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Temporal Analysis of Water Balance in a Sahelian City: Implication for Water Management

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Abstract

Water balance analysis is a valuable tool for assessing the general status of water resource availability and environmental comfort, particularly in the arid and the semi-arid regions. It also strengthens water management decision making. This research examines water balance in a Sahelian City (Niamey). Relevant meteorological and hydrology data of Niger Republic were captured. Descriptive and inferential statistics were used to analyze the data. Standard Deviation and Coefficient of Variation were employed to examine variation within the data set, Time Series to show a trend, and scattered plots for graphical presentation of results. Multiple Regression and Correlations adopted for relationships between variables and Warren and Lewis water balance equation for the water balance. The mean annual rainfall in Niamey was computed to be 516.38mm. The total annual water loss by evaporation was 3,906.5 mm. The result shows that the total annual water loss and mean annual runoffs were 3,906.5 mm and 11,600m^2/sec respectively, the rainy season last for three months and dry season last for nine months. Variation of runoff in Niamey revealed that River Niger has two hydrological seasons of high water discharge from September to January and low water discharge between February and August. There is a positive linear correlation between evaporation and water balance on one hand and run off and water balance on the contrary. The study concludes that Niamey had water deficit and classified as drought-prone area. Therefore, there must be an effective and efficient water resource management to redress deteriorating hydrology condition in Niamey.

Key Words: water, hydrology, water balance, water loss, discharge

Introduction

Demand for water in developing countries is ever increasing. Therefore, the supply of adequate water with a reasonable quality is a major constraint at both local and regional levels and also in rural and urban areas. In fact, it is critical in most cities. As observed by Mieno et al. (2011), in most cases, the demand for water exceeds its supply. The Sahel and Sahara are severely affected; they are areas of the globe where adequate water supply in quantity and quality is a major problem. This can be attributed to the climatic conditions of the area and the free use of little available water resources. Meanwhile, many Sahelian cities have been experiencing rapid population growth since 1970, and the drought episode of the 1970s and 1980s (Musa et al., 2008), have led to an increased water shortage in the region.

However, the complexity of urban water systems and urban water balances, in particular, has aroused the interest of many researchers. It has become apparent that meaningful planning to utilize and conserve water resources in any area should be on the assessment of its available water resources. Assessment of available water resources can be made possible through water balance analysis. Water balance is viewed an accounting of the inputs and outputs of water (Ritter, 2006). The balance has four components namely: precipitations, evapotranspiration, surface runoff and grand water recharge. These components may add water to an environment these are called input (rainfall), they may remove water from an environment these are called outputs (vaporization). Water held in the environment is in storage.

Water balance analysis is a highly effective tool that relates climate, geological, hydrological and land use conditions to the quantity of water available for surface runoff and groundwater recharge. This makes it possible quantitatively to evaluate water resources and their change under the influence of anthropogenic activities (Linsley and Kohler, 1992, Adei etal. 2012).

Water balance in simple terms is the application of the continuity equation derived from the principles of conservation mass, which states that, for any arbitrary volume and during any period, the difference between total input and output will balance by the change of water storage within the volume. Therefore, use of a water-balance technique, both storage and flux (rates of flow) of water are measured. By appropriate selection of the volume and the time for which the balance was applied, some measurements may be eliminated (UNESCO, 1971). This paper examines the temporal nature of water balance and generates information to improve the planning, design, construction, and operation of water resource project in a Sahelian city.

The Study Area

Niamey is the capital and largest city of the West African country, Niger Republic; it lies between latitude 13 31^0 17' N and longitude 02 06^0 19' E, (Fig.1) with 218 m altitude. Niamey lies on the Niger River, primarily situated on the east bank and found on the both sides of Niger River covers an area of over 250 km^2 (Bocquier and Traore, 1998 and INS,2011).

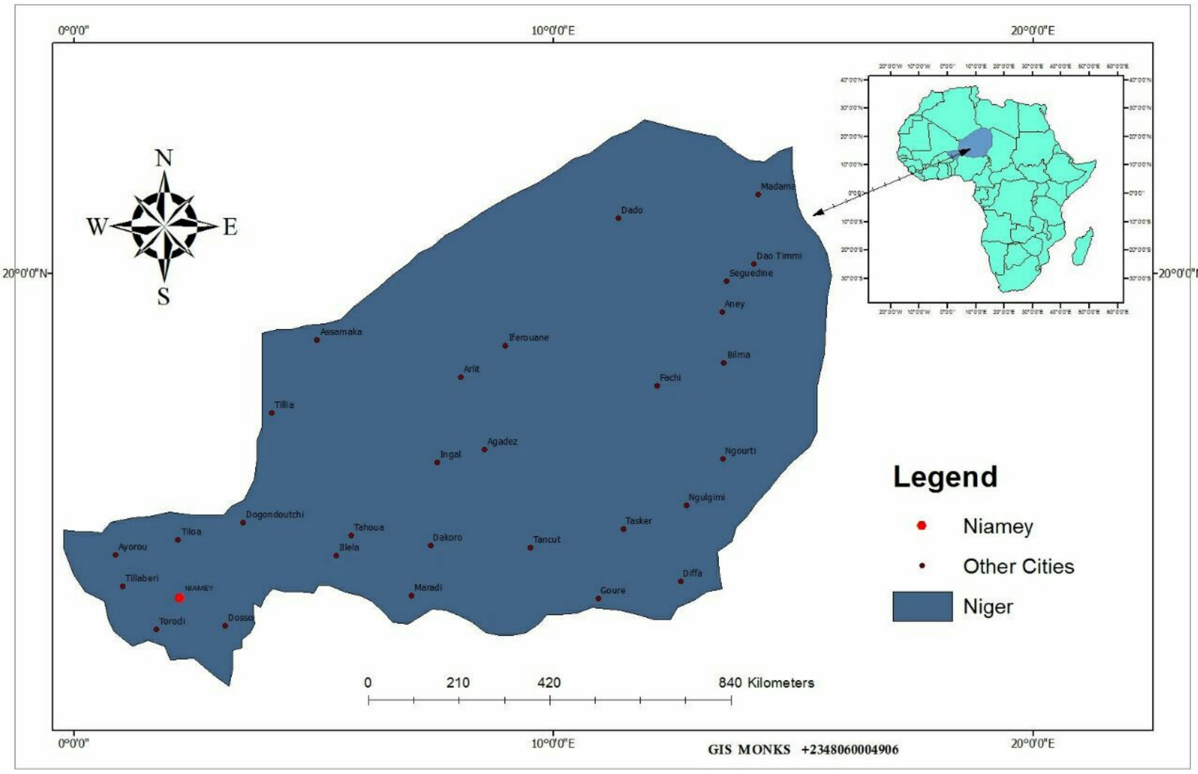

Figure 1. Map of Niger Showing Niamey

The relief intensity of geological area expressed by the quotient of high gradient slopes per geological area the relief sequence then is sedimentary basement (0.71), granitic basement (0.36), Continental terminal (0.22). Due to the climatic and the relief erosion force most terrain surfaces are covered with Aeolian deposit, ironstone basement material. The surface drainage is usually very rapid except for the depression or fluvial areas receiving additional water. The climate is hot semi-arid (Köppen climate classification), with an expected rainfall of between 500 mm (20 in) and 750 mm

(30 in) a year, mostly beginning with a few storms in May, then accelerating to a rainy season usually lasting from sometime in June to early September. Niamey is remarkably hot throughout the year. Average monthly high temperatures reach 38 °C (100 °F) four months out of the year and in no month does average high temperatures fall below 32 °C (90 °F). During the dry season, particularly from November through February, nights are cool the temperature range between 14 to 18 °C (Morel, 1980). The vegetation of Niger is Sahelo-Saharan, varying with the nature of the soil and is determined by climate. The Saharan zone covering 60% of the country has very little vegetation. The Sahelian band is covered with thorns, *momisease,* acacia, *graminaceae*, doum and scattered pastures of grass. Niamey is found in various formations of Precambrian West African shield and Paleozoic, Mesozoic, and Tertiary formations of the lullumeden basin. (Greigert, 1963; Ferier, 1981).

While Niamey's population has grown steadily since independence reaching 707,951 in 2001.The droughts of the early 1970s and 1980s, along with the economic crisis of the early 1980s, have propelled an exodus of rural inhabitants to Niger's largest city. In 2011, government press estimated the total urban population at over 1.5 million (encyclopedia.com). Niamey is the trade center for an agricultural region that specializes in growing peanuts. Manufactures include bricks, food products, beverages, ceramic goods, cement, shoes among others.

Methodology

Niamey, the capital city in the Niger Republic, was purposively selected for this study based on its location in the Sahelo-Sahara ecological zone of West Africa. It thus serves as the epitome of cities experiencing high water stress.

Data Required and Sources

The data needed in this research were mainly the data on therelevant climatic element for Niamey from 1997-2011. Specifically, Rainfall, Evaporation, and Runoff collected fromStation Météo Niamey and Institute National de la Statistique du Niger.Descriptive and inferential statistics were employed to analysis the data. Descriptive statistics mean, standard deviation and summarized the data and Coefficient of Variation were used to test the degree of homogeneity in the set of variables. Scatter plots were usedfor graphical presentation of the data and time series to show the trends of the data for the period adopted for this research. The inferential statistics employed in this work were multiple regression and multiple correlations.

i) Multiple regression can be approximated by the following regression model which is:

$Y = f(X_1, X_2, \ldots Xp) + e$……………………………………………………………Eq. 1

Where, e is the assumed random error representing the discrepancy on the approximation. It accounts for the failure of the model to fit the data exactly.

Equation one is usually expressed as follow:

$Y=\beta_0+\beta_1X_1+\beta_2X_2+\ldots..+\beta_pX_p+e$……………………………………………………Eq. 2

Where β_0, β_1, β_2,..., β_p are the regression coefficients which are unknown and yet to determined.

The variables in the above model are as follow: the computed water budget as the dependent variable (y), the independent variables are, rainfall (x_1), evaporation (x_2), and runoff data (x_3). Multiple regression, therefore, facilitates understanding the interrelationship among these variable and the implications on water resources of Niamey and such environment in general.

With multiple correlation analysis, the strength of linear relationship between these variables was analyzed based on the following equation.

$$r = \frac{n\sum xy - \sum x \sum y}{(\sqrt{n\sum x2 - (\sum x)2})(\sqrt{n\sum y2 - (\sum y)2})} \quad \text{……………………………Eq. 3}$$

Where, y is the dependent variable and x the independent variable. Where X may be x_1, x_2, or x_3.

The annual means of precipitation, evaporation and runoff data were used to compute the water audit using water balance equation with the assumption that, water audit is a balance between inflows, outflows, and changes in storage. This assumption gives the following mathematical statements, according to Warren and Lewis (1995), where all values are in units of volume (millimeters) per unit time (year).

1. Hydrologic budget above the surface

$P+R_1-R_2+R_G-E_S-T_S–I=\Delta S_s$ …………………..…………………………..…. Eq. 4.1

2. Hydrologic budget below the surface
$I+G_1–G_2-R_G–E_G-T_G=\Delta S_G$...Eq. 4.2

3. Hydrological budget for the region

$P–(R_2–R_1)–(E_s+E_G)-(T_s + T_G)-(G_2-G_1)=(Ss + S_G)$…………………….. Eq. 4.3

If the region subscripts are dropped from Eq4.3 so that letters without subscripts refer to total precipitation and net values of flow, underground flow, precipitation, transpiration and storage, the hydrologic budget can be simply as

$P–R–G–ET=\Delta S$………………………………………………………… Eq. 4.4

This formsthe core equation of hydrology. For simplified hydrological system where the terms, G and T do not apply, Eq 4.4 reduces to

$P–E-R=\Delta S$………………………………………………….…..……Eq. 4.5

For the study, the runoff data were converted from cubic meter (m^3) to millimeter (mm) based on the following assumption, $1m^3 = 1.10^9$ mm (wepcom.upfm.grenoble.fr). The data were analyzed using two software namely: Minitab14, RGui (32bit) version 3.03.

Results and Discussion

Monthly Rainfall (mm) in Niamey (1997-2011)

The mean monthly rainfall data presented in Table1, revealed that Niamey experiences little rainfall between October and April**.** The table also shows that October, November, December, January, February, March, and April are the dry months, and characterized as the dry season. The result also revealed that raining season is experienced from May to September and June, July, and August are the wettest months, with August having the highest record of rainfall (164.1 mm).

A summary of rainfall data revealed that the year 2000 has the least mean monthly rainfall of 171 mm while, 1998 has the highest record of 219 mm. The Standard Deviation (S.D) is highest at 551 in 2011 and least at 543 in 1998. The coefficient of variation C.V is highest (322.03) in 2000 and least (248.44) in 1998. This result suggests that rainfall is highly heterogeneous in this environment. Variation only exists when C.V. is greater than 33% (Olubusoye and Olaomi, 2002).

Table 1. The Mean Monthly Rainfall Data (1997- 2011)

N0.	YEARS	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	S.D	C.V
1	1997	0	0	2	1.7	54	62.5	95.1	91.2	56.5	48.6	0	0	185	546	294.45*
2	1998	0	0	0	32.7	26.8	89.1	205.9	281.9	207.8	1.7	0	0	219	543	248.44*
3	1999	0	0	0	4.8	27.8	44.9	219.2	150.6	188.7	5.8	0	0	203	545	268.46*
4	2000	0	0	0	9.4	5.4	82.5	36.8	36.8	50.2	0	0	0	171	550	322.03*
5	2001	0	0	0	0	12.2	107.8	211.6	121.9	152.8	0.9	0	0	201	546	272.07*
6	2002	0	0	0	0.3	10.5	110.1	134	119.2	79	32.4	0	0	191	546	285.6*
7	2003	0	0	0.3	0	33.6	115.8	85.2	228.7	108.5	0.5	0	0	198	547	275.98*
8	2004	0	0	0	29.6	0.7	38.3	110.3	177.6	92.3	0	0	0	189	548	290.6*
9	2005	0	0	0	0	29.7	154.9	185.4	154.4	83.2	38.2	0	0	204	546	267.5*
10	2006	0	0	0	0	0.8	45.6	110.6	168.2	69.2	10.6	0	0	185	550	296.3*
11	2007	0	0	0	0	19.8	42.2	145.2	255.9	59.6	0	0	0.6	195	550	282.49*
12	2008	0	0	0	0	12.4	94.3	163.8	160.8	41.6	0	0	0	191	549	287.89*
13	2009	0	0	0	14.4	18.9	27	183.3	196.6	96.2	35.3	0	0	199	548	276.2*
14	2010	0	0	0	6.9	26.5	74.9	147.2	179.6	46.3	62.1	0	0	196	548	279.1*
15	2011	0	0.3	0	2.3	14	42.4	79	137.6	35.6	37.9	0	0	182	551	303.6*
	Mean	0	0.02	0.19	9.28	19.54	75.4	140.8	164.1	91.2	19.57	0	0.04			
	S.D	0	0.08	0.57	11.72	14.1	3654	54.4	62.3	53	21.83	0	0.16			
	C.V	0	374*	300.5*	126.2*	72.1*	48.41*	38.65*	37.95*	58.17*	111.5*	0	374.1*			

Source: Station Météo Niamey Significant *C.V. > 33%

Monthly Evaporation (mm) in Niamey (1997-2011)

Table 2 presents the mean monthly evaporation data from 1997 to 2011; it revealedthat Niamey experiences excessive evaporation from September to May**.** The high records of evaporation occur in March, April, and May, and classified as the hottest months; the highest record happened in March at 446 mm. The decrease in evaporation in June, July and August, which coincides with the wettest period of the rainning season, the least record occurred in August at 202.4 mm. This result suggests that the presence of cloud in the raining season that, reflected back some part of solar radiation into the atmosphere. Thus, reduced the rate of evaporation.

The year 2007 has the least mean monthly evaporation (293.9 mm) while, 2011 recorded the highest (356.5 mm). Variation in evaporation is highest in 1999 (32.99) and least in (2000). This result explains that evaporation ishomogeneous in Niamey (C.V. values were less than 33%,).Olabode and Oriolaand (2013) reported similar homogeneity in the soils nutrients of irrigated rice field in Lade, Patigi Local Government Area of Kwara State.

Monthly Discharge in River Niger at Niamey (1997-2009)

The monthly mean data of runoff presented in Table 4, revealed that there is variationin the water discharged into River Niger at Niamey. The runoff data revealed that the year 1997 has the least mean monthly runoff of 758 while, 2009 has the highest record of 1115. The coefficient of variation is at it peak (75.16) in 2008 and least (59.78) in 2009. Therefore, runoff is heterogeneous in Niamey. In all the months The C.V is greater than 33%, establishing variability. In this case,the River Niger regime can be divided into two periods of water discharge within a year. These include the period of low water which ranges from February to July, with the least record of 75.95 in May and the period of high water which ranges from August to January with the highest record of 1684.4 in December. The result is inconsistent with the findings of Descroix et al. (2012) saying that the middle Niger River has two peaks. The first one, termed the red or local flood, arises from local rainfall draining through a series of tributaries enlargement and occurs between August and September. The second termed Guinean flood, originates from precipitation in the Fouta Djalon (Guinea) and takes place around January.

Trend in Hydro-Climatic Variables in Niamey between 1997 and 2011

a. Rainfall

The results of the trends analysis of rainfall data revealed that the mean annual rainfall within the period (1997-2011) ranges from 221.1mm to 845.9mm. The average rainfall for the period was 516.38mm. This value justifies the location of Niamey in a semi-arid partof the Sahel. The result is not consistent with Nicholson et al., (2012) description of the semi-arid region. Mean annual rainfall in the Sahel is on the order of 100 to 200 mm in the north, where the Sahel gives way to desert, and 500 to 600 mm at its southern limit.

The fit line (fig.2) shows a downward movement which means that there is a reduction in the annual mean of rainfall over time, at a rate of -6.909 mm which was the result of the trend equation (y= 14363 - 6,909x).

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Table 2. Mean Monthly Evaporation (mm) in Niamey (1997-2011)

No.	Yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	S.D	C.V
1	1997	377	398	406	443	487	322	286	253	240	316	356	341	352.1	74.6	21.18
2	1998	354	377	494	480	402	315	282	148	157	302	302	290	325.3	107	32.89
3	1999	390	373	497	386	408	373	223	154	157	264	294	304	318.6	105.1	32.99
4	2000	361	363	459	427	430	308	288	288	239	280	294	298	336.3	70.5	29.98
5	2001	338	334	403	451	439	340	241	172	198	295	306	305	318.5	87	27.3
6	2002	328	313	416	431	464	330	281	213	237	236	277	315	320.1	80.5	25.15
7	2003	319	341	415	417	438	287	232	185	171	309	313	309	311.3	86	27.64
8	2004	305	359	443	450	431	356	243	222	228	305	324	295	330.1	80.4	24.35
9	2005	321	377	444	421	432	258	252	199	222	277	295	292	315.8	83.7	26.51
10	2006	260	300	420	424	413	350	260	197	193	262	306	280	305.4	80.8	26.46
11	2007	310	312	405	379	252	252	253	179	235	320	320	310	293.9	63	21.43
12	2008	295	375	422	447	432	367	245	194	217	311	316	308	327.4	83.5	25.49
13	2009	319	360	453	434	443	356	284	211	206	316	318	332	336	80.9	24.07
14	2010	313	371	484	454	423	382	255	196	218	282	332	321	335.9	90.7	27
15	2011	353	361	529	478	494	246	313	225	270	338	344	327	356.5	97.1	27.24
	Mean	330	354	446	435	426	323	263	202.4	212.5	294.2	313	308.4			
	S.D	33.5	28.3	39.4	28.3	54.7	44.7	25.1	36.05	32.48	26.99	20.6	16.7			
	C.V	10.2	7.95	8.89	6.5	12.8	13.8	9.57	17.81	15.28	9.17	6.58	5.41			

Source: Station Météo Niamey C.V. < 33%

Table 3. Mean Monthly Discharges in River Niger at Niamey (1997-2009)

N0.	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	S.D	C.V
1	1997	1440	782	277	95	36	43	156	659	1010	1100	1320	1470	758	555	73.29*
2	1998	1280	648	215	88	47	194	509	1070	1560	1350	1450	1640	856	583	68.09*
3	1999	1650	1170	419	146	83	115	208	816	1330	1330	1550	1760	957	640	66.89*
4	2000	1800	1610	856	263	102	71	298	884	1100	1260	1450	1630	1052	645	61.25*
5	2001	1660	1210	463	131	49	96	438	974	1310	1270	1470	1680	973	613	62.99*
6	2002	1610	1110	405	146	90	120	142	652	1130	1360	1340	1470	878	594	67.64*
7	2003	1880	1470	602	228	129	59	451	746	1040	1180	1380	1510	1002	632	63.09*
8	2004	1210	536	187	68	22	112	613	1430	1750	1520	1710	1870	912	686	75.16*
9	2005	1200	612	232	105	74	208	669	1240	1410	1340	1490	1660	861	562	65.33*
10	2006	1500	797	291	119	63	47	232	1180	1430	1345	1529	1713	896	633	70.66*
11	2007	1680	1180	479	193	99	118	458	1100	1340	1320	1570	1780	1013	617	60.97*
12	2008	1728	1217	478	178	76	118	553	1073	1379	1384	1640	1830	1043	639	61.25*
13	2009	1922	1680	860	279	117	141	877	1046	1418	1443	1708	1884	1115	666	59.78*
	Mean	1581.5	1079	443	157	75.9	111	431	990	1323	1323	1508.2	1684			
	S.D	241	378	221	67.4	31.9	50.5	219	232	211.2	106.8	126.1	141.1			
	C.V	15.24	35.08*	49.9*	42.9*	41.99*	45.5*	50.87*	23.4	15.96	10.07	8.4	8.38			

Source: Annuaire Statistique des Cinquante ans d' Indépendance du Niger *C.V. > 33%

NB: 2010 and 2011 data were missing.

The zigzag movement of the precipitation trend across the fit line from one year to another revealed that there is a variation of rainfall annually at a rate of 0.044, which is given by R^2, which is the proportion of variation in the annual mean of rain, is explained by the years.

Trend line equation: $Y = 14363 - 6.909X$, $R^2 = 0.044$

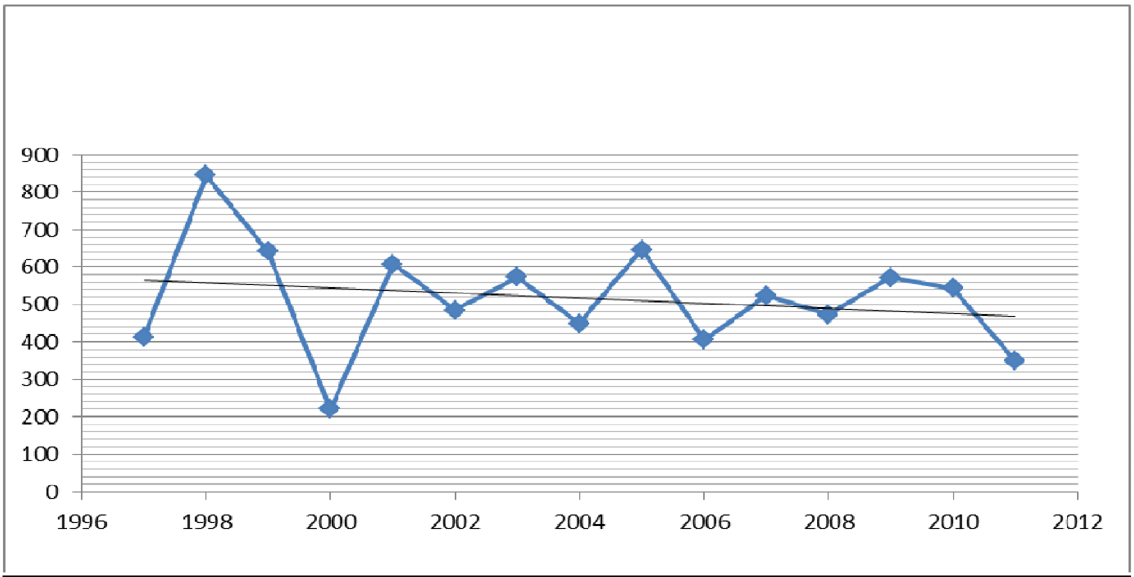


Figure 2. Rainfall Pattern in Niamey 1997-2011

b. Evaporation

The trend analysis of evaporation (Fig 6) shows that the mean annual evaporation within the period of 1997-2011, ranges from 3527 mm to 4278 mm. The average evaporation for the period was computed to be 3,906.5 mm. The fit line revealed that there is an upward trend, which means there is an increase in annual evaporation at a rate of 30.74 mm in Niamey (trend line equation). This increase may be the result of the excessive temperature that characterized the Arid regions of the world. The zigzag pattern of evaporation trend line across the fit line reveals that there is a variation in evaporation every year at a rate of 0.060 mm. The year 2008 shows an exceptional increase of evaporation (Fig 3) which, may also be attributed to climate change, that accounts account for the anomalous trend in all of the climatic factors in a given region.

Trend line equation: $Y = -57575 + 30.74X$, $R^2 = 0.06$

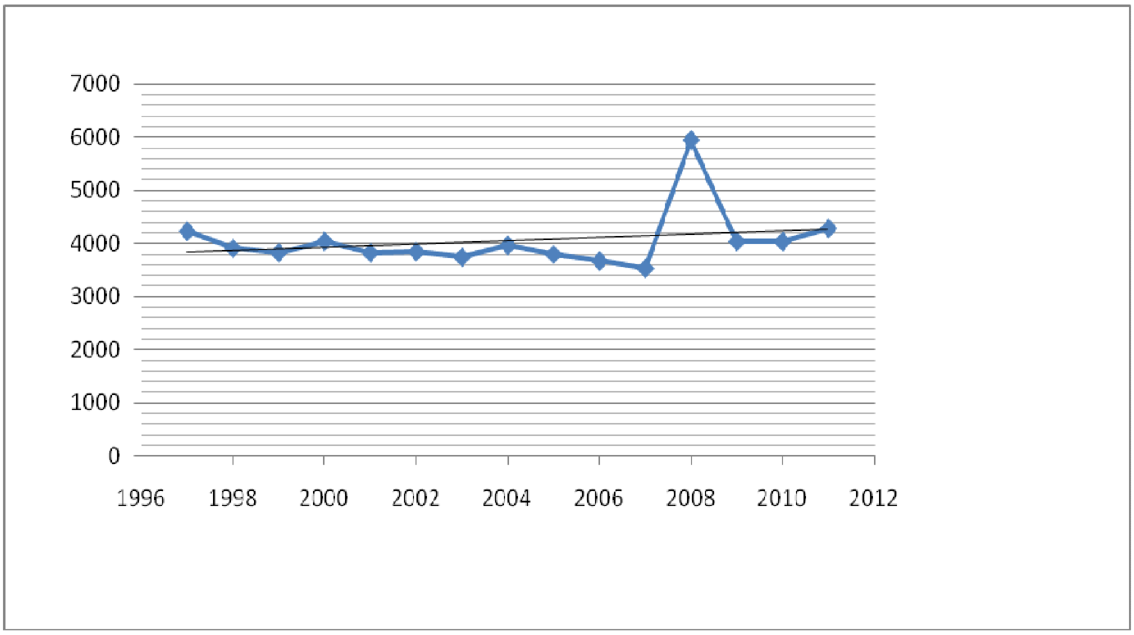


Fig.3. Evaporation Pattern in Niamey (1997-2011)

C. Runoff

Figure 4 shows the trend analysis plot for the annual runoff. The graph revealed the presence of a trend in the annual Runoff. The linear trend model obtained revealed that as time increases, the annual runoff also increases considerably. This phenomenon of increase in runoff is the result of a decrease in soil water holding capacity in the River Niger basin. The increase in runoff also correlate with a decrease in vegetation cover, due to land use changes include an increase in crop areas, overgrazing, and wood harvesting. This result isinconsistent with Maye et.al (2009) who analyzed the runoff of 8 right bank tributaries of the middle Niger River and noted that a decrease in rainfall did not lead to a decrease of runoff under the Sahelian climate as commonly observed in other basins in the world. Albergel, (2012) attributed this behavior to increasing bare soil and decreasing vegetation cover in the Sahelian basin. As the river receives tributaries from different climatic areas.

$Y = -34483 + 177.4X, R^2 = 0.495$

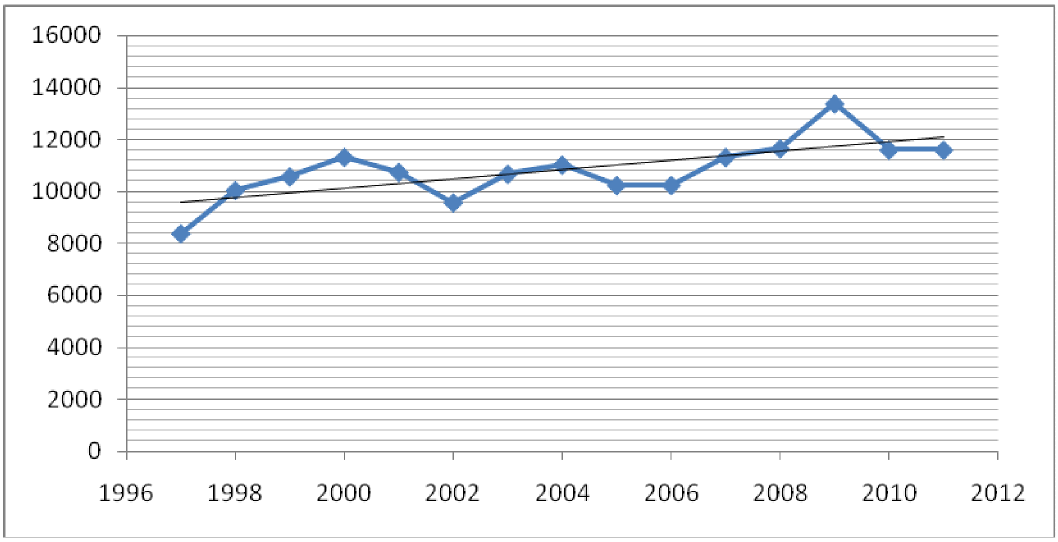


Figure 4. Runoff Pattern in Niamey (1997-2011)

Characteristics of Water Balance Indices in Niamey 1997-2011

According to Figure 5.1 to Figure 5.15 below, Niamey experiences more water deficit than water surplus every year. Suggesting that, Niamey is susceptible to drought.

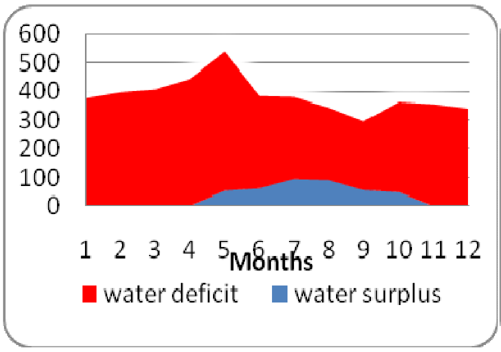


Figure. 5.1, Niamey Water balance in 1997

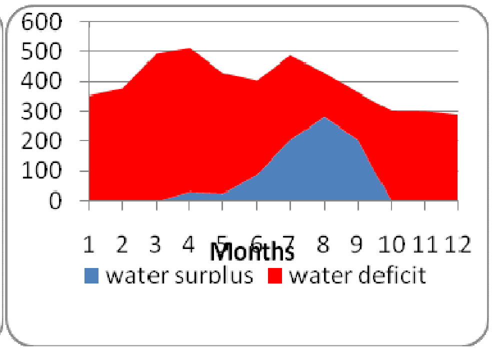


Figure.5.2, Niamey Water Balance in 1998

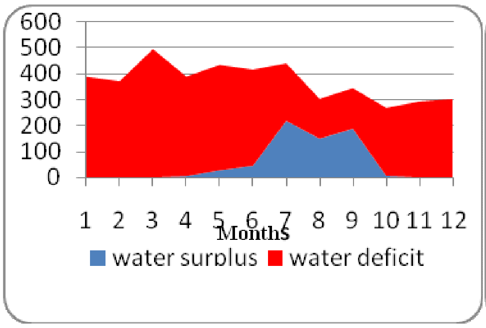


Figure.5.3. Niamey Water Balance in 1999

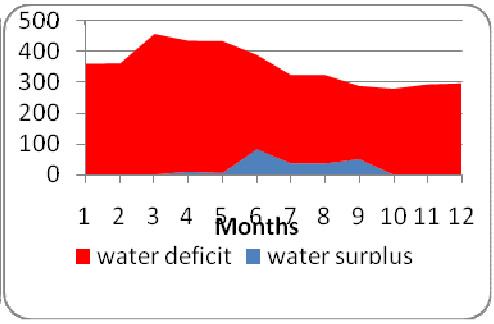


Figure.5.4. Niamey Water Balance in 2000

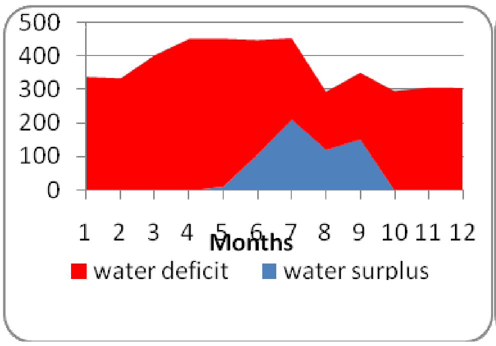


Figure. 5.5 Niamey Water Balance in 2001

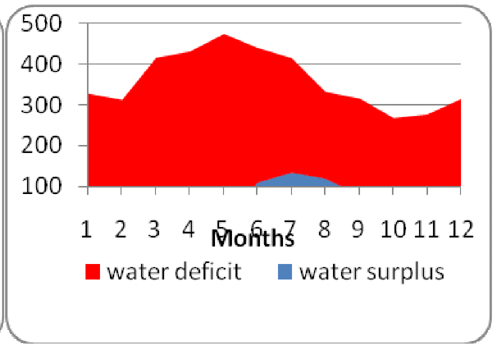
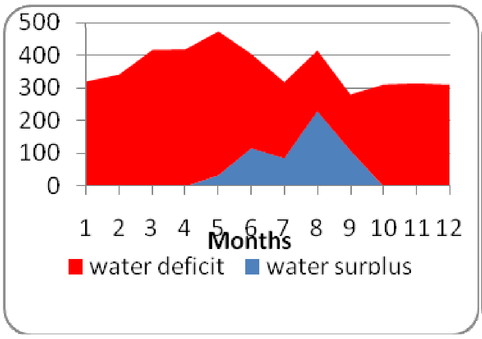


Figure 5.6 Niamey Water Balance in 2002



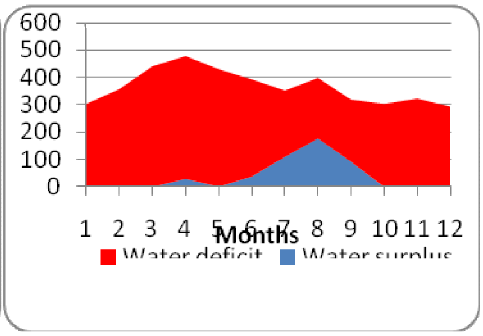
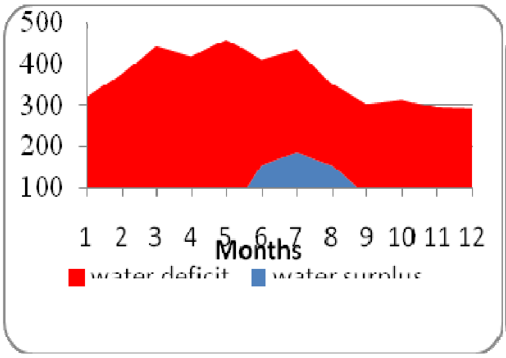


Figure.5.7 Niamey Water Balance in 2003 **Figure.5.8 Niamey Water Balance in 2004**



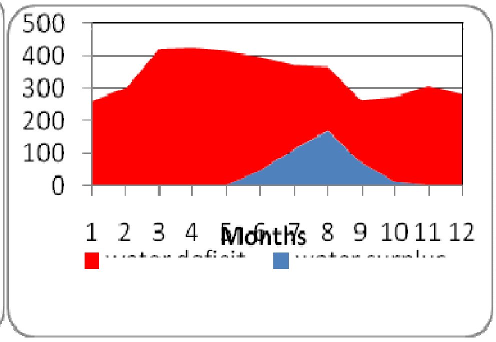
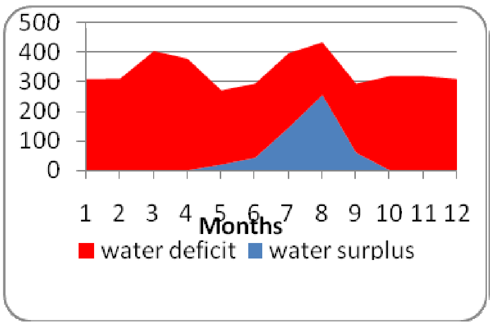


Figure.5.9 Niamey Water Balance in 2005 **Figure 5.10 Niamey Water Balance 2006**



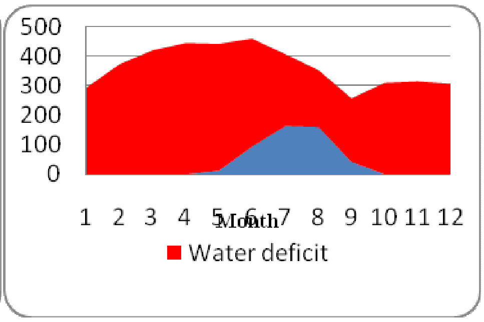
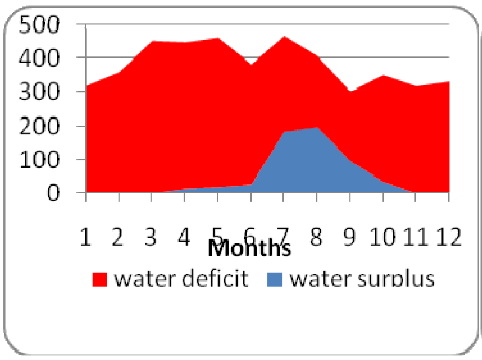


Figure. 5.11 Niamey Water Balance in 2007 **Figure.5.12 Niamey Water Balance in 2008**



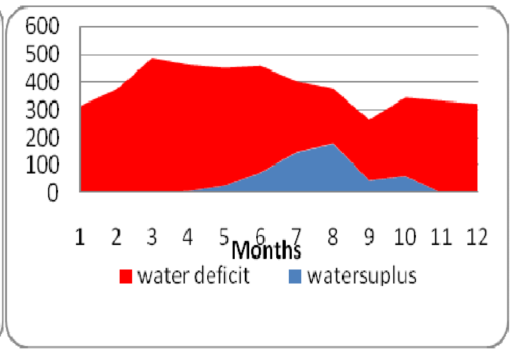


Figure.5.13 Niamey Water Balance in 2009 **Figure. 5.14 Niamey Water Balance in 2010**

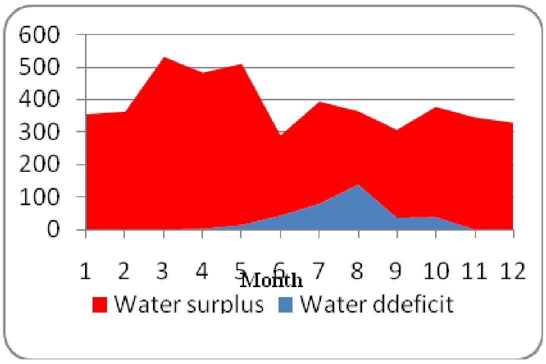


Figure 5.15 Niamey Water Balance in 2011

The analyses revealed that Niamey drought could be classified as years of moderate drought, years of excessive drought and years of complete dryness:

(i) Years of moderate drought are those years that, have received 500mm and above of rainfall. These include the following 1998, 1999, 2001, 2003, 2005, 2007, 2009 and 2010.

(ii) Years of excessive drought are those years that received between 400mm and 300mm of rainfall; theseyears are 1997, 2002, 2004, 2006, 2008 and 2011.This implies that there is a considerable reduction of rainfall received when compared with the amount received in the years of moderate drought. This outcome could lead to the inference that, at an interval of every two years Niamey experiences excessive drought. According to WEAP. (2011), several research works have shown that one of the three years there has been a drastic drop in rainfall causing poor harvest and extreme dryness on the river Niger.

(iii) Years of complete dryness, theonly year 2000 is completely dried, due to global climate change that causes climatic variables to move abnormally.

The above analysis depicts Niamey as a drought prone.

Fifteen Year Water Balance in Niamey (1997-2011)

The computed water balance model for Niamey revealed that there is water deficit in Niamey every year (Table 4). The deficit reveals the discrepancy of evaporated water and the amount of rainfall. Thus, for all of the years selected for this study evaporation is greater than precipitation. Also, about38.08 percent ofthe runoff in Niamey is evaporated. This outcome is due to high rate of temperature and absence of vegetation cover that can reduce the amount of solar radiation reaching the earth and water surfaces. This result corroborates the description of the semi-arid region of West-Africa by Nicholson et al, (2012). “The Sahel region of West African is a semi-arid expanse of grassland, shrubs, and small, thorny trees lying just to the south of the Sahara desert. Mean annual rainfall in the Sahel is in the order of 100 to 200mm in the north, where the Sahel gives way to desert, and 500 to 600mm at its southern limit.” Therefore, evaporation in Niamey is proportional to runoff rather than rainfall.

The Niamey water deficit expresses the sensitivity of Niamey to drought and desertification. The encroachment of Sahara desert constitutes a menace to the Sahelian environment in general and the water resources in the region in particular. Holistic measures and policies are therefore needed to reduce the scarcity of water to avoid subsequent conflicts that may result from various uses of water resources in Niamey.

Table 4. Niamey Water Balance (1997 – 2011)

No.	Years	Precipitation	Evaporation	Runoff	Water Balance
1	1997	411.6	4225	8388	-8.388
2	1998	845.9	3903	10051	-1.0051
3	1999	641.8	3823	10577	-1.0577
4	2000	221.1	4035	11324	-1.1324
5	2001	607.2	3822	10751	-1.0751
6	2002	485.5	3841	9575	-9.575
7	2003	572.6	3736	10675	-1.0675
8	2004	448.8	3961	11028	-1.1028
9	2005	645.8	3790	10240	-1.024
10	2006	405	3665	10246	-1.0246
11	2007	523.3	3527	11317	-1.1317
12	2008	472.9	5937	11654	-1.1654
13	2009	571.7	4032	13375	-1.3375
14	2010	543.5	4031	11600	-1.161
15	2011	349.1	4278	11600	-1.16

Source: Authors' Computation (2014)

All the runoff variables in Table 4. were expressed in 10^9mm, and both 2010 and 2011 data were computed by the use of the average method.

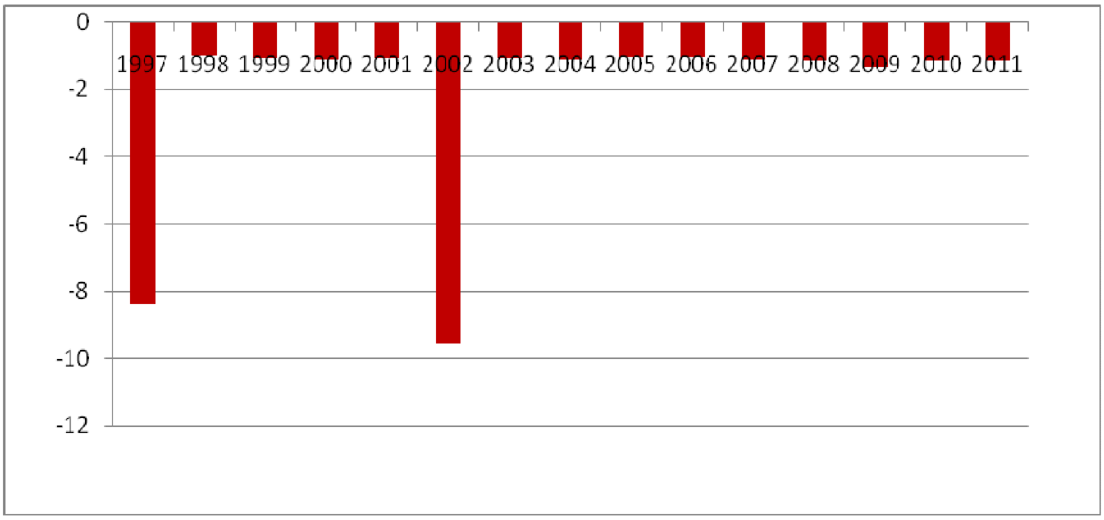


Figure 6. Graphical Representation of Water Balance For Niamey (1997 - 2011)

Predicting Water Balance for Niamey

Both multiple regression and correlation analysis were employed to examine the water balance in Niamey.The influence of rainfall, evaporation and runoff were recorded by the result of a multiple regression analysis carried out. The regression equation is as follows:

$Y = 2985.78 - 536 - 4.13x_1 + 0.27x_2 + 0.080x_3$
Where, x_1 = Rainfall, x_2 = Evaporation and x_3 = Runoff
$R^2 = 0.60$
Standard error = 2985.78

From the above analysis, it can be seen that both evaporation and runoff have positive coefficients while precipitation has a negative one. This result implies that the annual water balance depends more on evaporation and runoff, as both of them increase linearly with one another. It shows that evaporation and runoff account much more for the changes in the annual water balance than rainfall. Thus, rainfall is not favorable to the water balance.

The R^2 revealed that precipitation, evaporation, and runoff accounted for 60% of hydrological components in Niamey while the remaining 40% will be for other elements that are not available in this study. These include Evapotranspiration, Infiltration, Soil moisture, among others.

Analysis of Variance

An analysis of variance was conducted to test for the significant difference among the four variables.

Table 5. Analysis of Variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	3	6306738	2102246	0.24	0.870
Residual Error	11	98063895	8914900		
Total	14 104370633				

Source: Authors' Analysis (2014).

The p-value is greater than 0.05, and that means that there is a significant difference between Rainfall, Evaporation, Runoff and Water Balance.

Correlation Analysis of Water Balance, Rainfall, Evaporation and Runoff

The result of the Correlation analysis (Table 6) revealed the following:

Table 6. Matrix of Correlation

	Water Balance	Evaporation	Rainfall	Runoff
Water Balance	0	0.107	-0.236	0.06
Evaporation	0.107	0	-0.202	-208
Rainfall	-0.236	-0.202	0	-0.078
Runoff	0.06	-0.202	-0.078	0

Source: Authors' Analysis (2014).

Pearson correlation of Rainfall and Water Balance = -0.236, P-Value = 0.397
The P-value obtained is less than 0.05, and this confirms that there is a negative linear relationship between rainfall and water balance.
Pearson correlation of Evaporation and Water Balance = 0.107, P-Value = 0.704
Pearson correlation of Runoff and Water Balance = 0.062, P-Value = 0.826
The two P-value are greater than 0.05 then, lead to the same conclusion that there is a positive linear relationship between evaporation and water balance on one hand and run off and water balance on the other hand.

Implication of Water Balance on Water Management in Niamey

The outcome of multiple regression and correlation analyses revealed that the rate at which evaporation is increasing (0.27) is greater than the rate at which runoff is increasing (0.080). With rainfall decreasing (-4.128) at a rate greater than evaporation, it implies that there is little rainfall in Niamey, and despite the abundant amount of inflow of water through runoff, a greater part of it is lost to evaporation. The decrease in rainfall and increase in evaporation have caused poor harvest in Niamey and exacerbated the dryness along river Niger. This has led to theloss of the little vegetation cover, loss of soil nutrient to runoff, reduction in the volume of surface water and a decrease in water availability for irrigation, domestic and other uses of water in Niamey.It, therefore, implies that:

1. The Nigerien Government should revive the existing artificial forest (Laceintureverte de Niamey) so that the forest will serve as a canopy to reduce the impact of solar radiation that induces the high evaporation.

2. A quick intervention of the Government for the completion of the proposed Kandaji Dam, for storage of water, so that, water will be made available throughout the year for the regions of the River Niger.

3. The Government should develop and provide for the population the groundwater for their daily needs; this will reduce the stress on River Niger.

Conclusion and Recommendation

The raining season in Niamey lasts for three months, and the reduction in the annual rainfall does not correlate with the increase in runoff. Waters received from the little amount of rainfall and runoff has been lost to evaporation due to high temperature in Niamey. The phenomenon of high evaporation and the reduction in rainfall has made Niamey to experience water deficit every year and exacerbated the dryness condition of Niamey. Therefore, there must be an effective and efficient water resources management in Niamey to control and minimize this excessive loss of water that has put Niamey hydrology into a deteriorating condition.

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