Trend analysis of selected hydro-meterological processes

John Jiya MUSA[1,*], Martins Yusuf OTACHE[1], Peter Aderemi ADEOYE[1],
Kunle OKANLAWON[2], and Stephen Kolade OLORUNTOLA[2]

[1]Department of Agricultural and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna, Nigeria
[2]Research Assistant, Department of Agricultural and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna, Nigeria
E-mail(*):johnmusa@futminna.edu.ng

*Corresponding author: Phone: +234-809-474-7246

Abstract

Identification of the precise nature and attributes of the time series of climatological data is very important and is usually the first step of water resources planning and management. The major objective of this study was to determine the presence or otherwise of trend over time for some selected hydro-climatic components of Kaduna, Nigeria, and deduces the magnitude. Statistical approaches were used to investigate the presence and extent of persistence, trend analysis in hydro-climatic time series. Based on Mann Kendall test, twenty six years of hydro-climatic data were used. The non-parametric Man-Kendall test was used to detect monotonic trends, and the Mann-Kendall slope estimator was used to estimate the magnitude of trend on the variables. An evidence of trend was observed in all variables. Temperature and evaporation variables showed a positive and significant trend over time, while rainfall and stream flow had negative trend though not significant at the 95 % level of confidence. Thus, it could be concluded that the trend of change in temperature around River Kaduna is on the increase, with no significant increase in change of rainfall.

Keywords

Evaporation; Hydro-climatic; Man-Kendall; Rainfall; Stream-flow; Temperature; Trend

Introduction

Generally, the study of the weather and climatic elements of a region is vital for sustainable development of agriculture and planning, particularly, rainfall and temperature [1-3]. Temporal analyses for trends, fluctuations and periodicities are deemed necessary as such can indirectly furnish the "health" status of an environment. A declining and/or rising trend may be quite instructive for different segments of the human and natural systems. Impending long or short term weather–related natural disasters may be predicted and better adaptive actions initiated through the analysis of the fluctuations and return periods of the series. Extreme weather events that can lead to drought and prolonged heat spell, flooding, etc., can be accessed through the statistical analysis of a region's temporal rainfall regime [4]. The global concern on the apparent deterioration in all of the earth's natural systems, particularly the weather and climate sub-system and global warming with attendant climate change pandemic, renders credence to trend and periodicity analyses of weather elements. Climate is the most important driving parameter that causes year-to-year variability in socio-economic and environmental systems including the availability of water resources [5-7]. It affects the development and planning of water resources schemes such as flood prevention and control, drought management, food and fiber production. Further, change in climate will increase the uncertainty in water resources planning. Apart from this, changes in climatic pattern will have profound effects and consequences for natural and agricultural ecosystems and for society as whole [8, 9]. These changes could even alter the location of the major crop production regions on the earth [4]. The shifting from 'normal weather', with its associated extreme events will surely change the zones of crop adaptation and cultural practices required for successful crop production. Climate and weather induced instability in food and fiber supplies will alter social and economic stability and regional competitiveness [4]. Therefore, the analysis of hydro-climatic variables such as rainfall, potential evapotranspiration, stream-flow, temperature, becomes a prerequisite task to understand climatic changes.

In recent years, there has been a considerable concern about the possibility of climatic changes. Alteration in our climate is governed by a complex system of atmospheric and oceanic processes and their interactions [10]. Atmospheric processes such as humidity, solar radiation, evaporation also result in increase in surface-level ultraviolet radiation and changes in temperature and rainfall pattern. Human activities on the other hand are responsible for changes in ecosystem due to increased emission rates of CO_2 and other greenhouse gases. The evidence using state-of-art computer models incorporating as much of the theoretical understanding of the earth’s weather suggests that global warming is occurring along with shifting patterns of rainfall and incidents of extreme weather events [11].

It was demonstrated that global surface warming has been taking place at the rate of 0.74 ± 0.18 °C over the period of 1906-2005 [12] and it was expected more in the next century than what has occurred during the past 10,000 years [13]. The increased atmospheric moisture content associated with warming might be expected to increase the global mean precipitation. Global annual land mean precipitation showed a small, but uncertain, upward trend of approximately 1.1 mm per decade (uncertainty ±1.5 mm) over 1901-2005. During the 20th century, precipitation has generally increased from latitudes 30° to 85°N over land; but notable decreases have occurred between latitudes 10 °S and 30°N in the last 30-40 years. In western Africa and southern Asia the linear trends in rainfall decrease during 1900-2005 were 7.5% per century (significant statistically at <1% level), whereas over much of northwest India shows increase in the rainfall with more than 20% per century [14]. At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2°C), which would increase the food risk [13].

Considering all the issues involved herein, it can be stated that the study of hydro-climatic variables such as rainfall, potential evapotranspiration, temperature, humidity, etc becomes a prerequisite task to understanding climatic changes. Therefore, for water resources planning, it seems to be logical to analyze hydro-climatic variables at small scale for proper appreciation of their spatio-temporal variability. However, the change in climate is governed by the complex system of atmosphere and oceanic processes and their interaction, but due to limitation on availability of wide variety of atmospheric data, this study focus on the analysis of indicative hydro-climatic parameters to demonstrate the climate change or changes in weather patterns.

The objectives of this study were to determine the presence of long range trend over time for some selected hydro-climatic components and to establish whether climate change has already altered hydro-climatic process of rainfall, temperature, relative humidity, stream flow.

Material and method

Hydro-climatic data were collected from Kaduna. Kaduna state is located on the southern end of the high plains of northern Nigeria, bounded by parallels $9^0\ 03^1$ N and $11^0\ 32^1$ N, and extends from the upper River Mariga on 6º05' E to 8º48' E on the foot slopes of the scrap of Jos plateau. Stream valley incisions and dissections of the high plains are evident in several areas, especially in the Zaria region; they are due more to anthropogenic influences and climatic factors than regional geologic instability. The state experiences a typical tropical continental climate with distinct seasonal regimes, oscillating between cool to hot dry and humid to wet. These two seasons reflect the influence of tropical continental and equatorial maritime air masses which sweep over the entire country. However, in Kaduna state, the seasonality is pronounced with the cool to hot dry season being longer, than the rainy season. Again, the spatial and temporal distribution of rain varies, decreasing from an average of about 1530 mm in Kafanchan and Kagoro areas in the southeast to about 1015 mm in Ikaramakarfi districts in the northeast. High storm intensities (ranging from 60 mm/hr to 99 mm/hr) plus the nature of surface runoff build up the good network of medium sized river systems. High Evaporation during the season, however, creates water shortages especially in Igabi, Giwa, Soba, Makarfi and Ikara LGAs.

Data assembly and management

Hydro-climatic characteristic (i.e. rainfall in mm, evaporation in mm, stream flow in m^3/s, and temperature in ^oC) data of 26 years were obtained for this study from the Nigerian Metrological Station, Abuja. A non-parametric procedure was used to test for the presence of trend in the data collected. Prior to the analysis, the entire data was pre-processed to eliminate the seasonality implications and then followed by the adoption of Mann-Kendall and Mann-Kendall slope estimator for the tests. The data used for this analysis were not the raw data collected from the study location because of the messy nature of it, because of this the data was processed by pre-whitening hereby removing the impact of serial correlation from the series through $m_i=x_i-\phi x_{i-1}$ [8, 15], where m_i is the pre-processed series value, x_i is the original series value, and ϕ is the estimated lag 1 serial correlation.

For serial autocorrelation (Φ)s

$\Phi(i)=C(k)/C(0)$

where

$$C(K)=\frac{1}{n}\sum_{i=1}^{n-k}(x_i-\text{mean})(x_{i-k}-\text{mean}) \quad (1)$$

and k = 0, 1, 2. . . k

Mann-Kendall trend test (S)

$$S_i=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\text{sgn}(x_{ji}-x_{ki}) \quad (2)$$

where: n = number of years, I = number of season

$$\text{sgn}(x)=\begin{cases}1_{x>0}\\0_{x=0}\\-1_{x<0}\end{cases}$$

$E(S)=0$

$$\text{Var}(S)=\frac{1}{8}\left[n(n-1)(2n+5)-\sum_{i=1}^{m}t_i(t_i-1)(2t_i+5)\right] \quad (3)$$

where *S* is the Mann Kendall slope statistic, the mean value of this parameter E(S)=0, when a positive value is obtained, the trend is said to be positive and when it is negative, the trend is said to be negative, *n* is the number of years, i is the number of season, x_i is are data's collected for analysis, *Var(S)* is the variance of S and *Z* is the standard normal variant

Using the equations above, all hydro-climatic components under study was tested for seasonal trend (monthly) and annually trend (yearly) except for the stream flow component, which was tested for daily trend because of the availability of daily data set.

Mann-Kendall slope estimator (B)

In addition to identifying time series that exhibit trend, it may be desirable for some applications to estimate the magnitude of such trend.

$$d_{ijk}=\frac{x_{ij}-x_{ik}}{j-k} \quad (4)$$

where d_{ijk} is the various slope for the individual season; daily, seasonal or annual, i is the number of seasons, x_{ij} and x_{ik} are the set of data to be analysed, where $1 < j < k \leq n_i$. The Mann-Kendall slope estimator (B) is the median of all the slopes calculated, which is used to estimate the magnitude of the trend detected whether positive or negative. Using the median of these individual slope d_{ijk} values, the estimated B is quite relevant to appraise the effect of extreme values in the data. It is unaffected by seasonality because the slopes were computed between values that are multiple of 12 months apart. The various slopes were computed and the aggregate Kendall slope estimated by considering the median of the various slopes.

Results and discussion

Result of the Mann-Kendall trend test are as presented in Table 1-7 and the Pearson correlation test in Table 8 for the Hydro-climatic variables (i.e. rainfall, evaporation, temperature and streamflow) considered. The graphical representations of data are presented in Figures 1 to 4 for the monthly series of the decadal segment while that of the annual series is presented in Figures 5 to 8. These graphs show a clearer picture of the behavioral trend of these Hydro-climatic variables.

Table 1. Mann-Kendall tests for annual series

Hydro-climatic component	**Statistics**				
	τ	**Z**	**S**	**p Value**	**Trend/significance**
Evaporation	0.34	2.21	108.00	0.0271	+s (*)
Stream flow	-0.02	-0.13	-7.00	0.8966	-s (-)
Temperature	0.78	5.32	251.00	< 0.0001	+s (**)
Rainfall	-0.14	-0.97	-45.00	0.3320	-s (-)

+s – positive trend, -s – negative trend, (-) – no trend, (*) – 95% significance level, (**) – 99% significance level

Table 2. Mann-Kendall test for seasonal evaporation at Kaduna

Variable	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
S	-63.00	-53.00	8.00	98	101.00	128.00	122.00	20.00	36.00	-23.00	-4.00	-42.00
τ	-0.19	-0.16	0.02	0.30	0.31	0.39	0.38	0.06	0.11	-0.07	-0.01	-0.13
Z	-1.37	-1.15	0.15	1.96	2.20	2.80	2.67	0.42	0.77	-0.48	-0.07	-0.90
P-value	0.1707	0.2501	0.8808	0.05	0.0278	0.0051	0.0076	0.6745	0.4413	0.6312	0.9442	0.3681
Trend/Sign.	-s (-)	-s (-)	+s (-)	+s (-)	+s (*)	+s (**)	+s (**)	+s (-)	+s (-)	-s (-)	-s (-)	-s (-)

+s – positive trend, -s – negative trend, (-) – no trend, (*) – 95% significance level, (**) – 99% significance level

Table 3. Mann-Kendall test for seasonal rainfall at Kaduna

Variable	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
S	0.00	-30.00	-20.00	73.00	-6.00	95.00	55.00	29.00	29.00	-27.00	-95.00	14.00
τ	0.00	-0.09	-0.06	0.22	-0.02	0.29	0.17	0.09	0.09	-0.08	-0.29	0.04
Z	0.00	-0.64	-0.42	1.59	-0.11	2.07	1.19	0.62	0.62	-0.57	-2.07	0.29
P-value	1.0000	-0.64	0.6745	0.1118	0.9124	0.0385	0.2340	0.5353	0.5353	0.5687	0.0385	0.7718
Trend/Sign.	-	-s (-)	+s (-)	+s (-)	-s (-)	+s (*)	+s (-)	+s (-)	+s (-)	-s (-)	-s (*)	-s (-)

+s – positive trend, -s – negative trend, (-) – no trend, (*) – 95% significance level, (**) – 99% significance level

Table 4. Mann-Kendall test for seasonal temperature at Kaduna

Variable	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
S	81.00	148.00	121.00	135.00	91.00	85.00	-52.00	-173.00	-133.00	111.00	170.00	126.00
τ	0.25	0.46	0.37	0.42	0.28	0.26	-0.16	-0.53	-0.41	0.34	0.52	0.39
Z	1.76	3.24	2.64	2.95	1.98	1.85	-1.12	-3.79	-2.91	2.42	3.73	2.76
P-value	0.0784	0.0012	0.0083	0.0032	0.0477	0.0643	0.2627	0.0002	0.0036	0.0155	0.0002	0.0058
Trend/Sign.	+s (-)	+s (**)	+s (**)	+s (**)	+s (*)	+s (-)	-s (-)	-s (**)	-s (**)	+s (*)	+s (**)	+s (**)

+s – positive trend, -s – negative trend, (-) – no trend, (*) – 95% significance level, (**) – 99% significance level

Table 5. Mann-Kendall test for seasonal streamflow at Kaduna River

Variable	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
S	-65.00	-42.00	43.00	-14.00	5.00	44.00	66.00	32.00	-1.00	91.00	55.00	54.00
τ	-0.20	-0.13	0.13	-0.04	0.02	0.14	0.20	0.10	0.00	0.28	0.17	0.17
Z	-1.41	-0.90	0.93	-0.29	0.09	0.95	1.43	0.68	0.00	1.98	1.19	1.17
P-value	0.1585	0.3681	0.3524	0.7718	0.9283	0.3421	0.1527	0.4965	1.0000	0.0477	0.2340	0.2420
Trend/Sign.	-s (-)	-s (-)	+s (-)	-s (-)	+s (-)	+s (-)	+s (-)	+s (-)	-	+s (*)	+s (-)	+s (-)

+s – positive trend, -s – negative trend, (-) – no trend, (*) – 95% significance level, (**) – 99% significance level

Table 6. Mann-Kendall test for daily streamflow at Kaduna River

Hydro-climatic component	τ	Z	S	P-value	Trend/significance
Stream flow	0.02	2.53	778736.00	0.0114	+s (*)

+s – positive trend, -s – negative trend, (-) – no trend,
(*) – 95% significance level, (**) – 99% significance level

Table 7. Slope estimates for the series (Annual, Monthly and Daily)

Hydro-climatic component	Series (Estimated slopes)		
	Annual series	Monthly series	Daily series
Evaporation	1.34	0.08	-
Rainfall	-0.17	-0.02	-
Stream flow	-0.22	-0.01	-0.01
Temperature	3.58	0.37	-

Table 8. Correlation among the hydro-climatic variables

Variables	Temperature	Evaporation	Rainfall	Streamflow
Temperature	1			
Evaporation	0.663**	1		
Rainfall	0.515**	0.531**	1	
Streamflow	0.486*	0.470*	0.934**	1

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

It is important to note that a positive S value indicate an upward trend (increasing value with time) and a negative value of S indicates a downward trend and also that the test statistic Z follows a normal distribution which values were tested at 95% ($Z_{0.025}$±1.96) and ($Z_{0.001}$±2.58) level of significance. The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the level of significance. If the absolute value of Z is less than the level of significance, there is no trend [16].

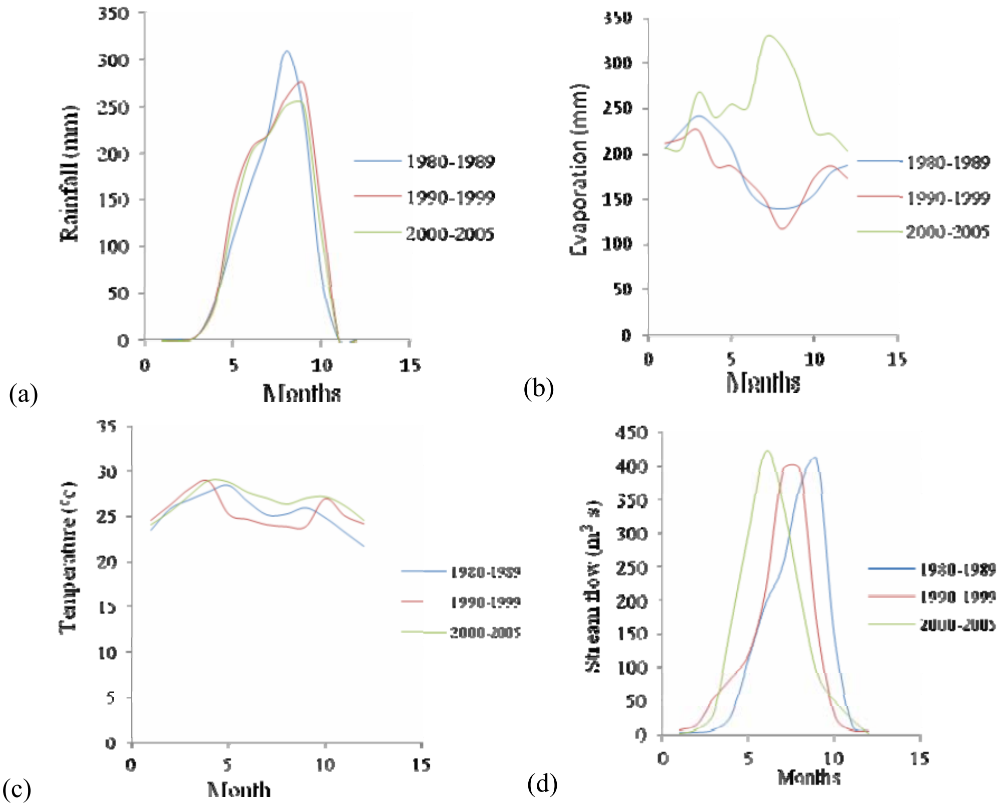
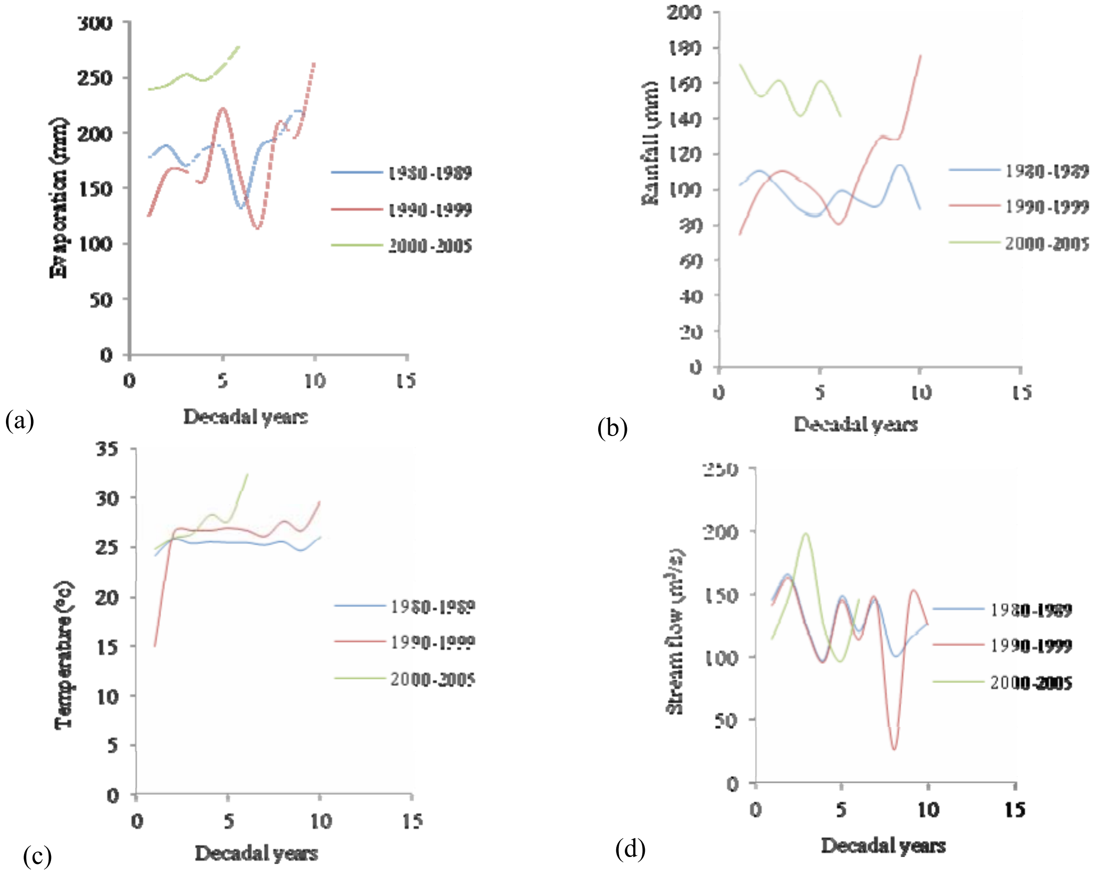


***Figure 1.** Decadal Segmentation of the Monthly hydro-meterological variables: (a) Rainfall (b) Evaporation (c) Temperature and (d) Streamflow*

The analysis of the annual series reveals a significant positive trend in temperature over the 26 years period. The temperature trend is significant over 95 and 99% level of significance, thus indicating a significant rise in temperature, the Mann-Kendall statistic S=251, Mann-Kendall slope estimate B=5.48 and Z value of 5.32 shows that the trend is highly significant. A Mann-Kendall statistic S of 108 and a positive Mann-Kendall slope estimate accompanied by a positive Z value of 2.21 also showed that evaporation around Kaduna has been in a significant positive trend over the analyzed 26 years.



(a) (b) (c) (d)

Figure 2. *Decadal Segmentation of the Annual Hydro-meterological variables (a) Rainfall (b) Evaporation (c) Temperature and (d) Streamflow*

The rainfall has been in a downward trend for the analyzed 26 years of available data. However a Z value of -0.97 indicates that the trend though negative is not significant at the 95 and 99% level of significance, also the analysis of the stream-flow at revealed a non-significant decrease in the stream-flow trend at Kaduna with a Mann-Kendall statistic S = -7.00 and Z value of -0.13.

With this variables having a high level of relationship, increase in temperature and evaporation might be having effect on the rainfall and stream-flow, however the effect is not significant. A review of a work by [17] on the impact of climate change on water resources reveals that there is tendency for high increase in evaporation, temperature and sunshine hour while there is no much/no change in rainfall.

The analysis of the monthly series for trend on various hydro-climatic variables brings to the fore that some month has positive trend and some months has negative trend on different level of significance. April, May, June, July, August and September shows a positive trend, while January, February, March, October, November and December shows a negative trend in evaporation, but only May, June and July are of significance. Analyzing the rainfall variable for trend on the monthly series, February, March, May, October and November shows a negative trend while April, June, July, August and September shows a positive trend although significant trend was only noticed in the month of June and November and no trend at all in January because no rainfall was recorded for January during the analyzed 26 years. Most of the months indicate the presence of positive and some indicate negative trend when the temperature variable was analyzed, most of the trend detected were of high significance at both 95 and 99 % level of significance except for January, June and July. Most of the monthly trends detected on the hydro-climatic variable (stream flow) are of no significance except for the trend detected on the month of October, which is only significant on the 95% level of significance, January, February and April indicate a negative trend, while March, May, June through to December indicate a positive trend. All the spatial distribution in trend in the monthly series can be attributed to the effect of the climate change phenomenon, which played a major role in the fast changing trends of hydro-climatic variables. The analysis of the daily series of the stream flow variable reveals that like the annual series the daily series of the stream flow indicate a decreasing/downward trend, though not significant.

From the result discussed above, the effect of climate change cannot be left out as the cause of the rapid or increasing trend in temperature over the years, this effect on temperature has significantly affected the rainfall, and this is made more visible in the Pearson correlation test, which shows there is significance in relationship of the various hydro-climatic variable tested.

These results show that increases in temperature caused by the phenomenal “Climate change” has had an adverse effect on the rainfall and evaporation, which in one way or the other has affected the stream flow over time, even though the test show that it not of significance.

Conclusions

There was presence of trend on all the variable analyzed, though at different level of significance, temperature and evaporation showed trend of high significance while the other (rainfall and stream flow) even though the presence of trend was detected, was seemingly insignificant. In addition, it could be strongly asserted that testing daily series for trend would not produce a significant result; as the time scale increases, i.e., monthly and annual presence of trend was strongly noticeable. The increasing trend on the temperature caused by the phenomenal climate change has a significant effect on the other hydro-climatic variables tested.

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