

Impacts of climate change on the water resources of Jebba hydropower reservoir

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Abstract

This paper presents the impacts of climate change on the water resources of Jebba Hydropower Reservoir. The Hydro-meteorological variables were obtained from Jebba Hydropower station and subjected to statistical, trend, and reduction pattern analyses. The statistical analysis was carried out to determine the measures of central tendencies, measures of dispersion and skewness. The regression and Mann-Kendall analysis were carried out to determine the nature of the trend and their significant level. The Reduction pattern analysis was used to study the fluctuation of each variable over the period of records. The reservoir inflow, outflow and temperature have shown significant positive trends, which indicates that the parameters has tendency to increase. Rainfall, evaporation and relative humidity were observed to have exhibited insignificant negative trends. This implies that there is tendency for the variables to reduce slightly over time. The tendency for slight reduction in evaporation could be as a result of vegetation cover around the reservoir.

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

1.0 Introduction

The climate of a place normally is concerned with the weather conditions of the place, over a long period of time. Since weather depends on numerous factors which vary with time, it is right to talk of a climate change. There has been a lot of work on the subject in advanced countries but this is not true of the developing nations. However a climate change is bound to have some effects on the social and technological standards of living in the countries where it occurs. The developing nations of Africa, Asia and South America are bound to be seriously affected, in the event of climate change, and so ought to be interested in the subject (Madueme, 1999). The IPCC described Africa as “one of the most vulnerable continents to climate change and climate variability”, and within Africa, Nigeria is one of the countries expected to be worst affected (ERM, 2009).

McBean and Motiee (2008) assessed the impacts of climate change on the water resources of North America. Seventy years of historical trends in precipitation, temperature, and streamflows in the Great Lakes of North America were developed using long term regression analyses and Mann-Kendall statistics. MINITAB and Microsoft Excel were used to calculate the trend lines, statistical values and plot the figures. The result they obtained demonstrated statistically significant increases in some precipitation and stream flows over the period 1930-2000.

Kavvas et al. (2006) assessed the impacts of climate change on the hydrology and water resources

of peninsular Malaysia. Climate change simulations of CGCM1 (Coupled General Circulation Model of the Canadian Center for Climate Modeling and Analysis) were downscaled by a Regional Hydroclimate Model of Peninsular Malaysia (RegHCM-PM) to the scale of the sub regions and watersheds of Peninsular Malaysia in order to assess the impact of future climate change on the hydrologic conditions of Peninsular Malaysia: Klang, Selangor, Terengganu, Kelantan, Pahang, Perak, Kedah, Johor. The assessment of the impact of climate change over Peninsular Malaysia was performed by the comparison of historical simulations of precipitation, evapotranspiration, and river flow by the CGCM1/RegHCM-PM combined models during the 1984–1993 period against their future counterparts, simulated by the same models during the 2041 – 2050 ten-year future period. Their results indicated that there is significant increase there is significant increase in the overall mean monthly streamflow during the 2041-2050 future period. However, it is also clear that the high flow conditions will be magnified in Kelantan, Terengganu, and Pahang River watersheds, while low monthly flows will be significantly lower in Selangor and Johor watersheds.

Changes in climate resulting from increasing atmospheric concentrations of greenhouse gases could have significant effects on water resources of Jebba Hydropower Reservoir. The quantity and quality of water are likely to be directly affected by climate change. Available water supplies also are likely to be affected by changes in demand from multiple sectors competing for water resources. Changes in the hydrological cycle will cause changes in ecosystems

which, in turn, affect human health (e.g., by altering the geographic distribution of infectious diseases) biological productivity and diversity.

Hence, it is of great theoretical and practical significance to study the impacts of climate change on water resources. Furthermore, adaptation will take time, and planning and adaptation needs to begin well before (and in many instances several decades before) the impacts are expected to occur.

2.0 Study Area

Jebba hydropower dam

The Station is located in Niger State along the River Niger and is the second Hydro Power Station in

Nigeria after Kainji Dam. It is formed by the Jebba dam which was built between 1981 and 1983 and which commenced operation in 1984. The reservoir is located on latitude 9° 08' N and longitude 4° 49' E. It is close to the famous Juju rock about 3 km upstream of the community of Jebba north in Niger State. The reservoir has a surface area of 270 km² and about 100 km long, with a width varying from 2 to 5 km. It is capable of storing 3.88×10^9 m³ of water at elevation of 103 m above sea level, with a live storage of 1.0×10^9 m³. The major source of reservoir water inflow is from the discharge from Kainji reservoir since it is located directly (about 100 km) downstream of Kainji dam. The impoundment of the dam in 1983 was reported to have led to physical displacement of 6,111 people comprising farmers and fishermen (Oyedipe, 1980). Fig 1 is a map showing location of Jebba Dam.

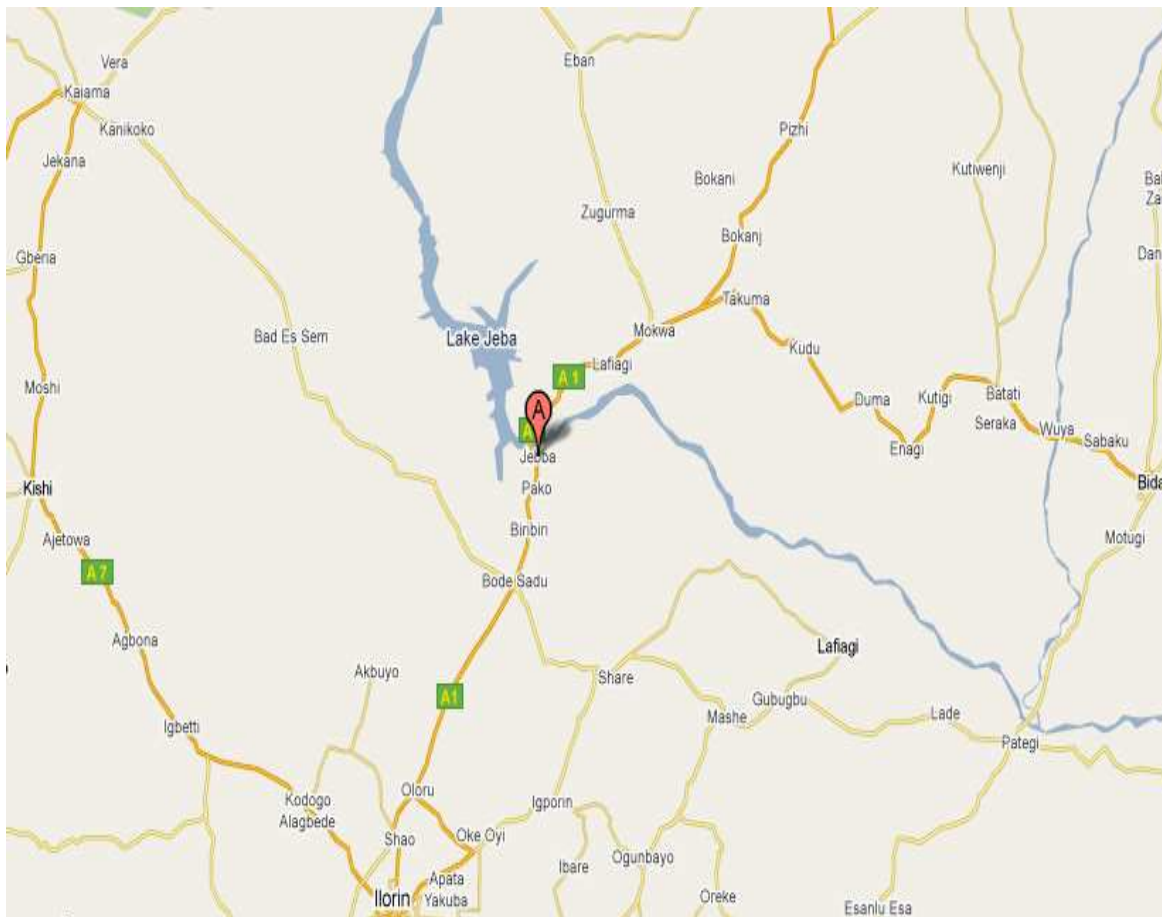


Fig.1 Map showing Jebba

3.0 Materials And Methods

3.1 Collection of data

The meteorological data, the stream flow, the turbine discharge were obtained from the Jebba Hydropower Station. All the data obtained and their corresponding years of record are shown in Table 1.

Table 1 Data and years of record

Variable	Period
Rainfall (mm)	1984-2009
Maximum Temperature (°C)	1987-2008
Minimum Temperature (°C)	1982-2008
Relative Humidity (%)	1982-2007
Reservoir Inflow (m ³ /s)	1984-2008
Reservoir Evaporation Loss (m ³ /s)	1987-2009
Turbine Discharge (m ³ /s)	1984-2008

3.2 Analysis of Data

All the parameters were subjected to: statistical analyses, Mann-Kendall, Regression and Reduction analysis procedures.

3.2.1 Statistical analysis

This involves the determination of measures of central tendencies (mean, median, range) and the measures of dispersion (standard deviation). The various parameters are enumerated below.

Arithmetic mean: the arithmetic mean is the sum of all observations divided by the number of observations n :

$$\bar{X} = \frac{\sum x}{n} \quad (1)$$

Mode

In statistics, the mode is the value that occurs the most frequently in a data set or a probability distribution. Like the statistical mean and the median, the mode is a way of capturing important information about a random variable or a population in a single quantity. The mode is in general different from the

mean and median, and may be very different for strongly skewed distributions.

Median: when you have n observations, and these are sorted from smaller to larger, then the median is equal to the value with order number $(n+1)/2$. The median is equal to the 50th percentile. If the distribution of the data is Normal, then the median is equal to the arithmetic mean. The median is not sensitive to extreme values or outliers, and therefore it may be a better measure of central tendency than the arithmetic mean.

Variance: the variance is the mean of the square of the differences of all values with the arithmetic mean. The variance (σ^2) is calculated using the formula:

$$\sigma^2 = \frac{\sum (x - \bar{x})^2}{n-1} \quad (2)$$

Standard deviation: the standard deviation (σ) is the square root of the variance, and is a measure of the spread of the data:

$$\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{n-1}} \quad (3)$$

Coefficient of variation

In probability theory and statistics, the coefficient of variation (CV) is a normalized measure of dispersion of a probability distribution. It is defined as the ratio of the standard deviation to the mean.

$$CV = \frac{\sigma}{\bar{x}} \quad (4)$$

Skewness

The coefficient of Skewness is a measure for the degree of symmetry in the variable distribution.

Negatively skewed distribution or Skewed to the left Skewness < 0; Normal distribution Symmetrical Skewness = 0; Positively skewed distribution or Skewed to the right Skewness > 0

The results of the statistical analysis are presented in Tables 2-8 for Rainfall, Max temperature, Min temperature, Relative Humidity, Reservoir inflow, evaporation and turbine discharge

Table 2 Statistical summary for Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	0.05	1.42	10.91	71.44	142.49	198.33	168.70	195.11	212.98	87.92	0.39	0.13

Median	0.00	0.00	1.60	68.50	136.85	189.40	161.35	197.23	215.95	73.78	0.00	0.00
Std	0.27	4.83	15.70	44.72	64.13	76.15	59.19	77.82	59.87	54.94	1.44	0.67
Min	0.00	0.00	0.00	5.50	31.30	73.00	81.80	36.70	117.20	14.40	0.00	0.00
Max	1.40	24.00	49.40	157.10	266.30	366.40	267.00	350.90	335.00	271.00	6.60	3.40
Range	1.40	24.00	49.40	151.60	235.00	293.40	185.20	314.20	217.80	256.60	6.60	3.40
Skew	5.10	4.44	1.22	0.18	0.25	0.62	0.12	0.24	0.32	1.60	3.89	5.10

Table 3 Statistical summary for Maximum Temperature (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	34.46	37.24	38.72	37.59	35.06	32.83	31.40	30.14	32.10	33.34	35.06	34.47
Median	34.65	37.00	39.00	38.00	35.00	33.00	31.00	31.00	32.00	33.00	35.00	34.00
Std	1.27	1.08	0.89	1.10	1.32	0.79	0.56	5.90	1.14	0.77	0.79	1.05
Min	32.80	35.00	37.00	36.00	33.00	31.00	30.30	4.00	30.00	32.00	34.00	33.00
Max	37.00	39.00	40.00	39.40	38.30	35.00	32.30	33.00	34.00	35.00	37.00	37.00
Range	4.20	4.00	3.00	3.40	5.30	4.00	2.00	29.00	4.00	3.00	3.00	4.00
Skew	0.22	-0.40	-0.28	-0.07	1.12	0.36	0.11	-4.53	0.44	0.58	0.49	0.62

Table 4 Statistical summary for Minimum Tempertaure (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	21.43	24.03	26.20	26.09	24.84	23.54	23.42	23.30	22.93	23.55	22.57	20.44
Median	21.45	24.00	26.00	26.00	25.00	23.20	23.00	23.00	23.00	23.30	22.50	20.00
Std	1.54	1.81	1.33	1.20	0.96	0.89	0.82	0.86	0.97	0.83	0.94	1.39
Min	18.40	21.00	23.30	23.00	23.50	22.00	21.90	21.80	21.00	22.00	21.00	19.00
Max	26.00	29.00	29.00	29.00	27.00	26.00	25.00	25.00	25.00	25.00	25.00	24.00
Range	7.60	8.00	5.70	6.00	3.50	4.00	3.10	3.20	4.00	3.00	4.00	5.00
Skew	0.94	0.70	-0.23	0.02	0.73	0.80	0.49	0.49	0.66	0.38	0.41	1.26

Table 5 Statistical summary for Relative Humidity (%)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	52.52	54.80	62.58	69.27	74.62	79.77	81.50	82.35	82.23	79.04	74.31	70.19
Median	53.00	57.00	65.00	69.00	75.00	81.00	81.50	82.00	82.50	79.00	74.50	70.00

Std	12.88	11.43	8.64	6.17	5.26	3.29	3.06	3.92	3.02	3.41	5.32	2.99
Min	9.00	32.00	39.00	49.00	64.00	72.00	75.00	74.00	75.00	73.00	63.00	63.00
Max	71.00	76.00	74.00	80.00	85.00	85.00	86.00	89.00	89.00	86.00	83.00	75.00
Range	62.00	44.00	35.00	31.00	21.00	13.00	11.00	15.00	14.00	13.00	20.00	12.00
Skew	-1.62	-0.20	-1.25	-1.07	-0.17	-0.93	-0.24	-0.32	-0.02	0.35	-0.11	-0.45

Table 6 Statistical summary for Reservoir Inflow (m³/s)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	1064.0	988.20	903.00	913.80	823.5	834.6	757.72	1055.4	1637.0	1642.2	1002.	1065
Median	1031.0	1023.0	969.00	895.00	782.0	814.0	719.00	988.00	1403.0	1396.0	941.0	1053
Std	320.32	340.85	304.11	276.06	241.3	259.9	288.46	453.32	705.46	942.13	338.3	265.
Min	518.00	378.00	417.00	436.00	428.0	359.0	378.00	445.00	750.00	666.00	516.	610.
Max	1575.0	1637.0	1422.0	1566.0	1282.	1332.	1567.0	2379.0	3182.0	3636.0	1688.	1565
Range	1057.00	1259.00	1005.00	1130.00	854.00	973.00	1189.00	1934.00	2432.00	2970.00	1172.	955.
Skew	0.15	0.09	0.06	0.30	0.19	0.02	1.17	0.92	0.79	1.08	0.55	0.11

Table 7 Statistical summary for Reservoir Evaporation Loss (m³/s)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	19.27	25.13	27.35	25.00	19.52	15.57	13.22	12.57	13.65	16.30	17.83	17.52
Median	19.00	25.00	27.00	25.00	19.00	15.00	13.00	13.00	14.00	16.00	18.00	18.00
Std	1.70	1.29	1.64	2.00	2.74	1.38	1.13	1.31	1.23	1.15	1.19	1.08
Min	16.00	23.00	25.00	20.00	16.00	13.00	12.00	10.00	10.00	14.00	16.00	16.00
Max	22.00	29.00	30.00	28.00	28.00	18.00	16.00	15.00	15.00	18.00	20.00	19.00
Range	6.00	6.00	5.00	8.00	12.00	5.00	4.00	5.00	5.00	4.00	4.00	3.00
Skew	-0.28	1.27	0.19	-0.78	1.49	0.31	0.58	-0.42	-1.51	-0.07	0.19	-0.06

Table 8 Statistical summary for Turbine Discharge (m³/s)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	1085.5	1006.7	908.56	908.56	845.5	811.2	762.12	992.00	1308.9	1306.3	1024.2	1014.5
Median	1054.5	1011.0	938.0	930.0	799.0	831.0	703.0	897.0	1252.0	1304.0	952.0	953.0
Std	312.99	352.73	291.49	310.04	230.2	246.1	292.85	414.58	395.70	440.37	336.29	278.64
Min	585.00	376.00	425.00	232.00	451.0	362.0	328.00	366.00	633.00	685.00	479.00	514.00

Max	1575.0	1643.0	1442.0	1672.0	1383.	1340.	1556.0	1927.0	2079.0	2143.0	1655.0	1606.0
Range	990.00	1267.00	1017.00	1440.00	932.00	978.00	1228.00	1561.00	1446.00	1458.00	1176.00	1092.00
Skew	0.08	0.04	0.06	0.12	0.40	0.10	0.95	0.37	0.12	0.35	0.31	0.22

3.2.2 Mann-Kendall Statistics

More recent studies indicate that the most widely used method is the non-parametric Mann-Kendall trend test. Mann (1945) originally derived the test and Kendall (1975) subsequently derived the test statistic commonly known as the Kendall's tau statistic. It was found to be an excellent tool for trend detection in different applications Paulin and Xiaogang (2005).

Mann-Kendall analysis theory is presented as follows:

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:

$$\sigma^2 = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^g (t_p - 1)(2t_p + 5)] \quad (7)$$

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of data points in the p^{th} group.

In the sequence {2, 3, non-detect, 3, non-detect, 3}, we have $n=6$, $g=2$, $t=2$ for the non-detects, and $t=3$ for the tied value 3.

Compute a normalized test statistic Z_s as follows:

$$Z_s = \begin{cases} (S - 1)/\sigma & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ (S + 1)/\sigma & \text{for } S < 0 \end{cases} \quad (8)$$

The test statistic, Z_s is used as a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H_0 : There is no monotonic trend in the data. If $|Z_s|$ is greater than $Z_{\alpha/2}$, where α

$$\text{sign}(T) = \begin{cases} 1 & \text{for } T_j > T_i \\ 0 & \text{for } T_j = T_i \\ -1 & \text{for } T_j < T_i \end{cases} \quad (5)$$

The Mann-Kendall statistic (S) is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(T_j - T_i) \quad (6)$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n , to statistically quantify the significance of the trend. (Prashanth, 2005)

Calculate the variance of S , σ by the following equation:

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. Being significant implies the trend has a causative factor and did not occur by chance.

Autocorrelation, or as sometimes called "serial correlation", refers to the correlation of a time series with its own past and future values separated by "k" lag time units. MINITAB software is used for calculation of the autocorrelation function coefficient (AFC) between the series with a lag one autocorrelation coefficient (k). McBean and Motiee (2008) indicated that the existence of positive autocorrelation in the data increases the probability of detecting statistically significant trends when actually none exist, and vice versa. Equations (5) to (8) were adopted for analysis, the results of the Mann-Kendall analysis for all the variables taken into account are summarized in the table below.

Table 9 Mann-Kendall Statistics Results

Variable	Autocorrelation coefficient	Kendall's S	Z _s	Nature of trend	Statistically Significant
Rainfall	0.0386	-33	0.7053	Negative	No
Max.Temp	0.2417	81	2.1168	Positive	Yes
Min. Temp	0.7186	149	3.0872	Positive	Yes
Rel.Hum	0.3982	-93	2.0278	Negative	Yes
Inflow	0.4942	164	3.8069	Positive	Yes
Eva. Loss	0.3262	-5	0.1058	Negative	No
Turbine discharge	0.5823	198	4.6009	Positive	Yes

3.2.3 Regression Statistics

The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship McBean and Motiee (2008). Normality implies that the population from which the sample is drawn is normal. Many statistical procedures rely on population normality. The null hypothesis for a normality test states that the population is normal. The alternative hypothesis states that the population is not normal.

The normality of the data is done by a special test for normality by using the Ryan-Joiner method McBean and Motiee (2008). The test of Ryan-Joiner can be carried out by MINITAB software by calculation of the Ryan-Joiner (RJ) coefficient.

The regression equation is obtained as:

$$Y = aX + b \quad (9)$$

Where, X =time (year), a =slope coefficient, b = leastsquare estimates of the intercept.

a and b are obtained from the following equations

$$a = \frac{n \sum(xy) - \sum x \sum y}{n \sum(x^2) - (\sum x)^2} \quad (10)$$

$$b = \frac{\sum y - a \sum x}{n} \quad (11)$$

P-value is the probability which determines the appropriateness of rejecting the null hypothesis in a

hypothesis test. P-values range from 0 to 1. The commonly used significance level is $\alpha = 0.05$. If the P-value is less than the α , the null hypothesis is rejected. In this case, the null hypothesis is that there is no trend in the data. Hence, a P-value less than 0.05 shows that the trend is significant. So the smaller the P, the more significant the trend (McBean and Motiee (2008).

The sample correlation, r , is obtained from the equation:

$$r = \frac{n \sum(xy) - \sum x \sum y}{\sqrt{[n \sum(x^2) - (\sum x)^2][n \sum(y^2) - (\sum y)^2]}} \quad (12)$$

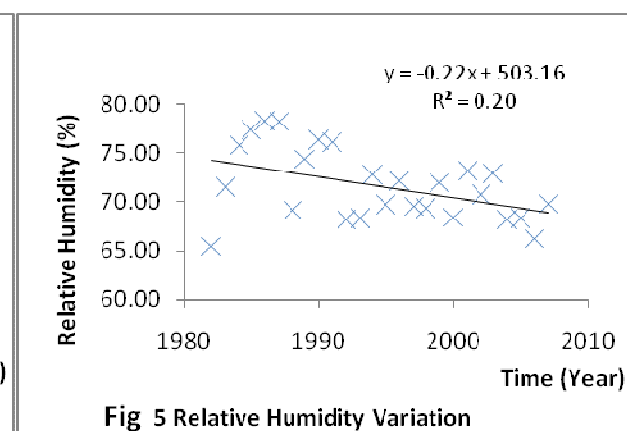
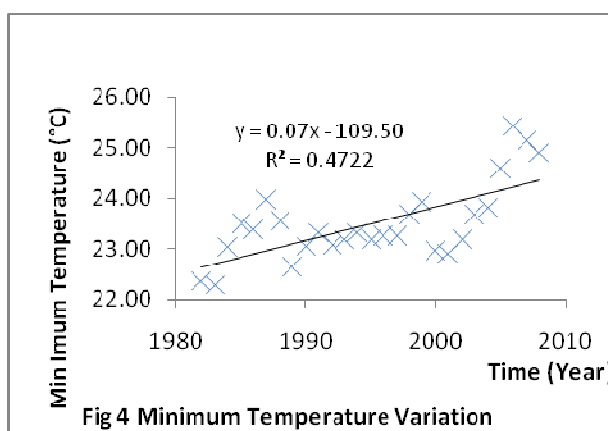
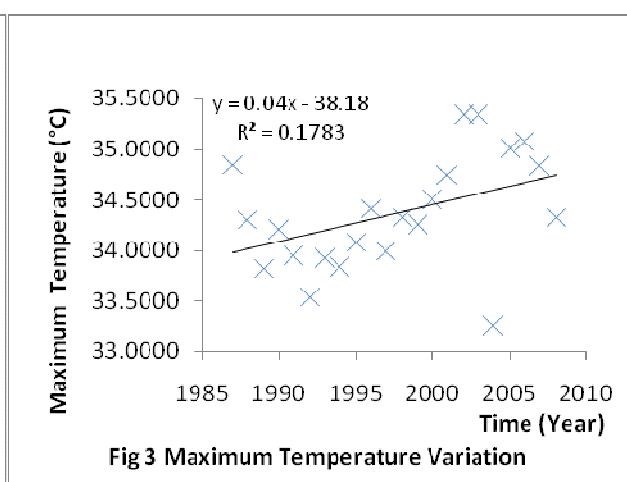
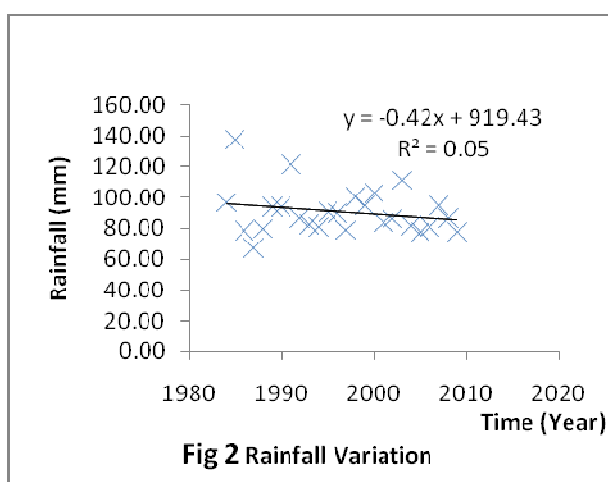
r ranges from -1 to 1. It measures the strength of the linear relationship between Y and X . A correlation value close to 0 indicates no association between the variables.

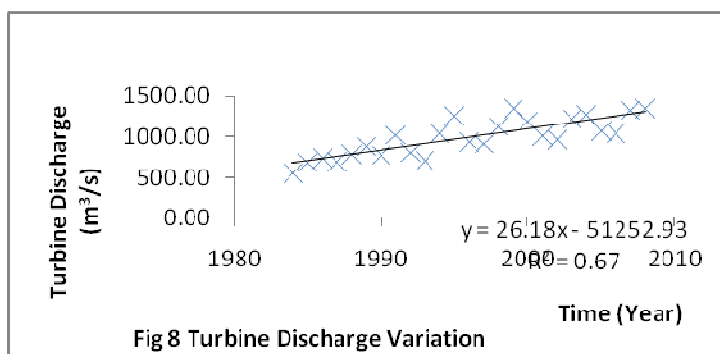
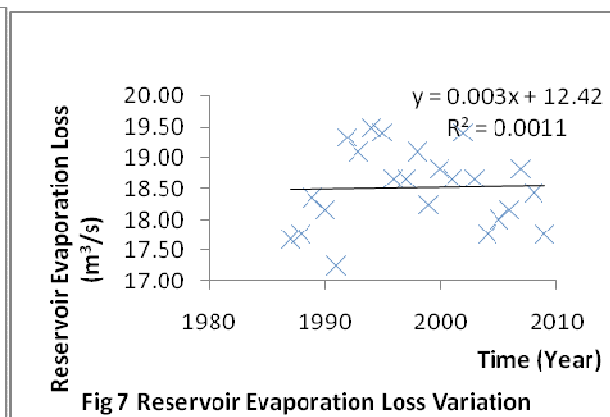
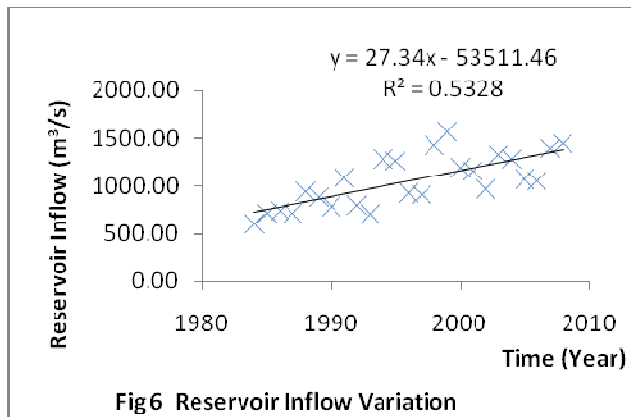
R-square (R^2), or the square of the correlation coefficient, is a fraction between 0.0 and 1.0.

A R^2 value of 0.0 means that there is not any correlation between X and Y and no linear relationship between X and Y. On the other hand, when R^2 approaches to 1.0, the correlation becomes strong and with a value of 1.0 all points lie on a straight line. The procedure was adopted for the analysis, the results of the regression analysis for all the variables are presented in the Table10 and the variation with time are presented in Figures 2-8.

Table 10 Regression Statistics Results

Variable	Regression Equation	Statistical Significance (P value)	Statistically significant	Sample Correlation	R-Square
Rainfall	$Y = 919.43 - 0.42X$	0.30	NO	-0.22	4.50%
Max.Temp	$Y = -38.18 + 0.04X$	0.05	YES	0.42	17.80%
Min. Temp	$Y = -109.50 + 0.07X$	0.00	YES	0.69	47.20%
Rel.Hum	$Y = 503.16 - 0.22X$	0.02	YES	-0.45	20.30%
Inflow	$Y = -53511.46 + 27.34X$	0.00	YES	0.73	53.30%
Eva. Loss	$Y = 12.42 + 0.0031X$	0.88	NO	0.03	0.10%
Turbine discharge	$Y = -51252.93 + 26.18X$	0.00	YES	0.82	67.20%





Reduction analysis

The average annual variable (X_m) for the years of record is obtained as in the equation below.

$$X_m = \frac{\sum_{i=1}^n X}{n} \quad (13)$$

where X = the average annual value for each year

n = number of years of record

The deviation, $(X - X_m)$ of each year's record from the average annual variable (X_m) is obtained. A graph of the deviation $(X - X_m)$ is

plotted against the years. The record years are divided into groups of appropriate class intervals say ten years. The average annual variable (X_i) for these numbers of years is calculated. The corresponding deviations from X_m for the groups are obtained and the corresponding percentage changes are obtained from equation (14). The nature of trend (whether positive or negative) is declared.

The percentage change is obtained from the equation

$$\frac{X - X_m}{X_m} \times 100\% \quad (14)$$

The results of the Reduction analysis for all the variables taken into account are presented in Tables 11 - 17 and Figures 9 – 15.

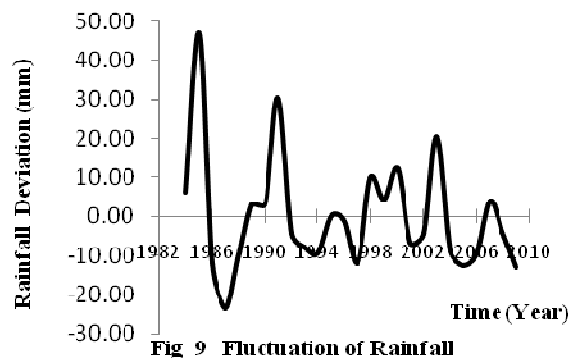


Fig. 9 Fluctuation of Rainfall

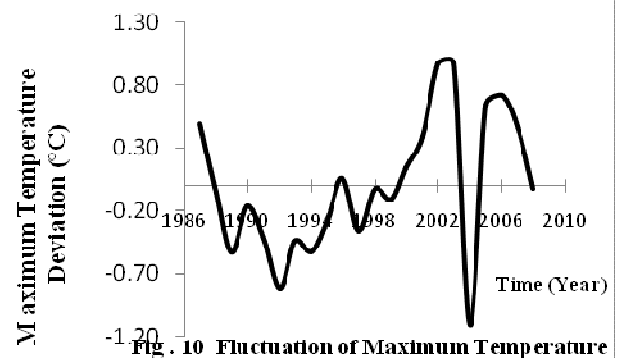


Fig. 10 Fluctuation of Maximum Temperature

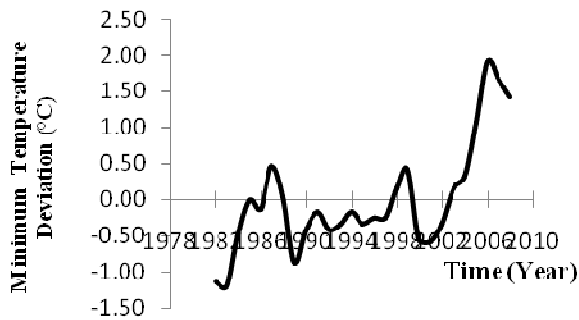


Fig. 11 Fluctuation of Minimum Temperature

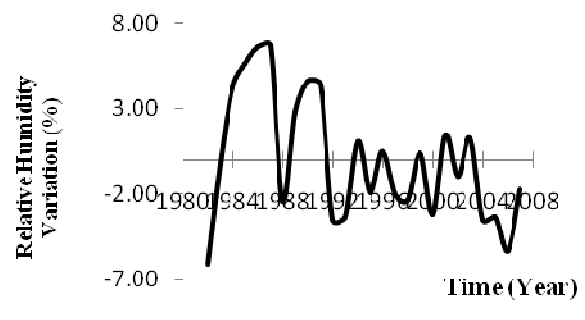


Fig. 12 Fluctuation of Relative Humidity

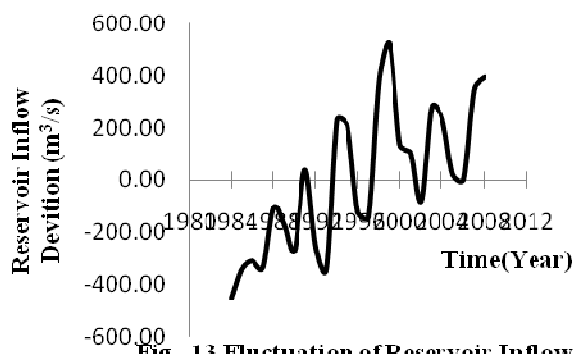


Fig. 13 Fluctuation of Reservoir Inflow

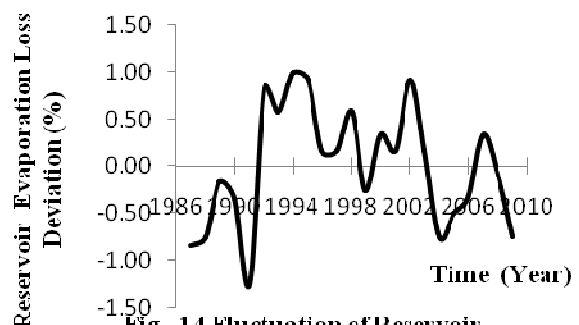


Fig. 14 Fluctuation of Reservoir Evaporation Loss

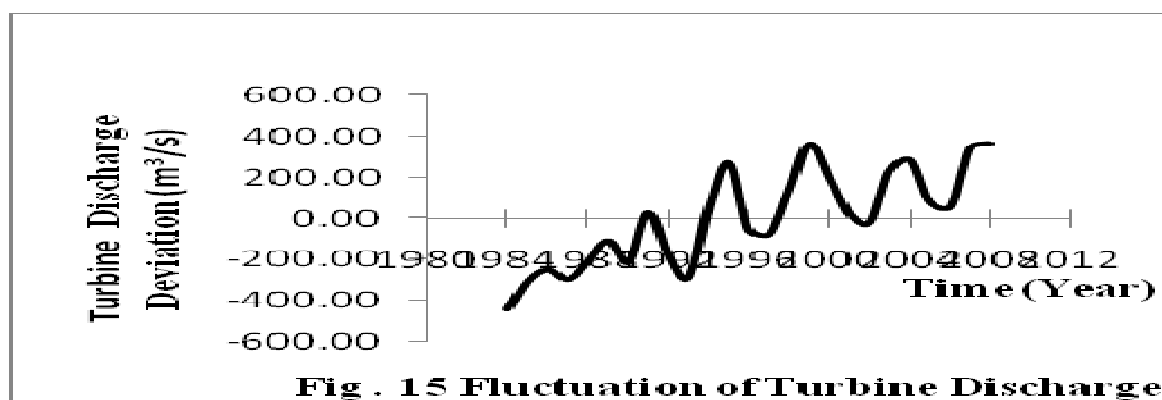


Table 11 Comparison of Rainfall

PERIOD	R_i	R_m	$R_i - R_m$	% change
1984-1992	95.15	91.34	3.81	4.17
1993-2000	90.33	91.34	-1.01	-1.11
2001-2008	88.07	91.34	-3.27	-3.58

Table 12 Comparison of Maximum Temperature

PERIOD	T_i	T_m	$T_i - T_m$	% change
1987-1994	34.05	34.36	-0.31	-0.90
1995-2001	34.33	34.36	-0.03	-0.08
2002-2008	34.74	34.36	0.38	1.10

Table 13 Comparison of Minimum Temperature

PERIOD	T_i	T_m	$T_i - T_m$	% change
1982-1995	23.13	23.50	-0.37	-1.57
1996-2008	23.90	23.50	0.40	1.70

Table 14 Comparison of Relative Humidity

PERIOD	R_i	R_m	$R_i - R_m$	% change
1982-1987	74.40	71.59	2.82	3.93

1988-1992	72.78	71.59	1.20	1.67
1993-1997	70.45	71.59	-1.14	-1.59
1998-2002	70.68	71.59	-0.90	-1.26
2003-2007	69.05	71.59	-2.54	-3.54

Table 15 Comparison of Reservoir Inflow

PERIOD	I_i	I_m	$I_i - I_m$	% change
1984-1992	811.95	1055.75	-243.80	-23.09
1993-2000	1166.13	1055.75	110.38	10.46
2001-2008	1219.65	1055.75	163.90	15.52

Table 16 Comparison of Reservoir Evaporation Loss

PERIOD	E_i	E_m	$E_i - E_m$	% change
1987-1998	18.58	18.51	0.07	0.37
1999-2009	18.43	18.51	-0.08	-0.41

Table 17 Comparison of Turbine Discharge

PERIOD	Q_i	Q_m	$Q - Q_m$	% change
1984-1992	774.82	994.24	-219.42	-22.07
1993-2000	1070.28	994.24	76.04	7.65
2001-2008	1165.06	994.24	170.81	17.18

The maximum and minimum rainfall values for the record years are 366.40mm and 0.00mm respectively. Range of values for standard deviation is 0.27-77.82mm. The maximum and minimum values for the maximum temperatures are 40.00°C and 4.00°C respectively. Range of values for standard deviation is

4.0 Discussion

4.1 Statistics

0.56-5.90°C. The maximum and minimum values for the Relative Humidity are 89.00% and 9.00% respectively. Range of values for standard deviation is 2.99-12.88%. The maximum and minimum values for the Reservoir Inflow are 3636.00m³/s and 359.00m³/s respectively. Range of values for standard deviation is 241.37-942.13 m³/s. The maximum and minimum values for the Reservoir Evaporation Loss are 30.00m³/s and 10.00m³/s respectively. Range of values for standard deviation is 1.08-2.74m³/s. The maximum and minimum values for the Turbine Discharge are 2143.00m³/s and 232.00m³/s respectively. Range of values for standard deviation is 230.29-440.37 m³/s.

4.2 Mann-Kendall

Rainfall: The value of S is negative which demonstrates an existence of a negative trend. The value of Z_s is 0.7053 (less than $Z_{0.025}$) which makes is statistically non-significant.

Maximum temperature: The value of S is positive which demonstrates an existence of a positive trend. The value of Z_s is greater than $Z_{0.025}$ which makes is statistically significant.

Relative humidity: The value of S is negative which demonstrates an existence of a negative trend. The value of Z_s is 2.0278 (greater than $Z_{0.025}$) which makes is statistically significant.

Minimum temperature: The value of S is positive which demonstrates an existence of a positive trend. The value of Z_s is 3.0872 (greater than $Z_{0.025}$) which makes is statistically significant.

Reservoir inflow: The value of S is positive which demonstrates an existence of a positive trend. The value of Z_s is 3.8069 (greater than $Z_{0.025}$) which makes is statistically significant

Reservoir evaporation loss: The value of S is negative which demonstrates an existence of a negative trend. The value of Z_s is 0.1058 (less than $Z_{0.025}$) which makes is statistically non-significant.

Turbine discharge: The value of S is positive which demonstrates an existence of a positive trend. The value of Z_s is 4.6009 (greater than $Z_{0.025}$) which makes is statistically significant.

4.3 Regression Analysis

Rainfall: Since the p-value for the slope is 0.296 (greater than 0.05), there is not a statistically significant relationship between rainfall and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 4.5% of the

variability in rainfall. The correlation coefficient of -0.22 indicates a very weak relationship between the variables.

Maximum temperature: Since the p-value for the slope is 0.05 (equals to 0.05), there is a statistically significant relationship between maximum temperature and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 17.8% of the variability in maximum temperature. The correlation coefficient of 0.42 indicates a slightly strong relationship between the variables.

Relative humidity: Since the p-value for the slope is 0.021 (less than 0.05), there is a statistically significant relationship between relative humidity and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 20.3% of the variability in relative humidity. The correlation coefficient of -0.45 indicates a very weak relationship between the variables.

Minimum temperature: Since the p-value for the slope is 0.000 (less than 0.05), there is a statistically significant relationship between minimum temperature and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 47.2% of the variability in minimum temperature. The correlation coefficient of 0.69 indicates a slightly strong relationship between the variables.

Reservoir inflow: Since the p-value for the slope is 0.000 (less than 0.05), there is a statistically significant relationship between reservoir inflow and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 53.3% of the variability in reservoir inflow. The correlation coefficient of 0.73 indicates a slightly strong relationship between the variables.

Reservoir evaporation loss: Since the p-value for the slope is 0.833 (greater than 0.05), there is not a statistically significant relationship between evaporation loss and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 0.1% of the variability in evaporation loss. The correlation coefficient of 0.03 indicates a very weak relationship between the variables.

Turbine discharge: Since the p-value for the slope is 0.000 (less than 0.05), there is a statistically significant relationship between maximum temperature and year at the 95% confidence level. The R-squared statistic indicates that the model, as fitted, explains 67.2% of the variability in maximum temperature. The correlation coefficient of 0.82 indicates a slightly strong relationship between the variables.

4.4 Reduction analysis

Rainfall: From rainfall records of 1984 to 2008, the average annual rainfall (R_m) was 91.3438mm. From 1984 to 1992, the rainfall (R) reduced to 95.1535mm showing a positive change tendency with a percentage flow difference of 4.17%. This situation changed from 1993 to 2000 with a negative rainfall difference of 90.3307mm and a percentage flow difference of -1%. Likewise, from 2001-2008, this situation continued with a negative rainfall difference of 88.0709mm and a percentage flow difference of -3.6%.

Maximum temperature: From the maximum temperature records of 1987 to 2008, the average annual temperature (T_m) was 34.3598°C. From 1987 to 1994, the temperature (T) reduced to 34.0521°C showing a negative change tendency with a percentage temperature difference of less than 1%. This situation continued from 1995 to 2001 with a negative temperature difference of -0.0265°C and a percentage flow difference of -.08%. However, from 2002-2008, the situation exhibited a positive flow tendency with a temperature of 34.7381°C and a percentage flow difference of 1.1%. This is an indication of slightly negative temperature tendency from 1987-2001.

Minimum temperature: From the minimum temperature records of 1982 to 2008, the average annual temperature (T_m) was 23.5022°C. From 1982 to 1995, the temperature (T) reduced to 23.1322°C showing a negative change tendency with a percentage temperature difference of -1.5%. However, from 1996-2008, the situation exhibited a positive flow tendency with a temperature of 23.9007°C and a percentage flow difference of 1.7%.

Relative humidity: From the relative humidity records of 1982 to 2007, the average annual temperature (R_m) was 71.5866%. From 1982 to 1987, the relative humidity (R) increased to 74.4028% showing a positive change tendency with a percentage temperature difference of less than 1%. This situation continued from 1995 to 2001 with a negative temperature difference of -0.0265°C and a percentage flow difference of -.08%. However, from 2002-2008, the situation exhibited a positive flow tendency with a temperature of 34.7381°C and a percentage flow difference of 1.1%. This is an indication of slightly negative temperature tendency from 1987-2001.

Reservoir inflow: From the reservoir inflow records of 1984 to 2008, the average annual temperature (I_m) was 1055.7494m³/s. From 1984 to 1992, the reservoir inflow (I) reduced to 811.9520 m³/s showing a negative change tendency with a percentage reservoir inflow difference of -23.092%. This situation changed from 1993 to 2000 with a positive flow difference of

1166.1250m³/s and a percentage flow difference of 10%. Likewise, from 2001-2008, the situation exhibited a positive flow tendency with a flow of 1219.6458m³/s and a percentage flow difference of 16%.

Reservoir evaporation loss: From the evaporation loss records of 1987 to 2009, the average reservoir evaporation loss (E_m) was 18.5073m³/s. From 1987 to 1998, the reservoir evaporation loss (E) increased to 18.5764m³/s showing a positive change tendency with a percentage temperature difference of 0.4%. However, from 1999-2009, the situation exhibited a negative flow tendency with a temperature of 18.4318m³/s and a percentage flow difference of -0.4%.

Turbine discharge: From the turbine discharge records of 1984 to 2008, the average annual discharge (Q_m) was 994.2443m³/s. From 1984 to 1992, the discharge (Q) reduced to 774.8241m³/s showing a negative change tendency with a percentage flow difference of -22%. This situation changed from 1993 to 2000 with a positive flow difference of 76.0369m³/s and a percentage flow difference of 8%. Likewise, from 2001-2008, the situation exhibited a positive flow tendency with a discharge of 1165.0551m³/s and a percentage flow difference of 17%.

4.5 Comparison between Mann-Kendall and the Regression Analyses

Rainfall: The results from both the Mann-Kendall test and the regression test indicate statistically non-significant relationship between the rainfall and the year. This implies that the negative trend demonstrated occurred by chance and not by a causative factor. Hence, it cannot be ascertained, based on the evidence at hand (1984-2009) that the rainfall would decrease in the future.

Maximum Temperature: The results from both the Mann-Kendall test and the regression test indicate statistically significant relationship between the maximum temperature and the year. This implies that the positive trend demonstrated did not occur by chance but by a causative factor. Hence, it can be ascertained, based on the evidence at hand (1984-2009) that the maximum temperature would increase in the future.

Relative Humidity: The results from both the Mann-Kendall test and the regression test indicate statistically non-significant relationship between the relative humidity and year. This implies that the negative trend demonstrated did not occur by chance but by a causative factor. Hence, it can be ascertained, based on

the evidence at hand (1982-2007) that the relative humidity would decrease in the future.

Minimum Temperature: The results from both the Mann-Kendall test and the regression test indicate statistically significant relationship between the minimum temperature and the year. This implies that the positive trend demonstrated did not occur by chance but by a causative factor. Hence, it can be ascertained, based on the evidence at hand (1982-2008) that the minimum temperature would increase in the future.

Reservoir Inflow: The results from both the Mann-Kendall test and the regression test indicate statistically significant relationship between the reservoir inflow and the year. This implies that the positive trend demonstrated did not occur by chance but by a causative factor. Hence, it cannot be ascertained, based on the evidence at hand (1984-2008) that the reservoir inflow would increase in the future.

Reservoir Evaporation Loss: The results from both the Mann-Kendall test and the regression test indicate statistically non-significant relationship between the evaporation loss and the year. This implies that the negative trend demonstrated occurred by chance and not by a causative factor. Hence, it cannot be ascertained, based on the evidence at hand (1987-2009) that the evaporation loss would decrease in the future.

Turbine Discharge

The results from both the Mann-Kendall test and the regression test indicate statistically significant relationship between the turbine discharge and the year. This implies that the positive trend demonstrated did not occur by chance but by a causative factor. Hence, it cannot be ascertained, based on the evidence at hand (1984-2008) that the turbine discharge would increase in the future.

Conclusion

The meteorological and hydrological variables under study were subjected to statistical, Mann-Kendall, Regression and Flow reduction methods of analyses. There were some notable changes in the climate of Jebba Hydropower station some of which are enumerated below.

For the past few years, rainfall and relative humidity have exhibited negative trends. This implies that both variables will decrease slightly in that their changes are insignificant.

For the past few years, the reservoir inflow, outflow and temperature have shown significant

positive trends. This indicates that the parameters have tendency to increase and rate of their changes are significant positive. The evaporation loss also shows negative trends and may be due to low relative humidity.

It can be concluded that there is positive impact of climate change on water resources of the study area due to increase in reservoir inflow and low evaporation, hence more water for hydropower generation.

Recommendations

Several areas of future research are critical for improving our understanding of and our ability to predict effects of climate change on water resources. These include

1. Initiation of integrated assessment of impacts, and analyses that define viable response options for future changes in climate.
2. There should be education, training and public awareness on climate change, to enable the full mobilization and participation of the society.

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