

Impact of climate change on surface water resources of Ilorin

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Abstract

This paper presents the impact of climate change on surface water resources of Ilorin. The study involved the collection of data on meteorological and hydrological variables. The hydrometeorological variables were subjected to statistical, trend, and reduction pattern analysis. The statistical analysis was used to determine statistical parameters while Mann-Kendall and regression analyses were used to detect the significance of the trend in each variable. Reduction pattern analysis was used to depict the fluctuation of the variables over time. Based on the analyses, it was discovered that there is tendency for an increase in rainfall while there is tendency for decrease in evaporation. It was also discovered that there will be no significant change in min. temperature, max. temperature, Oyun streamflow, and Asa streamflow.

Keywords: Climate change, Water resources, hydro-meteorological variables, Reservoir

1.0 Introduction

The surface of the earth is heated by solar radiation emanating from the sun at short wavelengths between 0.15 and 5 μm (Burns 2003). Each square meter of the earth receives an average of 342 watts of solar radiation throughout the year (Burns 2003). Approximately one-third of the incoming solar radiation is reflected back to space in the form of thermal infrared, or longer-wave radiation, at wavelengths of 3–50 μm (Burns 2003). Of the remainder, a portion is partly absorbed by the atmosphere, but most (168 watts per square meter) is absorbed by land, ocean, and ice surfaces (Burns 2003).

Some of the outgoing infrared radiation is absorbed by naturally occurring atmospheric gases—principally water vapor (H_2O)—as well as carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O), and clouds. This absorption is termed the natural greenhouse effect because these gases, which are termed greenhouse gases, operate much like a greenhouse: they are “transparent” to incoming short-wave radiation, but “opaque” to outgoing infrared radiation, trapping a substantial portion of such radiation and re-radiating much of this energy back to the earth’s surface. This natural process is critical to the sustenance of life on earth, elevating surface temperatures by about 33° Celsius (C) (Burns

2003). Increases in the concentration of greenhouse gases reduce the efficiency with which the earth’s surface radiates to space. It results in an increased absorption of the outgoing infrared radiation by the atmosphere, with this radiation re-emitted at higher altitudes and lower temperatures (Burns 2003).

This resulting change in net radiative energy, which is termed radiative forcing, tends to warm the lower atmosphere and the earth’s surface (Wigley 2001). The amount of radiative forcing that occurs is dependent on the magnitude of increases in the concentrations of greenhouse gases, the radiative properties of the gases, and the concentrations of existing greenhouse gases in the atmosphere. Overall, CO_2 accounts for 65 percent of the total radiative forcing resulting from anthropogenically released greenhouse gases, methane contributes an additional 19 percent, chlorofluorocarbons, 10 percent, and nitrous oxide about 6 percent (Burns 2003).

Climate change will lead to rising temperatures and changes in precipitation. Under these conditions, the rivers may experience a range of impacts, including lower water levels and shrinking surface area. The effects of warmer water also include decreased oxygen-carrying capacity, decreased volume of water (because of higher evaporation rates), and increased concentration of nutrients and pollutants because of reduction in volume of water for diluting chemical

inputs (Burns 2003). There are at least four approaches that are used to study the potential impact of climate change on the hydrology and water resources of catchments and river basins: 1. Estimates obtained by applying arbitrary changes in climate input to hydrological models, 2. Spatial analogue techniques, 3. Temporal analogue techniques, and 4. The use of results from GCMs, either directly or by downscaling (or disaggregating) to the appropriate catchment scale. These approaches provide insight into the behaviour of hydrological processes in a higher temperature and increased or decreased precipitation regime, but the hydrological changes do not arise from and are not necessarily consistent with the physical forcing changes and interaction that are responsible for climate change associated with increased concentrations of GHG in the atmosphere. (Arora & Boer 2001)

The potential hydrological impacts of climate change estimated by changing the climate inputs to hydrological models are studied by a number of researchers including: Singh and Kumar (1997), Roads et al (1996), Miller and Russell (1992), Kavvas et al (2006), Arora and Boer (2001), to mention but a few.

Simulated changes in precipitation, runoff, and soil moisture may be used directly to estimate some hydrological aspects of climate change. Miller and Russell (1992) for example determined the change in annual runoff due to increase in GHG in concentrations for 33 major river basins around the world using the output from Giddard Institute for Space Studies GCM and found that the majority of river basins experienced an increase in mean annual unroured runoff.

2.0 Materials & Methods

The data collected for this research work include: Rainfall(mm), Maximum Temperature(°c), Minimum Temperature(°c), Evaporation(mm), and Stream flow($\times 10^6 \text{ m}^3$). The meteorological data were obtained from NIMET office (Nigerian Meteorological Agency), off Kappa bus stop, Oshodi, Lagos, while the streamflow data were collected from Kwara state Water Corporation.

The meteorological data collected span between 1989-2008, while the streamflow data for Oyun span between 1972-1991 and that of Asa span between 1966-1985.

The methods of analysis used in the analysis of this paper are explained as follows:

2.1 Statistical Analysis

The statistical measures used for analysis in this research work are described below

Arithmetic Mean

The arithmetic mean, denoted $\bar{X}$, of a set of n numbers $x_1, x_2, \dots, x_n$ is defined as the sum of the numbers divided by n . The arithmetic mean (usually synonymous with average) represents a point about which the numbers balance. In statistics, the arithmetic mean is commonly used as the single value typical of a set of data. The formula for arithmetic mean is shown below.

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} \quad (1)$$

Where $\bar{X}$ = Mean

$X_1, X_2, \dots, X_n$ = Variables

Median

The median is another measure of central location that, unlike the mean, is not affected by extremely large or extremely small data values. When determining the median, the data values are first ranked in order from the smallest value to the largest value. If there is an odd number of data values, the median is the middle value; if there is an even number of data values, the median is the average of the two middle values.

Standard Deviation

Standard deviation is a measure of variability that are based on all the data in a set. Standard deviation can also be described as the square root of variance. The formula for calculating variance is shown in equation below.

$$S^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1} \quad (2)$$

$$\sigma = \sqrt{S^2} \quad (3)$$

Where S^2 = Variance; σ = Standard deviation; X = Variable;
 $\bar{X}$ = Mean;
 n = No. of Variables

Because the unit of measure for the standard deviation is the same as the unit of measure for the data, it is usually preferable to use the standard deviation as the descriptive measure of variability.

Minimum

This refers to the minimum value out of a given set of variables. It has no definite expression.

Maximum

Maximum refers to the highest value out of a given set of variables. It is gotten by comparing all the variables in the set and picking the one with the highest value.

Skewness

Skewness can be defined as the lack of symmetry of a distribution. The expression for coefficient of skewness is given below

$$C_s = \frac{a}{\sigma^3} \quad (4)$$

Where

$$a = \frac{n}{(n-1)(n-2)} \sum_{i=1}^n (q_i - \bar{q})^3 \quad (5)$$

and σ = standard deviation

This dimensionless measure relates to the third moment of the data and is a measure defining the shape of the distribution.

The analysis was carried out on the hydrologic and meteorological data to determine; Mean, Median, Standard deviation, Minimum, Maximum, and Skewness) using Microsoft Excel. The statistical summary obtained for Rainfall, Max. Temperature, Min. Temperature, Evaporation, Asa streamflow, and Ogun streamflow is presented in Tables 1-6 respectively.

Table 1 Summary of the statistical analysis for Rainfall (mm)

Parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	4.83	6.14	32.02	97.19	163.54	182.84	173.11	149.23	241.72	139.01	14.32	4.81
Median	0.00	1.50	23.75	100.25	150.40	171.15	162.95	134.75	261.00	144.00	4.95	0.00
Std. Dev	11.77	9.00	25.15	52.33	80.14	70.68	79.95	79.77	68.49	59.21	18.88	12.12
Min.	0.00	0.00	0.00	25.80	35.20	72.50	81.00	44.50	112.60	42.50	0.00	0.00
Max.	39.30	33.10	92.10	223.00	355.70	360.70	394.10	334.60	343.60	248.30	55.60	46.60
Skewness	2.46	1.76	0.77	0.67	0.66	0.84	1.35	1.11	-0.44	0.07	1.10	2.89

Table 2 Summary of the statistical analysis for Max. Temperature (°C)

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	28.45	25.99	28.52	26.84	26.65	25.75	25.06	28.08	26.53	28.32	30.12	30.32
Median	33.30	34.39	35.35	34.17	31.80	30.35	28.75	28.62	29.40	30.90	33.27	33.43
Std. Dev.	12.29	15.46	14.77	14.32	12.10	11.47	11.01	6.96	9.36	9.75	10.38	10.39
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.	34.73	36.54	38.74	36.20	34.13	35.66	35.08	34.67	34.46	33.80	35.59	35.76
Skewness	-2.11	-1.22	-1.56	-1.50	-1.89	-1.86	-1.94	-3.71	-2.56	-2.82	-2.81	-2.86

Table 3 Summary of the statistical analysis for Min. Temperature (°C)

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	18.54	19.61	22.31	21.98	21.20	20.94	20.30	21.79	21.34	21.10	20.99	20.58
Median	19.50	21.25	23.49	23.40	22.60	22.00	21.50	21.50	21.42	21.40	21.57	20.60
Std. Dev	4.83	6.88	5.48	5.43	5.37	5.41	4.99	1.55	0.94	1.28	1.71	1.96
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.30	18.00	18.39	16.60	16.20
Max.	23.61	25.96	26.42	25.00	23.90	25.67	22.71	26.10	22.53	23.46	23.39	24.49
Skewness	-3.18	-2.61	-3.91	-4.09	-3.82	-3.58	-4.14	0.91	-2.36	-0.60	-0.96	-0.02

Table 4 Summary of the statistical analysis for Evaporation (mm)

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	7.83	9.03	7.26	5.43	3.55	2.88	2.47	2.25	2.35	2.84	5.51	6.80
Median	8.05	9.65	7.40	5.90	3.53	2.90	2.50	2.35	2.45	2.80	5.60	5.60
Std. Dev	3.33	3.38	3.01	1.92	1.22	0.91	0.80	0.74	0.38	0.65	1.57	1.57
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.	12.40	13.80	13.60	8.50	5.50	4.20	3.30	3.10	3.00	3.84	8.00	8.00
Skewness	-0.74	-0.83	-0.30	-1.51	-1.64	-2.28	-2.28	-1.87	-1.06	-1.10	-0.57	-0.57

Table 5 Summary of the statistical analysis for Asa Stream Flow ($\times 10^6 \text{m}^3$)

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	1.45	1.01	1.25	3.26	11.63	15.80	26.62	48.43	62.61	52.45	2.39	2.65
Median	1.48	0.99	1.29	2.90	12.05	14.90	17.55	35.00	58.76	43.67	19.01	2.21
Std. Dev	0.74	0.64	0.83	3.39	5.77	8.19	20.83	37.50	37.86	24.57	14.96	1.92
Min.	0.15	0.07	0.04	0.00	1.89	2.31	1.13	5.74	9.50	15.80	3.47	0.15
Max.	2.96	3.09	3.10	13.19	22.33	33.20	70.00	145.00	147.20	93.76	69.43	7.46
Skewness	-0.04	1.72	0.59	2.33	0.24	0.22	0.96	1.62	0.48	0.41	1.78	1.17

Table 6 Summary of the statistical analysis for Oyun Stream Flow ($\times 10^6 \text{m}^3$)

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	0.34	0.77	1.73	1.89	1.45	1.77	1.64	1.45	3.97	1.94	1.46	1.15
Median	0.04	0.38	1.42	1.59	1.10	1.44	1.12	1.40	3.75	1.84	0.82	0.37
Std. Dev	0.61	0.95	1.11	1.04	1.07	1.26	1.90	1.17	1.65	0.97	1.63	1.86
Min.	0.00	0.02	0.43	0.63	0.64	0.79	0.51	0.13	1.32	0.65	0.03	0.00
Max.	2.27	3.66	5.07	5.14	5.44	6.52	9.24	3.97	9.27	3.87	5.90	7.70
Skewness	2.35	2.09	1.97	1.90	2.96	3.09	3.74	0.89	1.82	0.67	1.81	2.71

Mann-Kendall Analysis

Let the time series consist of n data points and T_i and T_j are two sub-sets of data where $i=1, 2, 3, \dots, n-1$ and $j=i+1, i+2, i+3, \dots, n$. Each data point T_i is used as a reference point and is compared with all the T_j data points such that:

$$\text{Sign}(T) = \begin{cases} 1 & \text{for } T_j > T_i \\ 0 & \text{for } T_j = T_i \\ -1 & \text{for } T_j < T_i \end{cases} \quad (6)$$

The Kendall test's S-statistic is computed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(T_j - T_i) \quad (7)$$

The variance for the S-statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{i=1}^n t_i(t_i-1)(2t_i+5)}{18} \quad (8)$$

in which t_i denotes the number of ties to extent i . The test statistic Z_S can be calculated as:

$$Z_S = \begin{cases} \frac{S-1}{\sigma} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sigma} & \text{for } S < 0 \end{cases} \quad (9)$$

Z_S follows a standard normal distribution. Z_S is used as a measure of significance of trend. If $|Z_S|$ is greater than $Z_{\alpha/2}$, where α represents the chosen significance level (usually 5%, with $Z_{0.025}=1.96$), then the null hypothesis is invalid, meaning that the trend is significant.

The non-parametric Mann-Kendall analysis is commonly used for hydrologic data analysis, to detect trends. The null hypothesis in Mann-Kendall test is that the data are independent and randomly ordered. The Mann-Kendall test does not require the assumption of normality, and only indicates the direction but not the magnitude of significant trends.

The Mann-Kendall test procedure was used to analyse all the parameters. The analysis was carried out and the results in Table 7. The time series consist of n data points ($n=20$) and T_i and T_j are two sub sets of data in the series where $i = 1, 2, 3, \dots, n-1$ and $j = i+1, i+2, i+3, \dots, n$. Each data point T_i is used as a reference point and is compared with all the T_j data above it as shown in equation (6).

Equation (6) implies that if T_i is greater than T_j , the value of T will be 1, and the second condition shows that if T_i is less than T_j , the value of T will be -1, while the last condition implies that if $T_i = T_j$, then the value will be 0. Mann Kendall analysis is started from the bottom and is computed towards the top values because the reference point is being compared with all the T_j values above.

The Kendall's S – statistic was computed using equation (7). After computing the Kendall's S value, the variance (σ^2) and test statistic Z_S were calculated using equations (8) and (9) respectively.

Table 7 Summary of Mann-Kendall Analysis

Hydrometeorological Parameter	Autocorrelation Factor	Kendall's S	Z_S	Possibility of positive trend-Significance at 5% level	Remarks
Evaporation	0.727	-90	-2.888	NO	Trend is not significant
Rainfall	0.219	94	3.082	YES	Trend is significant
Min. Temperature	0.326	31	1.038	NO	Trend is not significant
Max. Temperature	0.383	2	0.097	NO	Trend is not

					significant
Oyun Streamflow	0.262	10	0.292	NO	Trend is not significant
Asa Streamflow	0.092	-40	-1.265	NO	Trend is not significant

2.3 Regression Analysis

Simple Linear Regression is one of the most useful parametric models to detect trends. The model for Y can be described by the equation below:

$$Y = aX + b \quad (10)$$

where, X=time (year), a=slope coefficients; and b=least-square estimates of the intercept.

The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is statistically significantly different from zero, the interpretation is that it is entirely reasonable to interpret there is a change occurring over time. The sign of the slope defines the

direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative.

The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship. For this research, checking the normality of the data was done by a special test for normality by using the Ryan-Joiner method. The test of Ryan-Joiner was carried out using MINITAB software by calculation of Ryan-Joiner coefficient. The MINITAB software was also used to carry out autocorrelation test and probability plot of each of the parameters. The full result of the analysis of rainfall is shown below. The autocorrelation function and probability plot for rainfall is presented in Figure 1 and 2 respectively.

Lag ACF T LBQ
1 0.219093 0.98 1.11

Results for: RAINFALL

Autocorrelation Function: RAINFALL

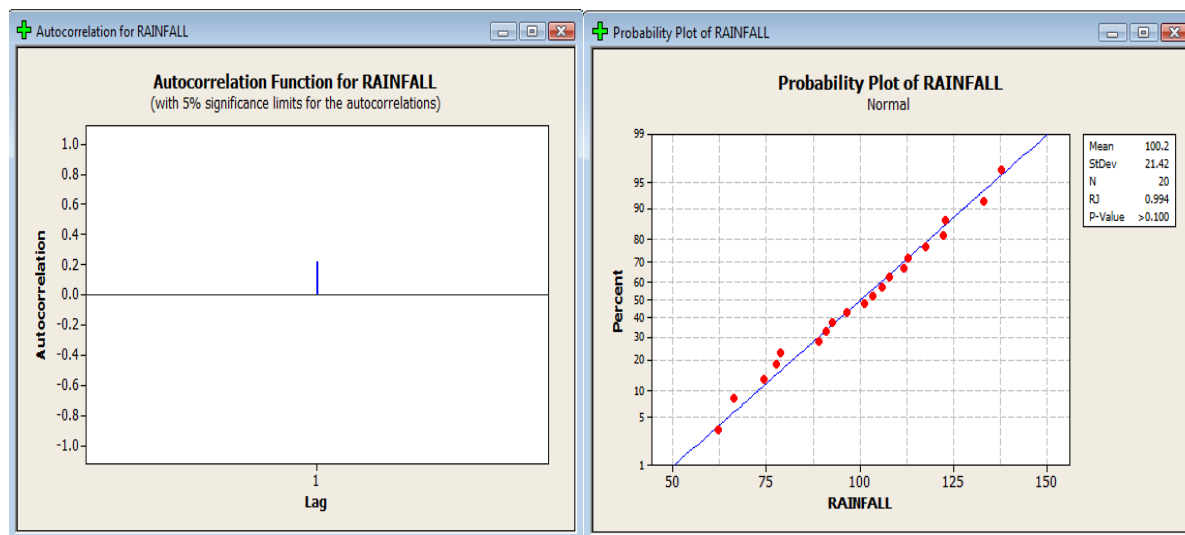


Fig. 1 Autocorrelation for RAINFALL Fig. 2 Probability Plot of RAINFALL

2.3 Regression Analysis: RAINFALL versus YEAR

2.3.1 Linear regression

The regression equation is

$$\text{RAINFALL} = -2260 + 1.18 \text{ YEAR}$$

Predictor	Coef	SE Coef	T	P
Constant	-2260	1612	-1.40	0.178
YEAR	1.1810	0.8068	1.46	0.161

S = 20.8067 R-Sq = 10.6% R-Sq(adj) = 5.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	927.5	927.5	2.14	0.161
Residual Error	18	7792.5	432.9		

Total 19 8720.0

R denotes an observation with a large standardized residual. Durbin-Watson statistic = 1.39977. The scattered plot of rainfall with time is presented in Fig. 3.

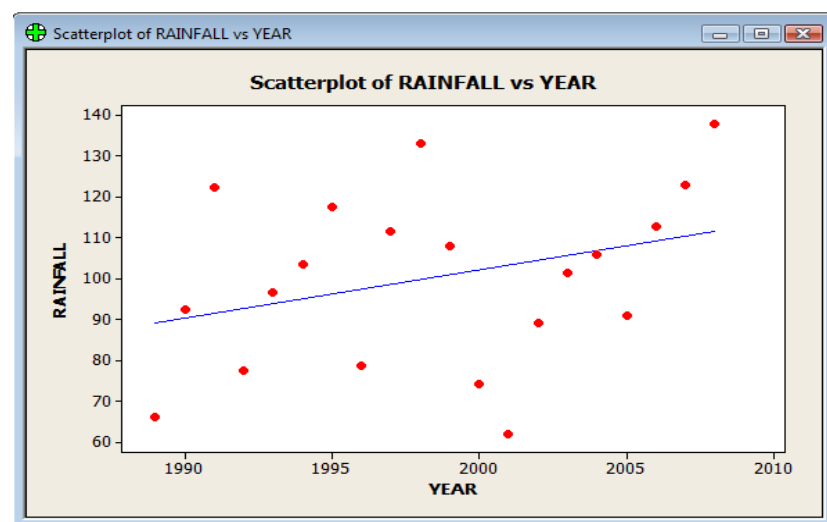


Fig. 3 Scatter plot of rainfall vs year

The same procedure was repeated for other variables and the results are presented in Table 8

Table 8 Results of regression analysis

Hydrometeorological Parameter	Regression Equation	Statistical significance (P value)	Sample Correlation	R-Square
Evaporation	$Y = -0.203X + 410$	0	0.036	62.20%
Rainfall	$Y = 1.18X - 2260$	0.161	0.807	10.60%
Max. Temperature	$Y = -0.063X + 152$	0.865	0.364	0.20%
Min. Temperature	$Y = -0.145X + 309$	0.477	0.199	2.90%
Asa Streamflow	$Y = -0.166X + 336$	0.147	0.273	6.60%
Oyun Streamflow	$Y = 0.003X - 5.1$	0.007	0.693	0.70%

2.3.2 Multiple Regression

Also, regression between Oyun streamflow and rainfall, evaporation, mean temperature, and relative humidity was done and the result is as presented below.

Oyun streamflow and Rainfall/Mean Temperature ($Q=[RT]$)

$$Q = -0.005R - 0.036T + 3.090$$

Oyun streamflow and Rainfall/Evaporation ($Q=[RE]$)

$$Q = -0.008R - 0.114E + 3.029$$

Oyun streamflow and Rainfall/Evaporation/Mean Temperature ($Q = f(R, E, T)$)

$$Q = -0.008R - 0.093E - 0.017T + 3.301$$

Oyun streamflow and Rainfall/Mean Temperature/Relative Humidity ($Q = f(R, T, H)$)

$$Q = -0.010R - 0.296T + 0.058H + 6.481$$

Oyun streamflow and Rainfall ($Q = f(R)$)

Reduction pattern analysis was carried out on all the variables. Using rainfall data as an example, the steps taken in the analysis are explained as follows: The mean of the rainfall data for the 20 year period was calculated. The calculated mean was then subtracted from the value for each year and the difference was plotted against time. After this, the data was divided into four subsets with 5 year period each. After the division, the average for each subset was

$$Q = -0.056R + 1.881$$

Oyun streamflow and Mean Temperature ($Q = f(T)$)

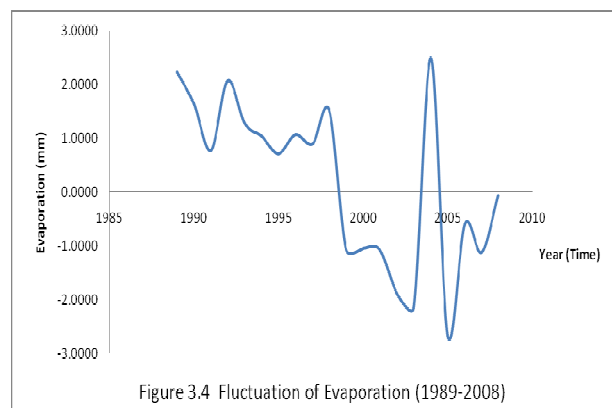
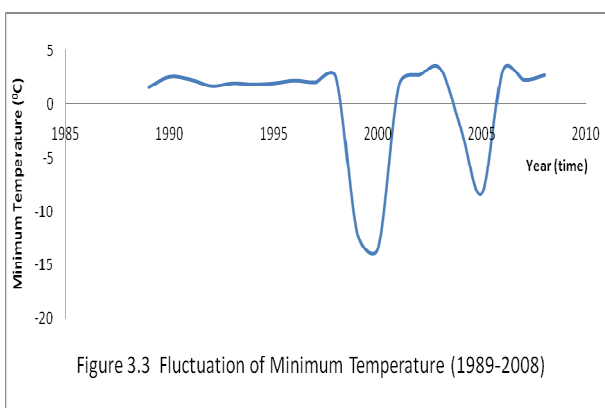
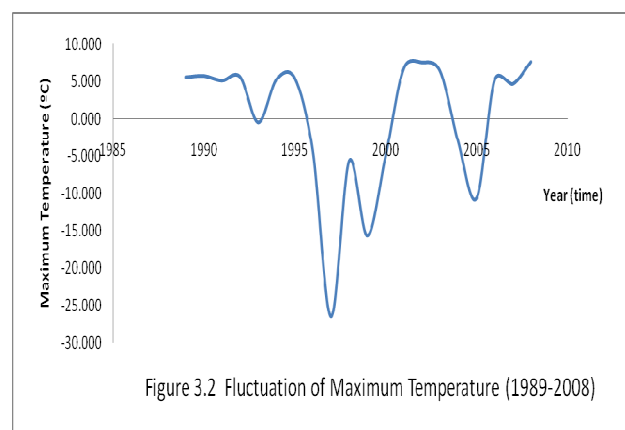
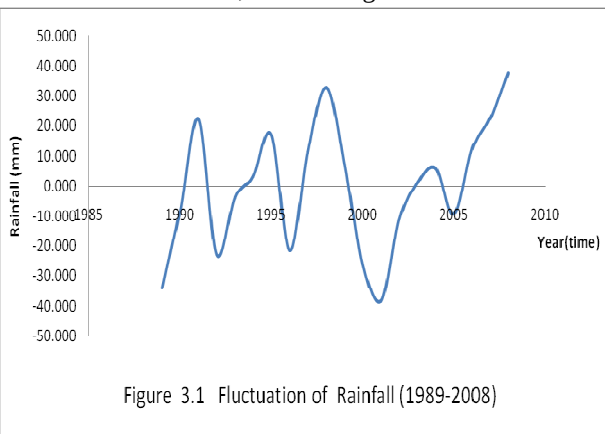
$$Q = -0.037T + 2.584$$

Oyun streamflow and Evaporation ($Q = f(E)$)

$$Q = -0.004E + 2.155$$

2.4 Reduction Pattern Analysis

calculated and compared with the mean of the whole data. The difference (subset average-total mean) in each subset was recorded and the percentage change in each was also calculated. The same procedure was repeated for all the other parameters. The fluctuations of the variables with time are shown in Figures 3.1-3.7 and the percentage reduction of all the parameters at 5 year intervals are presented in Table 9.



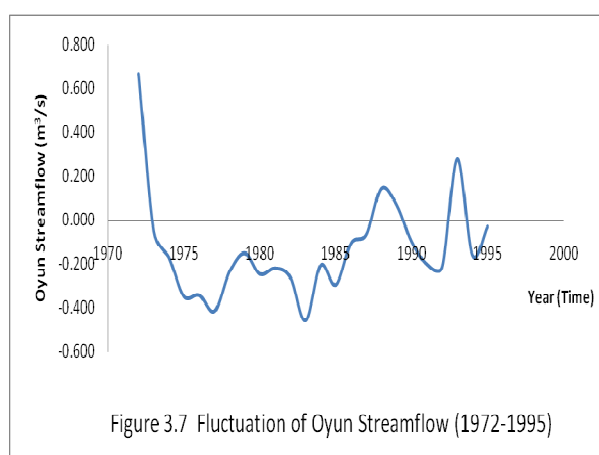
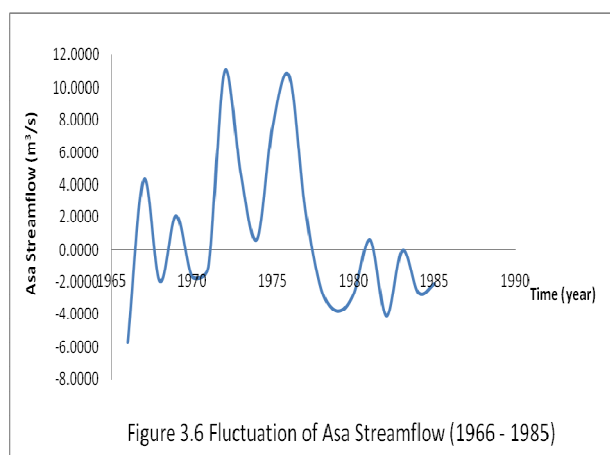


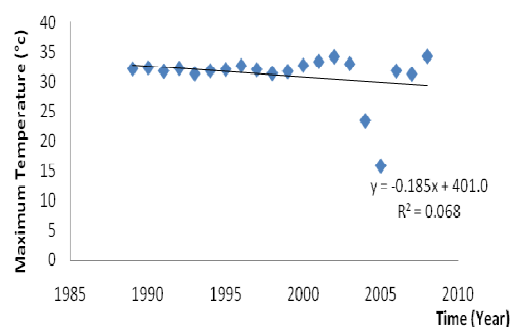
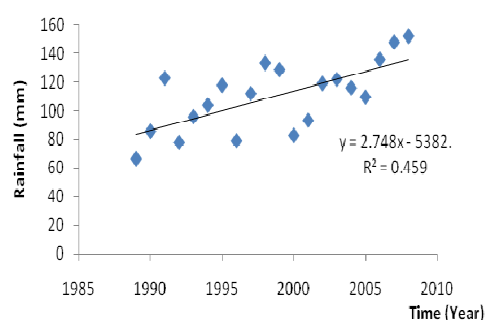
Table 9 Percentage Reduction of the variables

Periods	% change Rainfall	% change Max. Temp.	% change Min. Temp.	% change R. Humidity	% change evaporation	% change Asa discharge	% change Oyun discharge
1989-1993	-19%	3%	0%	3%	50%	-10%	0%
1994-1998	-0.90%	3%	5%	1%	25%	38%	-50%
1999-2003	-0.90%	6%	5%	13%	0%	-10%	-50%
2004-2008	20%	-13%	-10%	-13%	-25%	-24%	0%

Variation (Trend) Of Variables With Time

In order to show the variations in the hydrometeorological variables, relative to time, variation analysis was carried out on all the variables. The analysis was done using Microsoft

Excel. The annual average value of each variable was plotted against time (year) and the trend line of each plot is shown on the figures. Also, the equation of each variable plot is shown on the figures. The results of the variation analysis are presented in Figures 3.8-3.14.



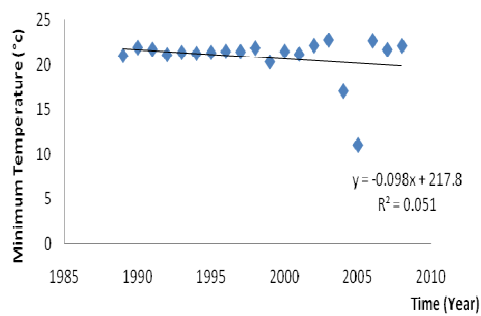


Figure 3.10 Variation of Min. Temp. with Time (1989-2008)

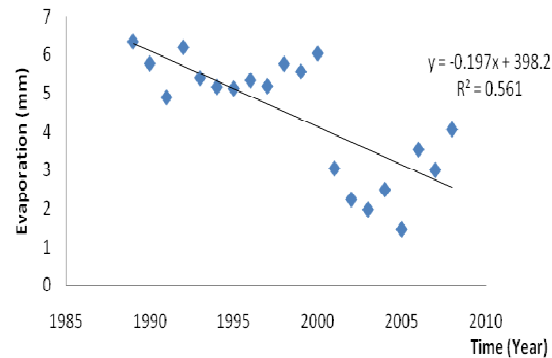


Figure 3.11 Variation of Evaporation with Time (1989-2008)

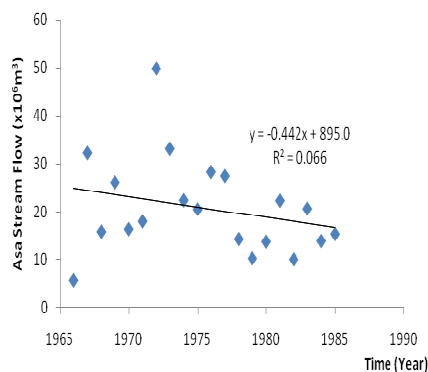


Figure 3.13 Variation of Asa streamflow with Time (1966-1985)

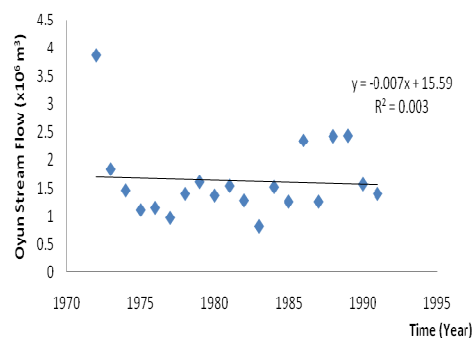


Figure 3.14 Variation of Ogun streamflow with Time (1972-1991)

Results and Discussion

Results

Statistics

The hydrometeorological data were evaluated by various statistical tests for the purpose of summarising the data. The statistical parameters include: Minimum, Maximum, Mean, Median, Standard deviation and Skewness. The results of the statistical tests have been presented in Tables 1-6.

Mann-Kendall

For the purpose of determining the significance of trend, Mann-Kendall analysis was adopted and the result of the analysis has been presented in Table 7.

Regression

Regression analysis was also carried out on the data in order to detect the trend, using MINITAB software to carry out Ryan-Joiner test, autocorrelation test and also for the probability plot of the parameters. The result of the regression analysis has been presented in the Table after the

explanation of the regression method. The results are presented in Table 8

Reduction Pattern

Reduction analysis was carried out in order to study the deviation of the data for five year periods from the overall mean of the whole data. This analysis was done on all the parameters and the results are as shown in Tables 9. Also, reduction pattern analysis was done on the complete data for each variable to show the fluctuation of the variables with time. The results are presented in Figures 3.1-3.7.

Variation (Trend)

In order to show the variations of the hydrometeorological variables, the variables were plotted against year. The variations are as shown in Figures 3.8-3.14.

Discussion of Results

Statistics

Rainfall of Ilorin, for the 20 year period has a minimum value of 0.00mm and a maximum value of 394.10mm. Also, it has a mean value of

100.73mm over the 20 year period. From the analysis, it was observed that rainfall is usually at its peak between May and September, and rainfall is at its minimum between December and February. For the maximum temperature of Ilorin from 1989-2008, the maximum value is 38.74°C, the minimum value is 15.88°C, and the mean value is 27.55°C. It was also observed that the maximum temperature is highest between February and April, which can be referred to as the peak of dry season. The minimum temperature has a minimum value of 11.11°C, a maximum value of 26.42°C, and a mean value of 20.89°C. It was observed from the analysis that the minimum temperature has two peak months; March and August. Also, it was observed that the minimum value from January-July is 11.11°C while the minimum value ranged between 16°C and 18.3°C from August-December. Evaporation of Ilorin for the 20 year period under consideration has a minimum value of 1.46mm, a maximum value of 13.800mm, and a mean of 4.89mm. It was observed that the evaporation value for January-March is very high compared to the evaporation value for April-December. Asa streamflow has a monthly maximum value of $147.20 \times 10^6 \text{ m}^3$, a monthly minimum value of $5.64 \times 10^6 \text{ m}^3$, and a monthly mean value of $19.13 \times 10^6 \text{ m}^3$. The peak streamflow occurs in August, which corresponds to one of the months with maximum rainfall. The minimum flow occurs in April. Oyun streamflow has a monthly maximum value of $9.27 \times 10^6 \text{ m}^3$ in September, a monthly minimum value of $0.001 \times 10^6 \text{ m}^3$ in January, and a monthly mean value of $1.63 \times 10^6 \text{ m}^3$.

Mann-Kendall

The Rainfall for Ilorin has a test statistic Z_S value of 3.082, which is greater than 1.96 (test statistic for a significance level of 5% i.e. $Z_{0.025}$). This result shows that a statistically significant positive trend is demonstrated for Rainfall i.e. rainfall for Ilorin has been increasing over time and the trend is likely to continue. The Maximum Temperature has a test statistic Z_S value of 0.097, which is less than 1.96 (test statistic for a significance level of 5% i.e. $Z_{0.025}$), meaning that a statistically significant positive trend is not demonstrated for Max. Temperature, this means that the increase in max. temperature of Ilorin is not significant. The Minimum Temperature for Ilorin has a test statistic Z_S value of 1.038, which is less than 1.96 (test statistic for a significance level of 5% i.e. $Z_{0.025}$). This shows that a statistically

significant positive trend is not demonstrated for Min. Temperature i.e. increase in min. temperature of Ilorin is not significant. The Evaporation variable for Ilorin has a test statistic Z_S value of -2.888, which is less than 1.96 (test statistic for a significance level of 5% i.e. $Z_{0.025}$). This result indicates that a statistically significant positive trend is not demonstrated for Evaporation. In other words, the evaporation rate in Ilorin will decrease with time. The streamflow of Asa has a test statistic Z_S value of -1.265, which is less than 1.96 (test statistic for a significance level of 5% i.e. $Z_{0.025}$). This result indicates that a statistically significant positive trend is not demonstrated for Asa streamflow, this means that the streamflow of Asa river will have no significant change over time. The streamflow of Oyun has a test statistic Z_S value of 0.292, which is less than 1.96 (test statistic for a significance level of 5% i.e. $Z_{0.025}$). This shows that a statistically significant positive trend is not demonstrated for Oyun streamflow i.e. there will be significant increase in the streamflow of Oyun with time.

Regression

The Ryan-Joiner method of regression test showed that the data series for rainfall is normal. Also, it has a positive trend line and an R^2 value of 0.459, which indicates that there is an average linear relationship between Rainfall and Year. Also, from the regression equation- $Y = 1.18R - 2260$, it is observed that there is a positive correlation between time (year) and rainfall for Ilorin. This indicates that there will be increment in rainfall relative to time as observed earlier in the result of the Mann-Kendall analysis. Maximum Temperature has a R^2 value of 0.068, indicating a very weak relationship between maximum temperature and time. The regression equation of max. temperature- $Y = -0.063T_{\text{Max}} + 152$ shows that there is a negative correlation between max. temperature of Ilorin and time(year), meaning that the max. temperature of Ilorin will reduce in relation to time, but at a very low rate.

Minimum Temperature has a R^2 value of 0.051, indicating a very weak linear relationship between Min. Temperature and Year. As observed in the Mann-Kendall analysis, the regression equation of min. temperature- $Y = -0.145T_{\text{Min}} + 309$ shows that the min. temperature will continue to reduce over time, at a low rate. Evaporation has a R^2 value of 0.561, meaning that there is an average linear relationship between Evaporation and Year, but the trend line is negative. Also, from the regression equation of Evaporation- $Y = -0.203E + 410$, it was

observed that there is a negative correlation between evaporation and time (year) i.e. there will be continuous decline in evaporation in Ilorin. Asa streamflow has a R^2 value of 0.066, meaning that there is a very weak linear relationship between Asa streamflow and Year, and the trend line is negative. From the regression equation of Asa streamflow- $Y = -0.166X + 336$, it was observed that there is a negative correlation between Asa streamflow and time i.e. the streamflow of Asa will decrease relative to time. Oyun streamflow has a R^2 value of 0.003, indicating a very weak linear relationship between Oyun streamflow and Year. The regression equation for Oyun streamflow- $Y = 0.003X - 5.1$ shows that there will be a decline in Oyun streamflow over time but the rate of streamflow reduction will be low.

Reduction Pattern

From the rainfall record of 1989-2008 at Ilorin, the average rainfall was 110mm. From 1989-1993, rainfall reduced to 89mm, showing a negative change tendency with a percentage difference of 19%. From 1994-1998, rainfall rose to 109mm and the situation continued from 1999-2003. From 2004-2008, rainfall at Ilorin rose sharply to 132mm, with a percentage difference of 20%. This result shows that rainfall will continue to increase with time. The average of the maximum temperature record was 31°C. From 1989 to 1993, the maximum temperature rose to 32°C, showing a positive change tendency with a percentage difference of 3%. The value stood at 32°C from 1994 to 1998 and it further increased to 33°C from 1999 to 2003, with a percentage difference of 6%. However, it reduced to 27°C from 2004 to 2008, with a percentage difference of 13%. From the result, it was observed that the reduction in maximum temperature is greater than the increment i.e. maximum temperature will reduce considerably over a long period of time. For minimum temperature, the average was 21°C. From 1989 to 1993, the minimum temperature remained constant, with a 0% change. From 1994 to 1998, it rose to 22°C, showing a positive change tendency, with a percentage difference of 5%. The situation continued from 1999 to 2003, with the minimum temperature standing at 22°C. From 2004 to 2008, the minimum temperature reduced to 19°C, showing a negative change tendency with 10% difference. This means that the minimum temperature will reduce with time but the rate of reduction might be low. For the evaporation record, the average was 4mm. From 1989 to 1993, the value increased to 6mm, with a positive percentage difference of 50%. A positive

percentage difference of 25% was also observed from 1994 to 1998. The minimum temperature stood at 4mm between year 1999 and 2003, but later reduced to 3mm from 2004 to 2008, with a negative change of 25%. Based on this observation, evaporation can be said to be increasing. For the streamflow of Asa river, the average was $21 \times 10^6 \text{ m}^3$. Between 1989 and 1993, the streamflow declined and reduced to $19 \times 10^6 \text{ m}^3$, with a percentage difference of 10%. However, from 1994 to 1998, the value increased to $29 \times 10^6 \text{ m}^3$, having a 38% difference. From 1999 to 2003, the streamflow declined again and reduced to $19 \times 10^6 \text{ m}^3$. This situation continued from 2004 to 2008 when it further reduced to $16 \times 10^6 \text{ m}^3$, with a percentage difference of 24%. Based on the observation, the streamflow of Asa river will decrease with time. For the streamflow record of Oyun river, the average was $2 \times 10^6 \text{ m}^3$. From 1989 to 1993, the value stood at $2 \times 10^6 \text{ m}^3$, with a zero percentage difference. A negative percentage difference of 50% was also observed from 1994 to 1998 when the streamflow value reduced to $1 \times 10^6 \text{ m}^3$. The situation continued from 1999 to 2003, with the value remaining at $1 \times 10^6 \text{ m}^3$. However, it showed positive change tendency from 2004 to 2008, when the streamflow rose to $2 \times 10^6 \text{ m}^3$. This shows that the streamflow of Oyun river will likely reduce over a long period of time if the declining trend continues.

Variation (Trend)

With a plot of the rainfall values against time, a graph with a positive trend line was obtained, showing that rainfall increased with time. The graph obtained from the plot of maximum temperature against time and minimum temperature against time has a negative trend line, with a very gentle slope i.e. max. temperature, min. temperature, and relative humidity has changed over time but at a very low rate. Also, the plot of evaporation against time produced a graph with a negative trend line, showing that evaporation in Ilorin has reduced with time. The plot of Asa and Oyun streamflows also produced negative trend lines but the slope of the trend line of Oyun is more gentle than that of Asa. This shows that the two streamflows have reduced relative to time but the streamflow of Oyun has reduced at a lower rate than that of Asa.

Relationship between variables

From the regression analysis (multiple regression) of Oyun streamflow with rainfall and

evaporation, it was observed that there is a negative relationship between Oyun streamflow and rainfall/evaporation. The regression of Oyun streamflow with mean temperature also showed a negative relationship. This means that Oyun streamflow will reduce as rainfall, evaporation and mean temperature increase. From the regression analysis of rainfall with evaporation, the result showed that there is a negative correlation between

Conclusions and Recommendations

Conclusions

From the analysis of the meteorological and hydrological data of Ilorin using five methods of analysis, it was observed that rainfall showed a positive trend to a significant extent. Also, it was observed that the month in which the peak rainfall occurred in each of the years changed over time; this can be attributed to the change in climatic conditions. From the result of the Mann-Kendall analysis, this trend (increase in rainfall) will likely continue in future i.e. rainfall will continue to increase with time.

Also from the analysis, it was observed that the streamflow of the two rivers has reduced over time. The result of most of the analysis method adopted also revealed that the decrease in the streamflow of the two rivers is not likely to persist. All the other variables (maximum temperature, minimum temperature, evaporation, relative humidity) also showed negative trend over time. This shows that the variables will reduce in relation to time. This reduction trend is due to the change in climate.

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rainfall and evaporation i.e. evaporation will reduce with an increase in rainfall. The result of the regression between rainfall and relative humidity shows a positive relationship between the two variables, meaning that relative humidity will increase with an increase in rainfall. Also, the result of the regression between rainfall and mean temperature shows that there is a positive relationship between rainfall and mean temperature.

Based on all the observations made from the results of the analysis (most especially the increase in rainfall, and the reduction in temperature, evaporation and relative humidity), climate change can be said to have had a positive impact on the surface water resources of Ilorin.

Recommendations

Based on the outcome of the study, the following recommendations were made:

- i. The measuring facilities at the meteorological centers need proper maintenance and improvement to ensure reliable data and also to avoid missing data. For example, the record obtained for sunshine hours had some missing data, and that is the reason why it was not used in this study.
- ii. Further work can be done on this study. Prediction of future data could be included so as to study the impact in the future.

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