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*International Journal of Current Research*
*Vol. 9, Issue, 07, pp.54482-54485, July, 2017*

**INTERNATIONAL JOURNAL OF CURRENT RESEARCH**

**ISSN: 0975-833X**

**RESEARCH ARTICLE**

# INVESTIGATING THE MINIMAL QUANTITY OF SOIL WATER RESERVE AND ITS TIME TENDENCY IN N'DJAMÉNA AND SURROUNDINGS – CHAD

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**ARTICLE INFO**

***Article History:***
Received 22nd April, 2017
Received in revised form
12th May, 2017
Accepted 16th June, 2017
Published online 31st July, 2017

***Key words:***

Water reserve, Reference Evapotranspiration, Water requirements, Pluviometry, Precipitations, Deficit of water.

**ABSTRACT**

The soil water reserve in N'djaména and surroundings is investigated using data onpluviometry and reference evapotranspiration for the period from 1980 to 2007. Monthly averages and standard deviations calculated for each year show that the soil of this area was under a permanent deficit of water. The driest year was 2001 with the highest average deficit of -155.8 mm/month compare to the year 1994 with a minimal amount of -105.6 mm/month. The analysis of its time tendency shows that from year to year that deficit was becoming deeper and deeper. Modeling this tendency brought to a decreasing linear relationship between time t and the soil water reserve WR. Simulation indicates a good fitness of the obtained model. The monthly averages and corresponding standard deviations computed from data in the considered month during the whole period indicate that March is the driest month with a deficit of -220.9 mm/month compare to July with a minimal amount of -7.2 mm/month. Standard deviations indicate that soil water reserve has a high time variability. Monthly and daily soil water requirements were estimated based on the obtained results.

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**Citation: NJIPOUAKOUYOU Samuel, AOUDOU DOUA Sylvain and GALMAI Orozi, 2017.** "Investigating the minimal quantity of soil water reserve and its time tendency in N'djaména and surroundings – Chad", *International Journal of Current Research*, 9, (07), 54482-54485.

## INTRODUCTION

Many human activities depend on the presence of water, in particular agricultural activities to which more attention will be paid in this paper. Nowadays, the climate change and the growth of desertification make this product becoming rare in some countries. This situation has negatively affected these regions, both socially and economically. To overcome this problem, some scientists have started investigating on how to rationally manage the available quantity of water in the world in general and sahelian countries in particular. Among others, we have the followings. Allen R. G. (ALLEN, 1995) has evaluated the procedures for estimating grass reference evapotranspiration using only air data. Sylvain M. D. (Sylvain, 2006) has pointed out the method of Penman – Monteithfor estimating the evapotranspiration as the most fitting one for tropical areas. Saidati *et al*. (SAIDATI *et al*., 2006) investigated the reference evapotranspiration in the arid area of Tafilalet in the south-east of Morocco. Bouteldjaoui F. *et al*. (Bouteldjaoui *et al*., 2012) did a comparative study of different methods for estimating evapotranspiration in semi-arid zones. Njipouakouyou S. *et al*. (Njipouakouyou *et al*., 2017) investigated the minimal value of hydrous deficit indexon the earth-atmosphere system in southern part of Chad. Allen R. G. *et al*. (Allen *et al*., 1998) prepared guidelines for computing crop water requirements. Telibi A. (Telibi, 2004) has studied both the evapotranspiration and the crop water requirements in a semi-arid zone. Ungaro F. (Ungaro, 2002) indicated how to use soil and climatic data in modeling and investigating the spatial management of natural resources. As it can be seen, many of these works have theoretical character. Some results were obtained at the basis of not sufficient chronological data and they concerned mainly the problem of evapotranspiration. The present paper is about the soil water reserve in N'djaména and surroundings, almost the first in this domain. Thus, information on precipitations, water flow on the earth surface and evapotranspirationis needed. The available data covers a period from 1980 to 2007, almost 30 years which is already a climatic period according to the World Meteorological Organization. Hence, the obtained results are climatic ones. Two kinds of monthly averages of soil water reserve are determined and analyzed. The first ones are calculated on the base of the yearly monthly data, the second ones on the base of all monthly data for the whole period of investigation. Time modeling of the first monthly averages for some operational goals as forecast has been done. The second monthly averages have permitted to estimate the monthly and daily quantities of water to be added to the soil to reach a null deficit of water. The paper has four paragraphs and the references presented in

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an alphabetic order. The first and present one introduces the subject of the study and the revue of the literature. The data and methodology are in the second paragraph. The results are presented and discussed in the third paragraph. The fourth paragraph is the conclusion and recommendations.

**Data and methodology**

**Data**

This data is the pluviometry and the reference evapotranspiration covering a period of 27 years, from 1980 to 2007 for N'djaména, Chad. The choice of this locality has many reasons. Between others, it is the capital of the country and hence, is well-equipped with instruments. It has qualified personnel. Meteorological data here covers sufficiently long periods. Therefore, it is understandable that this data is representative. The data is not primary. It is already treated and presented in tabular forms of monthly averages. The monthly values of reference evapotranspiration were calculated using the formula of Penman-Monteith (Sylvain, 2006).

**Methodology**

It is obvious that this soil water reserve is the difference between the precipitations, the water flow on the earth surface and the water lost through evapotranspiration, assuming that the remaining quantity of water infiltrates into the soil. As N'djaména is a big plain, it is clear that the water flow on the earth surface can be neglected. Recalling that the reference evapotranspiration is the maximal quantity of water to be lost through this phenomenon, it is evident that the soil water reserve will be minimal.

Thus, letting WR the soil water reserve, P – the pluviometry and ETP – the reference evapotranspiration, our working formula is reduced to the following:

$$WR = P – ETP. \qquad (2 – 1)$$

The ETP was estimated by the next formula of Penman – Monteith:

$$ETP = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{t+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}, \qquad (2\text{-}2)$$

Where

$R_n$ - is the exact solar radiation on the considered surface,
G – the heat flux density in the soil,
t, $u_2$ – the air temperature and the wind velocity at 2 meters above the earth surface,
$e_s$– the tension of saturation of the water vapor,
$e_s$ – the tension of the water vapor in the air,
$\Delta$ - the slope of the curve of the tension of saturation of the water vapor as function of the air temperature,
$\gamma$ – the psychrometric constant, $\gamma$ = 0.66hPa/°C,
900 – the correction term.

Monthly averages over a year are determined, analyzed and modeled for the forecast use. Monthly averages over each month of the period of investigation are also determined for the estimation of the quantity of water to be supplied to the soil when it is deficit.

## RESULTS AND ANALYSIS

The monthly averages and corresponding standard deviations of WR calculated using a year data are presented in Table 3-1. In order to simplify further computations when modeling, a fictive time variable t is introduced with t = 0 for year 1994. In this table and the coming ones, the soil water reserve, WR, and standard deviations,$\sigma$, are measured in mm/month. Table 3.1. shows that during the whole of investigation the soil water reserve in N'djaména and surroundings was negative, indicating the insufficiency of water in the soil of that locality. These estimations are the minimal monthly quantity of water to be supplied to the soil to reach equilibrium between pluviometry and evapotranspiration, i.e. to have WR = P – ETP = 0, or P = ETP. Thus, for 1980, a minimal quantity of 116.8 mm of water are to be supplied to the soil to expect WR = 0. For the whole period, the maximal deficit of 155.8 mm/month occurred in 2001 and the minimum deficit of 105.6 mm/month – in 1994 with standard deviations of 123.3 and 93.2 mm/month, respectively. Analysis of Table 3.1 also indicates that the period of investigation can be divided into two parts. The first one from 1980 to 1993 is characterized by estimations of WR not exceeding 130.0 mm/month except in 1984, 1987, 1990 and 1992 with respectively the following deficits 135.9, 138.6, 149.3 and 138.5 mm/month. For this sub period the standard deviations did exceed 90.0 mm/month.

**Table 3-1. Monthly averages of WR and corresponding $\sigma$estimated over each year**

| years | 1980 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t | -14 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 |
| WR | -116.8 | -109.0 | -111.5 | -135.9 | -126.9 | -126.0 | -138.6 | -123.5 | -119.0 | -149.3 | -115.8 | -138.5 | -133.0 |
| $\sigma$ | 65.1 | 70.4 | 58.8 | 33.1 | 60.1 | 89.6 | 50.5 | 85.4 | 76.4 | 56.0 | 89.4 | 82.2 | 68.5 |

| 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| -105.6 | -139.2 | -148.1 | -144.4 | -108.9 | -137.8 | -135.4 | -155.8 | -132.3 | -123.7 | -146.0 | -143.3 | -128.0 | -114.9 |
| 93.2 | 82.4 | 92.9 | 109.6 | 117.4 | 112.4 | 114.9 | 123.3 | 88.9 | 106.4 | 89.0 | 100.4 | 122.7 | 98.9 |

Their extreme values of 33.1 and 89.6 mm/month occurred respectively in 1984 and 1986. For what concerns the second sub part, most of the estimations were above 135.0 mm/month and their standard deviations above 90.0 mm/month, some even greater than the corresponding estimation, like in 1998 where $\sigma$=117.4 mm/month while WR=-108.9 mm/month. Comparison of both sub periods shows that the deficit of soil water reserve in N'djaména and surroundings and its variability increase with the time increasing. This confirms the intensification of the desertification with the rarefication of precipitations in the considered areas during the second sub period.

**Table 3.2. Empirical and simulated estimations. Degree of fitness of the model**

| t | -14 | -12 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $WR_i$ | -116.9 | -109.0 | -111.5 | -135.9 | -126.9 | -126.0 | -138.6 | -123.5 | -119.0 | -149.3 | -115.8 | -138.5 | 133.0 |
| $WR_{th}$ | -118.4 | -120.1 | -120.9 | -121.7 | -122.5 | -123.3 | -124.2 | -125.0 | -125.8 | -126.6 | -127.4 | -128.3 | -129.1 |
| $\|\delta\|$ | 2.1 | 11.1 | 9.4 | 14.2 | 4.4 | 2.7 | 14.4 | 1.5 | 6.6 | 22.7 | 11.6 | 10.2 | 3.9 |
| $\sigma$ | 65.1 | 70.4 | 58.8 | 33.1 | 60.1 | 89.6 | 50.5 | 85.4 | 76.4 | 56.0 | 89.4 | 82.2 | 68.5 |

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -105.6 | -139.2 | -148.1 | -144.4 | -108.9 | -137.8 | -135.4 | -155.8 | -132.3 | -123.7 | -146.0 | -143.3 | -128.0 | -114.9 |
| -129.9 | -130.7 | -131.5 | -132.4 | -133.2 | -134.0 | -134.8 | -135.6 | -136.5 | -137.3 | -138.1 | -138.9 | -139.7 | -140.6 |
| 24.3 | 8.5 | 16.6 | 12.0 | 24.3 | 3.8 | 0.6 | 20.2 | 4.2 | 13.6 | 7.9 | 4.4 | 11.7 | 25.7 |
| 93.2 | 82.4 | 92.9 | 109.6 | 117.4 | 112.4 | 114.9 | 123.3 | 88.9 | 106.4 | 89.0 | 100.4 | 122.7 | 98.9 |

**Table 3.3. Monthly averages of WR and standard deviations estimated over months**

| Months | Jan. | Feb. | March | April | May | June | July | Aug. | Sept.. | Oct. | Nov. | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WR | -167.1 | -186.8 | -220.4 | -210.9 | -178.0 | -134.0 | -7.2 | 37.8 | -57.8 | -133.4 | -156.9 | -151.7 |
| $\sigma$ | 20.6 | 16.4 | 39.3 | 32.9 | 33.0 | 34.3 | 56.6 | 63.5 | 54.0 | 30.6 | 24.1 | 21.6 |

To investigate the time tendency of WR, we placed points M(t, WR) in a coordinates system with t on the x axis and WR on the y axis. We obtained a cloud of points. Analyzing its configuration brought us to a conclusion that the relationship between t and WR is linear. Thus, we may write:

$$WR(t) = at + b, \quad (3\text{-}3)$$

where a and b are coefficients to be found.

Treating the data with the least square method gave us the next empirical function:

$$WR(t) = -0.82t - 129.9. \quad (3\text{-}4)$$

Formula (3-4) tells us that WR(t) decreases with time increasing with the velocity of -0.82 mm/year.

Simulation with formula (3-4) permits us to calculate the theoretical estimations $WR_{th}$, and compare them the empirical ones, $WR_i$. The results are presented in Table 3-2 where

$$|\delta| = |WR_i - WR_{th}|, \quad (3\text{-}5)$$

is the absolute value of the degree of fitness of the model.

Comparison of both estimations shows that they are of the same order and closer to one another. The degree of fitness of the model is at least one order less than its corresponding standard deviation. This confirms the validity of the model for operational works, assuming that the meteorological conditions have remained unchanged.

The monthly averages of WR estimated for all monthly data during the whole period are presented in Table 3.3.

The locality of study belongs to the sahelian zone. It has two seasons, the dry season from January to May and October to December, and the rainy one the remaining period. Thus, it is understandable that the soil is the driest during the first period. March is the month when the soil needs a maximal quantity of water estimated to 220.4 mm for the equilibrium between pluviometry and evapotranspiration. That soil water requirement is minimal in July with 7.2 mm. The monthly variability of WR is high during the rainy season compare to the dry one. This is due to the high time-spatial variability of the precipitations.

**Conclusion and Recommendation**

This study indicates that the soil of N'djaména and surrounding areas is under an important permanent deficit of water and this situation is a big handicap to some socio-economic activities such as agriculture. Hence, it is clear that irrigation is not avoidableunder such conditions. It is obvious that irrigation needs a lot of means, material and financial, between others. This is what many developing countries are not able to feel, particularly today. Thus, for such localities, inhabitants should look for agricultural species with court vegetative cycle and low water requirements.

Also, this paperclearly estimates the needed quantity of water to eliminate the deficit. For example, in January, the monthly deficit is 167.1 mm. If we have a field of $10^4$ $m^2$, the minimal quantity of water to supply for that month is 1671 $m^3$ or 55.7 $m^3$ per day. To have the maximal quantity of water to be added, we should take into consideration the water requirements of the species in the field and their stage of development. It is sure that this kind of information will be very helpful for the managers to take a best decision on the quality of the required irrigation tools.

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