170	6150	6130
δ	3169	-831	1282	136	1515	1101	-155	1190	-816	3731	-817	1671

1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
4904	4971	4772	5874	5933	6160	5612	4645	6528	4229	6028	3147	4242
-3	-3	-3	-2	-2	-1	-6	-3	-1	-3	-2	-4	-3
-1.53	-1.55	-1.57	-1.59	-1.61	-1.63	-1.65	-1.67	-1.69	-1.71	-1.73	-1.75	-1.77
6110	6090	6070	6050	6030	6010	5990	5970	5950	5930	5910	5890	5870
-1206	-1119	-1298	-176	-97	150	-378	-1325	578	-1701	118	-2743	-1628

1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	2	3	4	5	6	7	8	9	10	11	12	13
7459	6514	5393	6662	5470	3970	4511	3820	3782	2261	3652	5558	4051
0	-1	-2	-1	-2	-4	-3	-4	-4	-5	-4	-2	-4
-1.79	-1.81	-1.83	-1.85	-1.87	-1.89	-1.91	-1.93	-1.95	-1.97	-1.99	-2.01	-2.03
5850	5830	5810	5790	5770	5750	5730	5710	5690	5670	5650	5630	5610
1609	684	-417	872	-300	-1780	-1219	-1890	-1908	-3409	-1998	-72	-1559

1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
14	15	16	17	18	19	20	21	22	23	24	25	26
6307	5937	2962	6294	5373	4597	6278	4450	4980	4221	7759	6607	6766
-1	-2	-5	-1	-2	-3	-1	-3	-3	-3	0	-1	-1
-2.05	-2.07	-2.09	-2.11	-2.13	-2.15	-2.17	-2.19	-2.21	-2.23	-2.25	-2.27	-2.29
5590	5570	5550	5530	5510	5490	5470	5450	5430	5410	5390	5370	5350
717	367	-2588	764	-137	-893	808	-1000	-450	-1189	2369	1237	1416

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
27	28	29	30	31	42	33	34	35	36
6143	5440	6640	5442	5202	7112	6743	6557	5553	5676
-1	-2	-1	-2	-2	-1	-1	-1	-2	-2
-2.31	-2.33	-2.35	-2.37	-2.39	-2.41	-2.43	-2.45	-2.47	-2.49
5330	5310	5290	5270	5250	5230	5210	5190	5170	5150
813	130	1350	172	-48	1882	1133	1363	383	526

Table 4. Simulation of the yearly temperature of the air (in °C) in Ndjamena from 1950 to 2009

Years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
t	-24	-23	-22	-21	-20	-19	-18	-17	-16	-15	-14	-13
θ_{exp}	28.1	27.6	28.2	28.1	28.1	27.6	28.0	27.8	28.5	27.3	28.0	27.5
θ_{th}	27.6	27.6	27.6	27.7	27.7	27.7	27.8	27.8	27.8	27.9	27.9	27.9
δ	0.1	0.0	0.6	0.4	0.4	-0.1	0.2	0.0	0.7	0.6	0.1	-0.4

1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
27.9	28.3	27.7	27.8	28.0	28.1	27.9	28.9	28.1	28.2	28.6	29.4	28.1
27.9	28.0	28.0	28.0	28.1	28.1	28.1	28.2	28.2	28.2	28.2	28.3	28.3
0.0	0.3	-0.3	-0.2	-0.1	0.0	-0.2	0.7	-0.1	0.0	0.4	1.1	-0.2

1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	2	3	4	5	6	7	8	9	10	11	12	13
27.8	28.0	27.6	28.4	-	-	-	28.4	28.9	29.3	29.1	29.1	28.5
28.3	28.4	28.4	28.4	28.5	28.5	28.5	28.5	28.6	28.6	28.6	28.7	28.7
-0.5	-0.4	-0.8	0.0	-	-	-	-0 .1	0.3	0.7	0.5	0.4	-0.2

1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
14	15	16	17	18	19	20	21	22	23	24	25	26
28.0	28.5	28.9	28.5	28.5	28.4	28.6	29.0	28.3	28.5	29.9	27.4	28.6
28.7	28.8	28.8	28.8	28.8	28.9	28.9	28.9	29.0	29.0	29.0	29.1	29.1
-0.7	-0.3	0.1	-0.3	-0.3	-0.5	-0.3	0.1	-0.1	-0.5	0.9	-1.7	-0.5

2001	2002	2003	2004	2005	2006	2007	2008	2009
27	28	29	30	31	42	33	34	35
28.9	29.0	29.3	29.5	29.8	29.5	29.1	29.5	30.2
29.1	29.1	29.2	29.2	29.2	29.3	29.3	29.3	29.4
-0.2	-0.1	0.1	0.3	0.6	0.2	-0.2	0.2	0.8

Table 5. Simulation of the yearly humidity of the air (in %) in Ndjamena from 1950 to 2010

Years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
t	-24	-23	-22	-21	-20	-19	-18	-17	-16	-15	-14	-13
f_{exp}	49	48	47	48	51	51	51	53	47	41	46	46
f_{th}	47	47	47	47	47	47	46	46	46	46	46	46
δ	2	1	0	1	4	4	5	7	1	-5	0	0

1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
47	44	46	51	42	46	49	49	45	44	44	39	45
46	46	46	46	46	46	45	45	45	45	45	45	45
1	-2	0	5	-4	0	4	4	0	-1	-1	-6	0

1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	2	3	4	5	6	7	8	9	10	11	12	13
48	49	43	49	-	-	-	-	49	37	35	36	39
45	45	45	45	45	45	44	44	44	44	44	44	44
3	4	-2	4	-	-	-	-	5	-7	-9	-8	-5

1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
14	15	16	17	18	19	20	21	22	23	24	25	26
36	44	42	37	44	43	45	43	46	42	43	46	47
44	44	44	44	44	43	43	43	43	43	43	43	43
-8	0	-2	-7	0	0	2	0	3	-1	0	3	4

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
27	28	29	30	31	42	33	34	35	36
46	45	47	45	46	46	45	44	44	43
43	43	43	43	43	42	42	42	42	42
3	2	4	2	3	4	3	2	2	1

Analyzing the cloud of experimental points $M(t,f_{exp})$ and using the least square method have led to the analytic equation of its regression line:

$$f(t) = -0.08t + 45. \qquad (12)$$

The negative coefficient of (12) tells that this factor was decreasing during the period of investigation. It is clear that of order 10^{-2}–10^{-1}, the coefficients of all the regression lines were very small to provoke such a deep dryness of the water of Lake Chad. Despite that they have contributed to that process, their cumulative contributions could not have such an impact within such a short period. So the causes of this phenomenon should be searched elsewhere. The values of the temperature and relative humidity of the air were of order 10^1 and their degree of fitness of orders 10^{-1} for the first factor and 10^0 for the second one. Therefore, the obtained models were acceptable. For the remaining factors, their values were of order 10^2 in Bol and 10^3 in Ndjamena. Some of them were of the same order than the main values. Thus, their corresponding models were roughly acceptable, but coherent with the simulations.

Demography and the dryness of Lake Chad

In 1960 and 2018, the populations of Chad were estimated respectively to 3 and 15.5 millions. It was reported the next rates of the populations growth: 2.94% in 1986, 3.86% in 2002, 3.02% in 2018, (Guengant, 2018). This populations growth should lead to the increase of the number of persons on the river banks and the daily quantities of water to be consumed. As exact data on demography in Chad was not available, we have proceeded by simulations. Thus, assume that on the banks of the river which provides water to Lake Chad were 10^4 families, each having cattle, goat and cow. Put a family daily water consumption to be 10 liters. So, all the families should need 10^5 liters per day and 36500 m^3 per year. As Chad is a sahelian country with permanent deficit of precipitations, it is obvious that irrigation should be a popular practice during agricultural activities. Usual cultivated species are rice and vegetable which need a lot of water to grow. Therefore, it is clear that for the irrigation thousands of cubic meters of water should be used. If on the river banks were 10^6 inhabitants, this quantity of water should be multiplied by 10^2. Taking into account that the majority of these farmers have no education and cannot rationally use water, it is certain that they abusively consume it when irrigating. With the permanent growth of the populations these quantities of water should progressively increase. It is then obvious that the social factors - the main cause of the dryness of water in Lake Chad compared to the cumulative contributions generated by the remaining factors.

Conclusion

This study clearly indicates the predominance of social factors on the natural ones in the process of dryness of water in Lake Chad. The permanent growth of the populations, the constant increase of the food demand, between others, should always reinforce this process. To slowdown this problem, education of the populations, particularly those ones on the banks of the river and around Lake Chad, is strongly recommended. They should learn how to rationally use less water and reach optimal results like in Israel. The populations should also learn how to protect the environment from ecological destruction to reduce and even eradicate the degradation of the natural factors. The authors extend their thanks to Tatolnan who authorized them to use part of the data containing in his M. Sc. thesis on atmospheric physics.

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