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Research Article

TREND ANALYSIS OF EVAPORATION AND SOLAR RADIATION USING INNOVATIVE TREND ANALYSIS METHOD

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ABSTRACT

Analysis of trends in monthly evaporation and solar radiation in the face of climate change gives useful information for better planning and management of water resources. This paper examines the monthly evaporation and solar radiation trend using the recently developed innovative trend analysis method (ITAM). The monthly evaporation trend result shown that 75% of the months indicated decreasing trend with the month of February, March, August and April decreased significant at 0.1%, 10%, 10% and 5% significance level respectively. As regards solar radiation all the months indicated decreasing trend with January, July and October shown a decreasing trend at 5% significant level. By comparing the Mann-Kendall method with the ITAM the reliability of ITAM was ascertained. Hence, ITAM can be effectively utilized in climate change scenarios where useful information is needed for accurate management and planning of water resources.

Keywords: Trend; Climate change; Sen's slope test; Mann-Kendall; innovative trend analysis method; Ibadan.

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1. INTRODUCTION

Globally, planning and developing water resources projects in any region have become a major concern. Such projects include agricultural and food development projects, assessing different methods for erosion and flood control, irrigation scheduling and effective techniques for water planning and management. As reported by Intergovernmental Panel on Climate Change (IPCC) [1], due to change in climate, some locations globally are expected to have change in the frequency of flooding, specifically in floodplain watersheds and in the northern latitudes. Changes in precipitation and evaporation could result to increase in the frequency and flinty of drought episodes [2]. Hence, investigations of the characteristics of variations in evaporation is highly relevant to the hydrological communities for identifying and understanding climate and hydrological changes.

Traore *et al.* [3], noted that the determination of changes in evaporation has been widely applied to determine the crops water demand. The rate of change in evaporation are considered important for water resources management and planning, irrigation control and the response of plant water to different climates [4,5]. It is commonly used as an evapotranspiration index and to forecast the evaporation rate of reservoirs, canals and lakes. In order to assess baseline evapotranspiration, evaporation is also a useful variable [6,7]. Basically, evapotranspiration is a complex non-linear energy balance process that can be obtained indirectly according to FAO56 Penman - Monteith, which requires huge data [8].

To detect trends in climatic variables on an annual, monthly and seasonal basis, significant research has been undertaken using either the non-parametric or parametric test of trend analysis, such as the Sen's slope test [9], Mann–Kendall method [10,11], linear regression method [12], Spearman's rho test [13] and cumulative sum [11]. For instance, the study of Caloiero *et al.* [12] focused on the use of Mann–Kendall and linear regression test to determine the presence of trends in seasonal and yearly precipitation in Calabria region of Italy. They found out that annual and autumn–winter rainfall had a downward trend and upward trend was observed for summer rainfall. Gemmer *et al.* [14], in their study to determine the presence of trends on daily, yearly and monthly rainfall values on Zhujiang River Basin employed the Mann–Kendall test. The results of the study of Oguntunde *et al.* [5] on changeability and trends in evaporation and other hydro-meteorological variables in Ibadan region of Nigeria by applying the Sen slope and Mann-Kendall (MK) test showed that solar radiation, wind speed and evaporation were significantly reduced ($P < 0.001$), while rain, temperature and relative humidity did not show significant increasing trends over the past four decades.

Furthermore, Salami *et al.* [15] employed the Mann-Kendall and standard anomaly index methods to examine the presence of trends in the hydro-metrological variables of Lagos state coastal areas. Their result showed the presence of increasing trend over time for rainfall, relative humidity, wind speed and sea level rise, while temperature result implies decreasing trend over time. Patra *et al.* [16] applied Sen's slope, linear regression and Mann–Kendall test to determine the presence of trends in seasonal, annual and monthly precipitation over Orissa State, India (1871 - 2006). The result of their study showed that the post-monsoon season have a positive trend while monsoon and annual precipitation showed the presence of a lengthy negative trend that's not significant. Tabari *et al.* [17] on their study on Penman-Monteith ET_0 in Iran western part used the Sen's slope, MK and linear regression test to studied the presence of trends in annual, monthly and seasonal basis. The result of their findings showed that winter and summer ET_0 values have significant increasing trends on the seasonal scale as compared to autumn and spring ET_o values. More so, MK and Sen's slope tests has been used by Pingale *et al.* [9] to inspect the spatio-temporal trends in extreme temperatures and precipitation in Rajasthan region of India. The result of their study implies that urban centers of the state of Rajasthan shows negative and positive trends. Tabari and Marofi [18] investigate the presence of temporal changes of pan evaporation by employing the Mann-Kendall, Sen's slope and linear regression methods on pan evaporation variables in Hamedan province of Iran western part. The result of their showed that over the last 22 years the Hamedan province has become warmer and drier, therefore, there is increased in crop water requirements. Much success has been achieved using different non parametric methods of trend analysis in the literature, however, these methods mentioned earlier have some drawbacks such as, length of data, normally distributed and independent structure of time series.

To this end, a newly developed method called the innovative trend analysis method (ITAM) [19,20] has been used successfully in planning and management of water resources [7,11,21-23]. To check the reliability of the results obtained from the ITAM, the Mann-Kendall test was often applied alongside the ITAM due to the fact that it's not susceptible to outliers and time series data normally distributed. For example, Ay & Kisi [24] used the ITAM to examine the presence of trend in monthly precipitation in six different areas of Turkey and their result showed that significant upward trends was observed in the provinces of Samsun and Trabzon, while the four other provinces showed insignificant trend. The ITAM was also applied by Ahmad *et al*. [22] to study trends in monthly rainfall for 25 stations and an increasing trend was found towards the southern parts while in the northern part of the Macta river basin in Algeria, declining trend was observed between the period of 1970 and 2011. Cui *et al.* [23] analyze characteristics of air temperature and rainfall changes in China Yangtze River Basin (CYRB) on seasonal and annual basis during the period of 1960-2015, by employing Sen's slope estimator, Mann-Kendall test, linear regression analysis (LR) and the innovative trend analysis method (ITAM). Kisi [7] applied the ITAM alongside the Mann-Kendall (MK) method to studied the presence of trend in pan evaporation across six provinces in Turkey. Güçlü *et al.* [25] applied the innovative trend analysis method coupled with air quality index for air quality identification in Istanbul megacity. Wu and Qian [11] in their study on yearly and seasonal precipitation at fourteen (14) precipitation positions in Shaanxi area of China used the ITAM alongside the linear regression (L-R) analysis and Mann-Kendall method of trend analysis. Therefore, innovative trend analysis method (ITAM) has been used to a great extent in comparison with the Spearman's rho tests and Mann-Kendall method (MK), which have some restrictive assumptions. In addition, using the ITAM, graphical representations of significant trends in sub-series (sub-trends) can be seen. So far, there has been no study across this region by employing ITAM in comparison with MK and Sen's slope method to analyze the trends of evaporation particularly the monthly evaporation and solar radiation variability.

The objectives of this study are: i. To determine recent trends in evaporation and solar radiation in Ibadan using innovative trend analysis method. ii. Analyze and compare the results of trends from 1973-2018. iii. Assess the capacity of the innovative trend analysis method (ITAM).

2. METHODOLOGY

2.1. Study area

The city of Ibadan is situated in the south-eastern region of Oyo State, and is sited approximately on longitude 3 ° 54' S of the Greenwich meridian and latitude 7 ° 22 'N of the equator. The city is located in South-west region of Nigeria, in a wooded area near the border between forest and savannah. The physical setting of Ibadan is about 110 km northeast of Lagos and on seven hills with an average altitude of 200 m and 160 km off the Atlantic coast and thus provide the visitor a panoramic view of the city. Ibadan city population grew rapidly in the mid-19th century, with increasing population from approximately one million in 1963 to approximately 3.6 million in 2007. The city was the most populated and largest in Nigeria as at the time when Nigeria got her independence. More so, the city has two seasons namely dry and wet season which is the climatic classification of Köppen, with an extended raining season and temperatures that's somewhat regular throughout the year. According to Sangodoyin [26], the mean rainfall is around 1300 mm / year and the average temperature on monthly basis varied from 28.8 ° C in February to 24.5 ° C in August. The city season of rainfall in the city extends from March to October, but August shows little calm in the rainfall. This calm in August is term "August break" and it almost divides the season of rainfall into two different rainfall seasons. The remaining season form the city's dry season.

2.2. Data source

Monthly precipitation and solar radiation data for the period of 45 years (1973-2018) were procured from the database of the International Institute of Tropical Agriculture, Ibadan with 7 ° 30 'N, 3 ° 54' S and 243 m above sea level. The installations of the meteorological instrument met the World Meteorological Organization standards.

2.3. Data analysis

To understand the nature of variations in evaporation and solar radiation as well as the relationship that exit between these variations, Mann-Kendal statistics with Sen's slope test and innovative trend analysis method (ITAM) were employed. These approaches used time series of evaporation and solar radiation which was examined on a monthly basis. various similar studies by researchers around the world has utilized these statistical trend tests to test the presence of trends in hydro-meteorological variables [5,27]. In this study, spreadsheet (Makesen 1.0) developed by the Finnish Meteorological Institute which was used for estimating and detecting time series trend [28,29] was employed in this study to analyze the trends of Mann-Kendall test with Sen's slope test. While, analysis of the innovative trend analysis method was carried out using R software packages.

2.3.1. Mann-Kendall trend test

The Mann-Kendal (MK) test is a non-parametric method and it has been widely employed by researchers around the world to detect trends in hydro-metrological variables [7,23]. In this study, this trend test (MK) was applied to the variable examine in other to determine the presence of trends in the time series trends. The Mann-Kendall trend test uses S test statistics, which are given by:

$$S = \sum_{f=1}^{n-1} \sum_{j=f+1}^{n} sgn\,(X_j - X_f) \quad (1)$$

The trend test is applied to the data values X_f (f = 1, 2 ... n - 1) and X_j (j = i + 1, 2…. n).

The data values of each X_f are used as a reference point for comparison with the data X_j given as:

$$sgn(x) = \begin{cases} if\,(x) > 0 & \text{then} + 1 \\ if\,(x) = 0 & \text{then} \;\; 0 \\ if\,(x) < 0 & \text{then} - 1 \end{cases} \quad (2)$$

The average of the *S test statistics* is *E(S)* = 0

The variance σ^2 is given as:

$$\sigma^2 = \{n(n-1)(2n+5) - \sum_{r=1}^{p} t_r(t_r - 1)(2t_r + 5)\}/18 \quad (3)$$

Where p is the data set tied groups number

t_r is the number of data points in r^{th} related group. The S statistics are distributed approximately normally in as much as the following Z-transformation is used as follows:

$$z = \begin{cases} \frac{S-1}{\delta} if\; S > 0 \\ 0\; if\; S = 0 \\ \frac{S+1}{\delta} if\; S < 0 \end{cases} \quad (4)$$

From equation 4, if a positive value of Z is obtained, this implies an increase (upward) in trends, while decrease (downward) trend is obtained when Z values are negative. To examine both upward and downward trends at the level of significance α, the null hypothesis of an absolute value of Z greater than $Z_{1-\alpha/2}$, obtained from the standard normal cumulative distribution tables was rejected [7,17]. In this study, Significance levels of α = 10%, 5%, 1% and 0.1% were employed.

2.3.2. Sen's slope test

In this method, slope of all pairs of ordinal time points are calculated and then the general slope is evaluated using the average slopes obtained [30]. According to Khan *et al.* [31], the actual slope can be used to evaluated using a simple non-parametric procedure provided that a linear trend was noticed over a series of times. This signify that for a decreasing and increasing continuous monotonic function of time f(t), then f (t) is given as:

$$f(t) = \beta t + K \quad (5)$$

Where β is the slope and K is the constant. primarily, in order to obtain the slope "β", all the data pairs slopes are calculated according to:

$$\beta' = (X_{t'} - x_t)/ (t' - t) \quad (6)$$

Where, β' in equation 6 is the Slope between the points of $x_{t'}$ and x_t while x_t' and x_t are the time taken to measure data at x_t' and t.

Hence, the Sen slope estimator is simply given by the average slope,

$$\beta = \beta'_{(N+1)/2} \text{ if N is odd} \quad (7)$$

$$= \{\beta'_{(N+1)/2} + \beta'_{(N+2)/2}\}/2 \text{ if N is even} \quad (8)$$

Where N represented the slopes number. On a slope estimate, a bilateral confidence interval of 100 (1- α) % is obtained using a normally distributed non-parametric test [31].

2.3.3. Innovative trend analysis method (ITAM)

The ITAM has proposed by [19] has been employed to determine the trends in hydro-meteorological variables by various researches globally [7,11]. In this approach, the time series data is separated in two equal halves and both sub-series are sorted in increasing order. Furthermore, the two equal parts are placed in a coordinate system with the X axis having the first half (X_i: i = 1, 2, 3, ... n / 2) of the time series and the Y-axis having the second half of the time series (X_j: j = n / 2 + 1, n / 2 + 2, ... n). From figure 1, the ITAM clearly in the Cartesian coordinate system can be clearly seen. The figure clearly shows that if the time series data on the scatter plot is collected in a 1: 1 straight line (45°), this means that the sub-trends are equal and this does not indicate a trend. Nevertheless, the trend increases when the data points are above the ideal 1: 1 straight line, and decreases in trend is observed when the data points are below the 1:1

straight line [19,20]. Hence, the presence of any trend in the time-series is visible using this method.

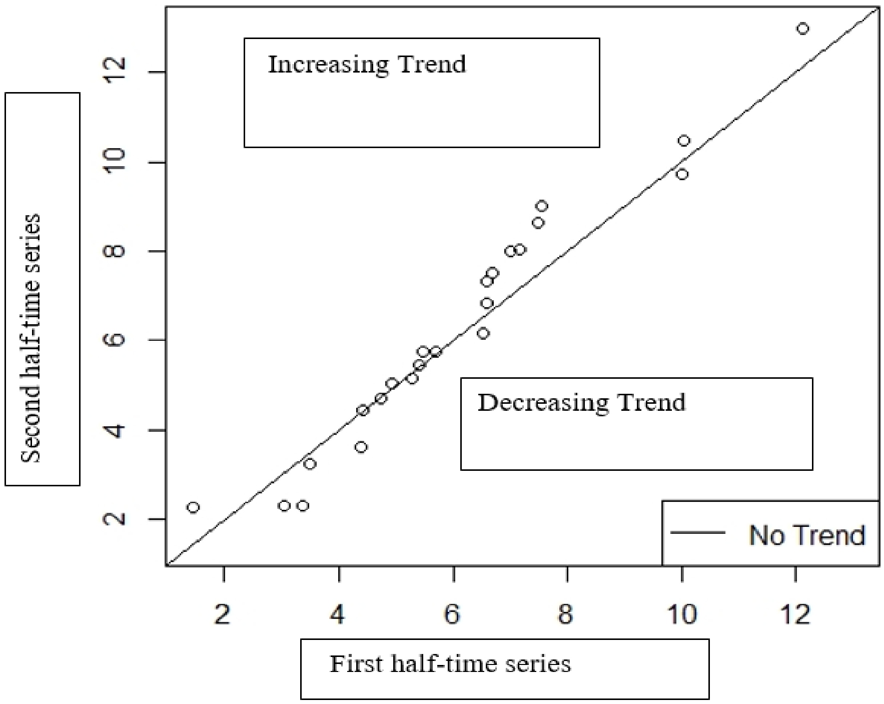


Fig.1. Illustration of an innovative trend analysis method

3. RESULTS AND DISCUSSION

3.1. *Trend of evaporation and solar radiation using Mann-Kendall with Sen's slope test*

The monthly analysis of each variable in the calendar makes it possible to identify unique weather characteristics for each month. Each month evaporation and solar radiation results obtained from the Mann-Kendall with Sen's slope test are listed in Table 1 and Table 2 respectively according to the significant levels of 10%, 5%, 1% and 0.1%. In this study, pre-whitening was not carried out because it results in a loss of originality in the time series [19,32].

From Table 1, it can be seen that monthly evaporation results for the month of January, February, March, April, May, June, August, October and November indicated a decreasing trend, while July, September and December shown an increasing but not significant trend. The month of February shown a downward trend at 0.1% significance level. The months of March and August, on the other hand, showed a downward trend at the 10% significance level. In addition, April also shown a downward (decreasing) trend of 5% level of significance level. Over the twelve months, only two months shown a non-significant upward (increasing) trend. It can also be visualized from Table 1 that the evaporation for the month of January, February, March, April, May, June, August, October and November have a trend magnitude which decreases at the rate of 0.011 mm / year, 0.035 mm / year, 0.012 mm / year, 0.015 mm / year, 0.011 mm / year, 0.008 mm / year, 0.008 mm / year, 0.007 mm / year and 0.012 mm / year respectively. The months of July, September and December on the other hand shown an increase in trend magnitude of 0.008 mm / year, 0.011 mm / year and 0.006 mm / year respectively.

Table 2 indicated the MK monthly trend results for solar radiation. From this Table, it is apparent that all the twelve months (January to December) shown a decreasing trend. January, July and October indicated a decreasing trend at 5% significant level. February, April, May and June showed a decreasing trend at 0.1% ($\alpha = 0.001$) significance level. March, August, September and November on the other hand, have a decreasing trend at $\alpha = 0.01$(1% significant level). However, among the twelve-month only December shown decreasing trend without any significant level. It is also apparent from this table that the solar radiation for all the month from January to December shown decreasing trend magnitude with the rate of -0.040 $MJ/m^2/day$, -0.094 $MJ/m^2/day$, -0.060 $MJ/m^2/day$, -0.074 $MJ/m^2/day$, -0.071 $MJ/m^2/day$, -0.074 $MJ/m^2/day$, -0.060 $MJ/m^2/day$, -0.066 $MJ/m^2/day$, -0.061 $MJ/m^2/day$, -0.053 $MJ/m^2/day$, -0.062 $MJ/m^2/day$ and -0.031 $MJ/m^2/day$ respectively.

Table 1: Mann-Kendall with Sen's slope test results of the monthly Evaporation (1973-2018)

Months	First year	Last year	n	Mann-Kendall Z-statics	Sen's slope (β) value
January	1973	2018	45	-1.53	-0.011
February	1973	2018	45	-3.79 ***	-0.035
March	1973	2018	45	-1.67 +	-0.012
April	1973	2018	45	-2.06 *	-0.015

May	1973	2018	45	-1.16	-0.011
June	1973	2018	45	-1.07	-0.008
July	1973	2018	45	1.31	0.008
August	1973	2018	45	-1.72 +	-0.008
September	1973	2018	45	1.46	0.011
October	1973	2018	45	-0.91	-0.007
November	1973	2018	45	-1.51	-0.012
December	1973	2018	45	0.83	0.006

***trend at α= 0.001 level. **trend at α= 0.01 level. *trend at α= 0.05 level. +trend at α= 0.1 level.

Table 2: Mann-Kendall with Sen's slope test results of the monthly Solar radiation (1973-2018)

Months	First year	Last year	n	Mann-Kendall Z-statics	Sen's slope (β) value
January	1973	2018	45	-2.10 *	-0.040
February	1973	2018	45	-3.94 ***	-0.094
March	1973	2018	45	-3.05 **	-0.060
April	1973	2018	45	-3.50 ***	-0.074
May	1973	2018	45	-4.28 ***	-0.071
June	1973	2018	45	-3.84 ***	-0.074
July	1973	2018	45	-2.25 *	-0.060
August	1973	2018	45	-2.71 **	-0.066

September	1973	2018	45	-2.65 **	-0.061
October	1973	2018	45	-2.57 *	-0.053
November	1973	2018	45	-2.94 **	-0.062
December	1973	2018	45	-1.29	-0.031

***trend at α= 0.001 level. **trend at α= 0.01 level. *trend at α= 0.05 level. +trend at α= 0.1 level

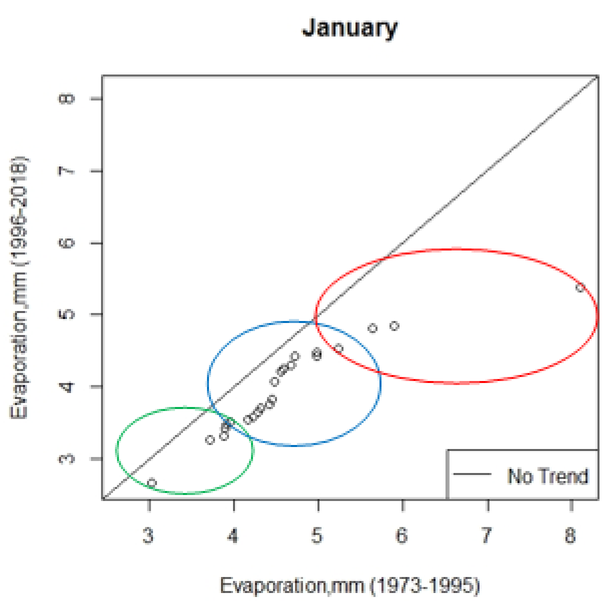
3.2. *ITAM results for evaporation and solar radiation*

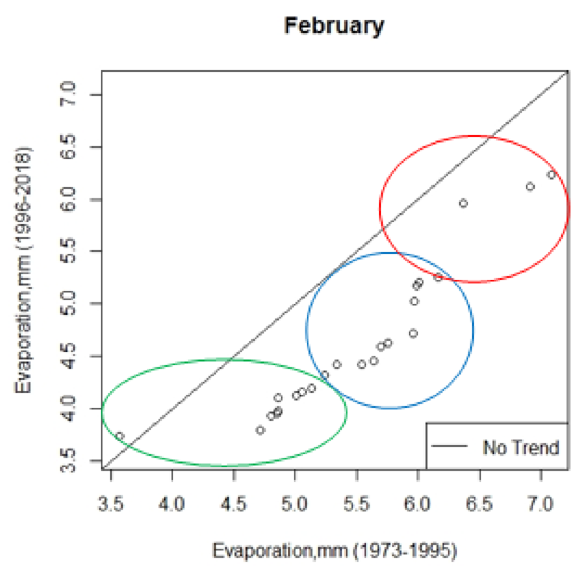
In this study, the ITAM results for monthly evaporation and solar radiation trends were obtained. The data for the variables distributed along the 1: 1 line were divided into low, medium and high groups after the study by Sen [19]. The results of the ITAM are presented in Figure 2 and Figure 3 respectively.

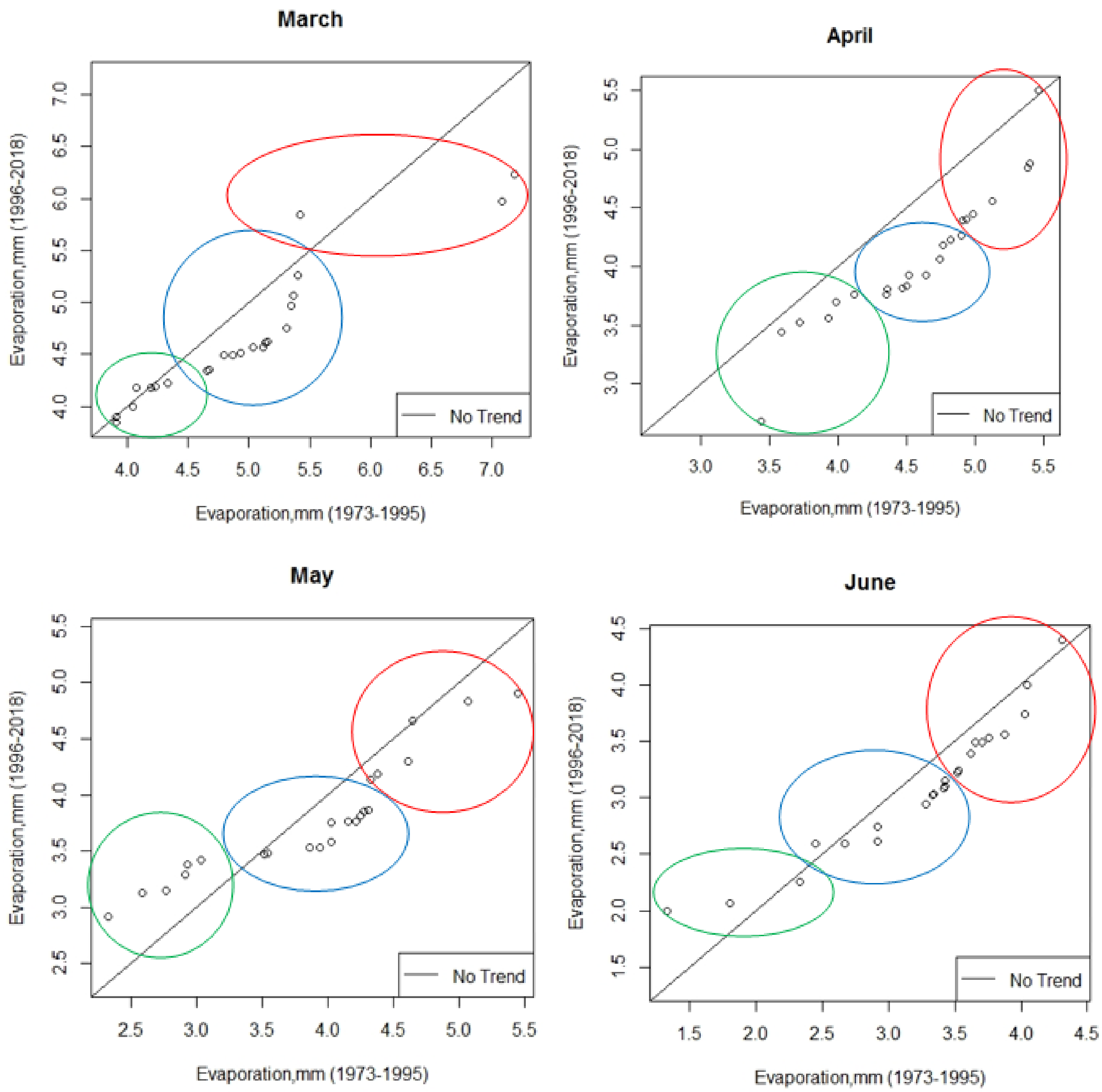
Evaporation ITAM result is presented in figure 2. From this figure, it is observed that the month of January shown a monotonic downward trend for low, medium and high duration values in the first half time series (1973-1995) with respect to the second half (1996-2018). In comparison, most of the evaporation values are occupied by the medium cluster (4 mm - 5.5 mm), and the trend of low evaporation values is shorter than in the medium cluster values. The months of February and April shows a significant monotonic declining trend (> 3.5 mm) for the low, medium and high values. In addition, the medium clusters value contained most of the evaporation duration in both months (February and April) while the high values have a short duration compared to the low evaporation groups in the month of February.

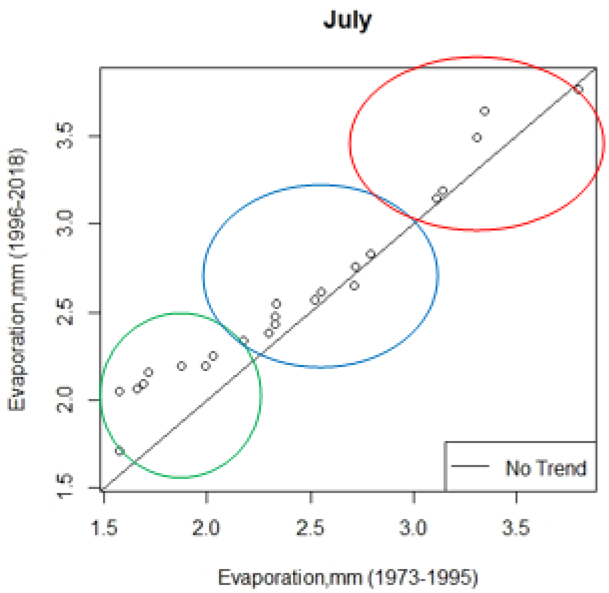
The low cluster values for the month of March, which is between 3.8mm and 4.5mm, indicates a free trend, as most of the values fell on the ideal 1:1 straight line, while high and medium values above 4.5 mm indicated a downward trend. The high values have a shorter duration compared to the evaporation values of the lower clusters, and most of the evaporation duration is contained in the medium cluster group, ranging from 4.7 mm to 5.5 mm. The months of June and August indicated an upward trend for low values above 1.8 mm with high and medium values having a downward trend of over 2 mm. However, for the month of July, most of the values shown an upward trend for low cluster values and almost free trend for medium and high cluster values since the values are so close to the ideal 1:1 straight line. Comparatively, the medium cluster values ranging from 2.2 mm to 3.8 mm contained most of the evaporation duration compared to the low and high cluster values. The month of November on the other hand, shown a downward trend in low and medium values, while a high value above 4.5 mm shown an upward trend. In addition, most of the evaporation time is occupied by the clusters of the low value group compared to the medium and high values.

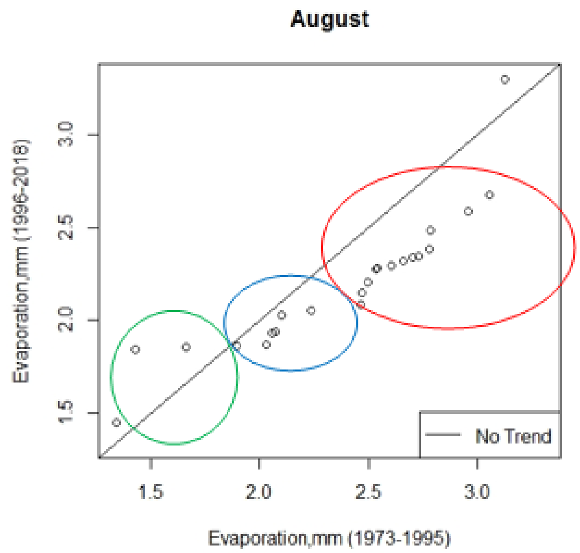
The low cluster value for the month of December of less than 3.5 mm indicated a monotonic increasing trend, while a medium values implied a decreasing trend and a high value greater than 4.5 mm indicated a rise in (increasing) trend. Furthermore, the medium values of the clusters in the range of 3.5 to 4.5 mm contained a greater proportion of duration compared to the low and high evaporation values.

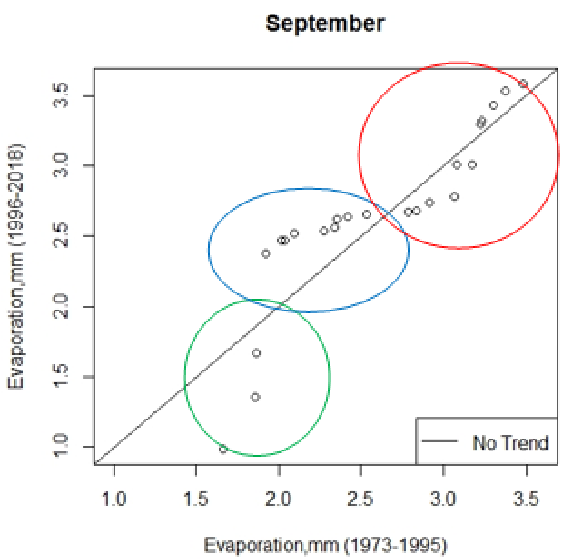


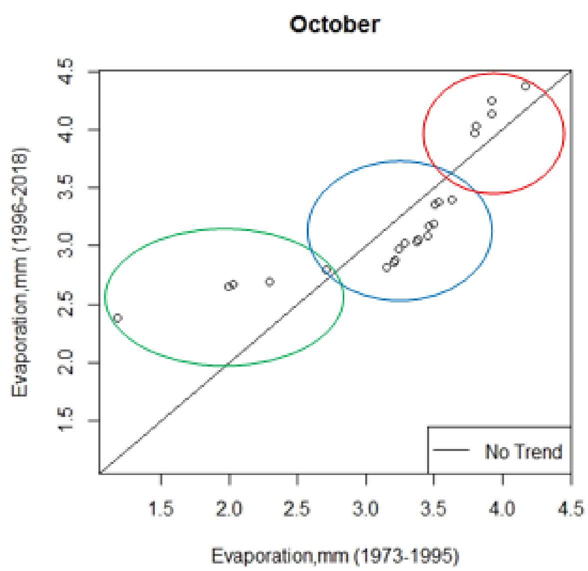



March
Evaporation,mm (1996-2018)
4.0 4.5 5.0 5.5 6.0 6.5 7.0
Evaporation,mm (1973-1995)
4.0 4.5 5.0 5.5 6.0 6.5 7.0
No Trend
April
Evaporation,mm (1996-2018)
3.0 3.5 4.0 4.5 5.0 5.5
Evaporation,mm (1973-1995)
3.0 3.5 4.0 4.5 5.0 5.5
No Trend
May
Evaporation,mm (1996-2018)
2.5 3.0 3.5 4.0 4.5 5.0 5.5
Evaporation,mm (1973-1995)
2.5 3.0 3.5 4.0 4.5 5.0 5.5
No Trend
June
Evaporation,mm (1996-2018)
1.5 2.0 2.5 3.0 3.5 4.0 4.5
Evaporation,mm (1973-1995)
1.5 2.0 2.5 3.0 3.5 4.0 4.5
No Trend


July
Evaporation,mm (1996-2018)
Evaporation,mm (1973-1995)
No Trend


August
Evaporation,mm (1996-2018)
Evaporation,mm (1973-1995)
No Trend


September
Evaporation,mm (1996-2018)
Evaporation,mm (1973-1995)
No Trend


October
Evaporation,mm (1996-2018)
Evaporation,mm (1973-1995)
No Trend

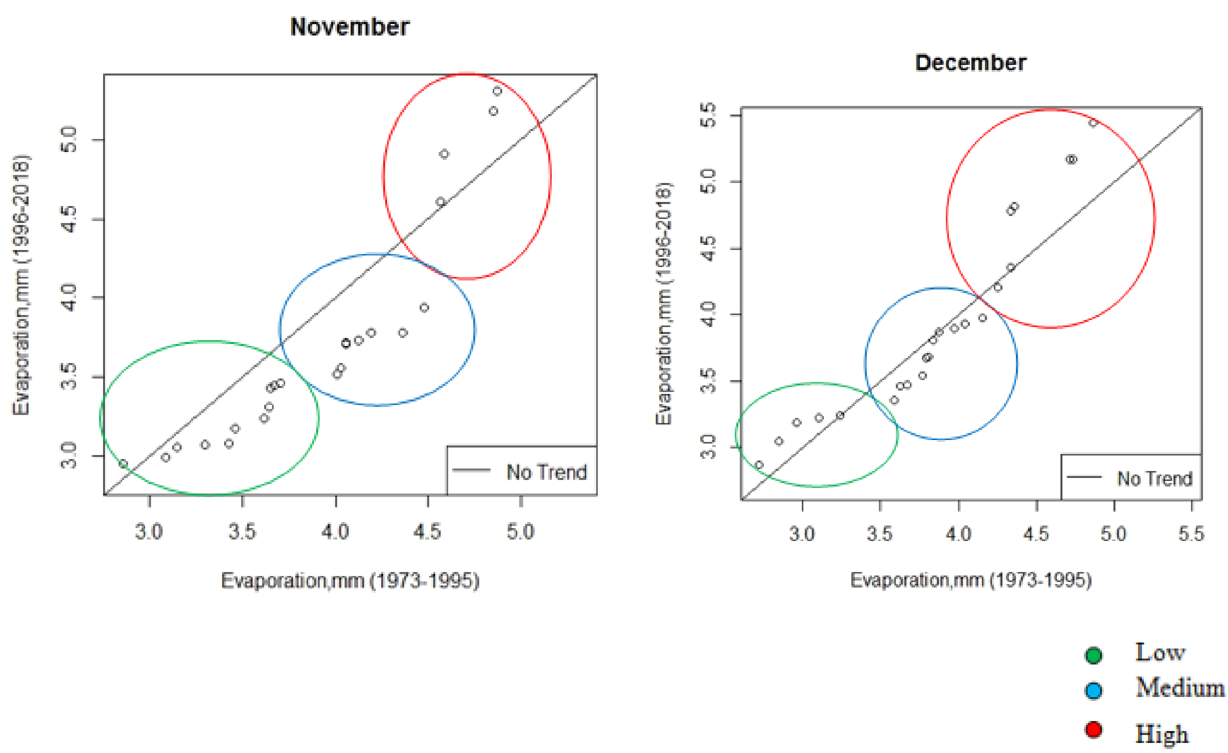
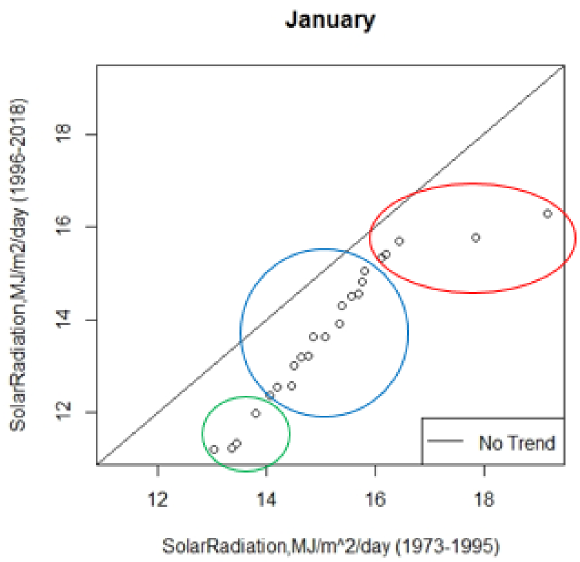
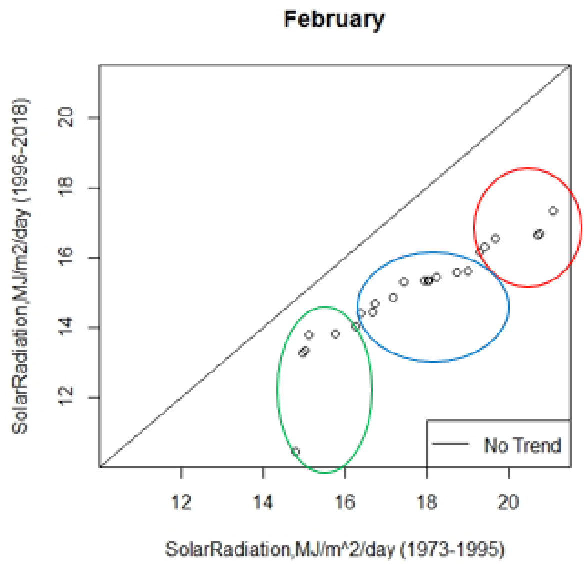


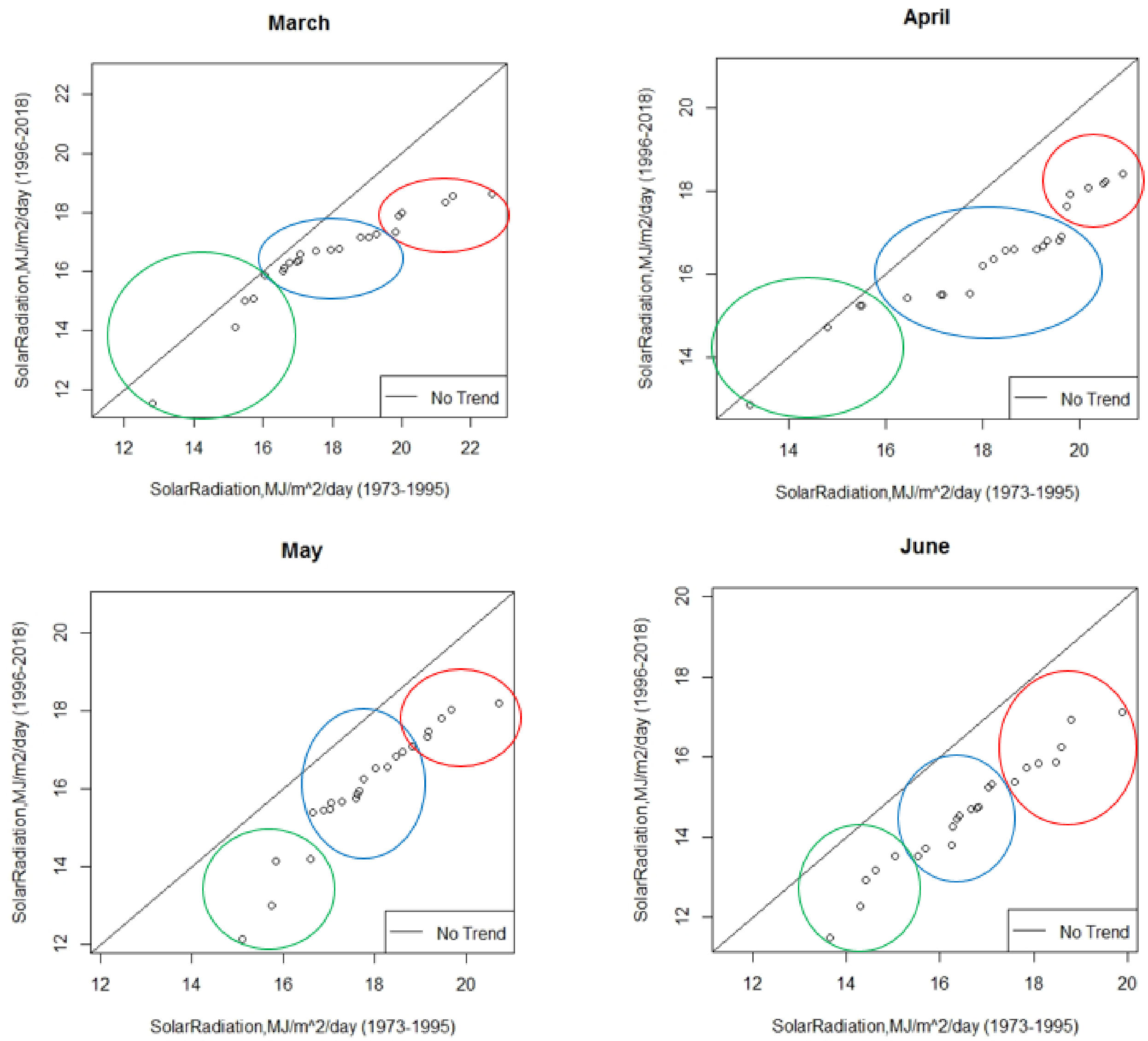
Fig.2. ITAM result for monthly evaporation

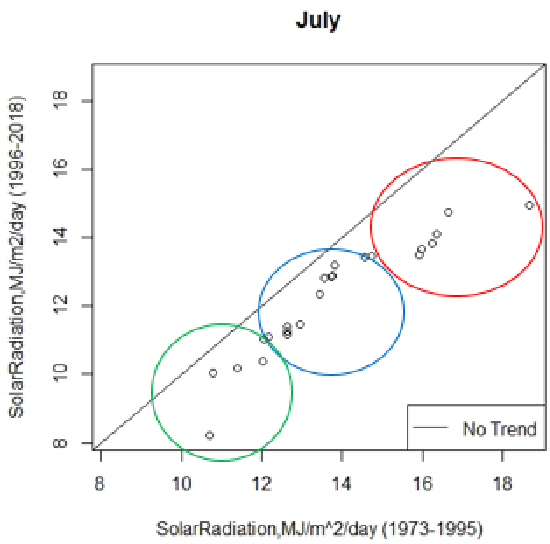
Figure 3 showed the monthly solar radiation result for the ITAM. From this figure, it is apparent that the month of January, February, March, April, May, June, July, August, September, October and November indicated a decrease in trend for the high, medium and low solar radiation values during the second half of the historic record (1996 – 2018) with respect to the first half (1973 – 1995). Most of the duration in these months is occupied in the medium cluster apart from the month of September which has most of its duration occupied by the high cluster solar radiation values. Furthermore, there are presence of significant trend component for these months ranging from January to November. The trend is said to be significant as the cluster values are distance away from the ideal straight line. Comparatively, solar radiation trends have a shorter duration in the low cluster values than in the high cluster portion.

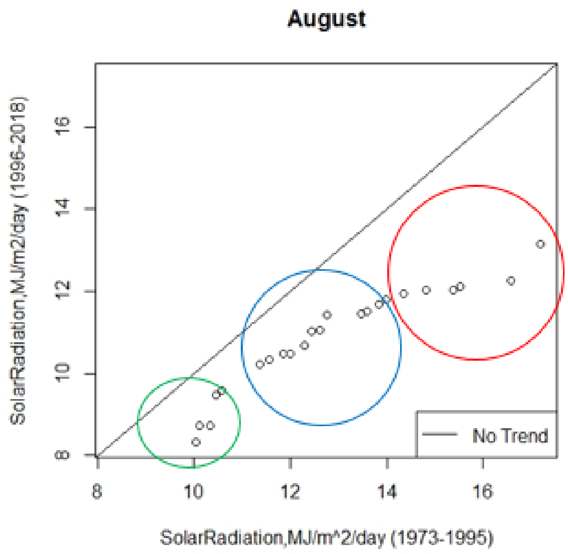
The month of December, however, showed a decreasing trend for the medium cluster solar radiation values (14 – 17 MJ/m^2/day) while the low and high values indicated a free trend. More so, in this month, medium cluster contained most of its' duration with the presence of significant trend component. Relatively, the low cluster values are greater than the high cluster portion.


January
SolarRadiation,MJ/m2/day (1996-2018)
18
16
14
12
12
14
16
18
No Trend
SolarRadiation,MJ/m^2/day (1973-1995)


February
SolarRadiation,MJ/m2/day (1996-2018)
20
18
16
14
12
12
14
16
18
20
No Trend
SolarRadiation,MJ/m^2/day (1973-1995)


March
April
May
June
No Trend
SolarRadiation,MJ/m2/day (1996-2018)
SolarRadiation,MJ/m^2/day (1973-1995)
12
14
16
18
20
22


July
SolarRadiation,MJ/m2/day (1996-2018)
SolarRadiation,MJ/m^2/day (1973-1995)
No Trend


August
SolarRadiation,MJ/m2/day (1996-2018)
SolarRadiation,MJ/m^2/day (1973-1995)
No Trend

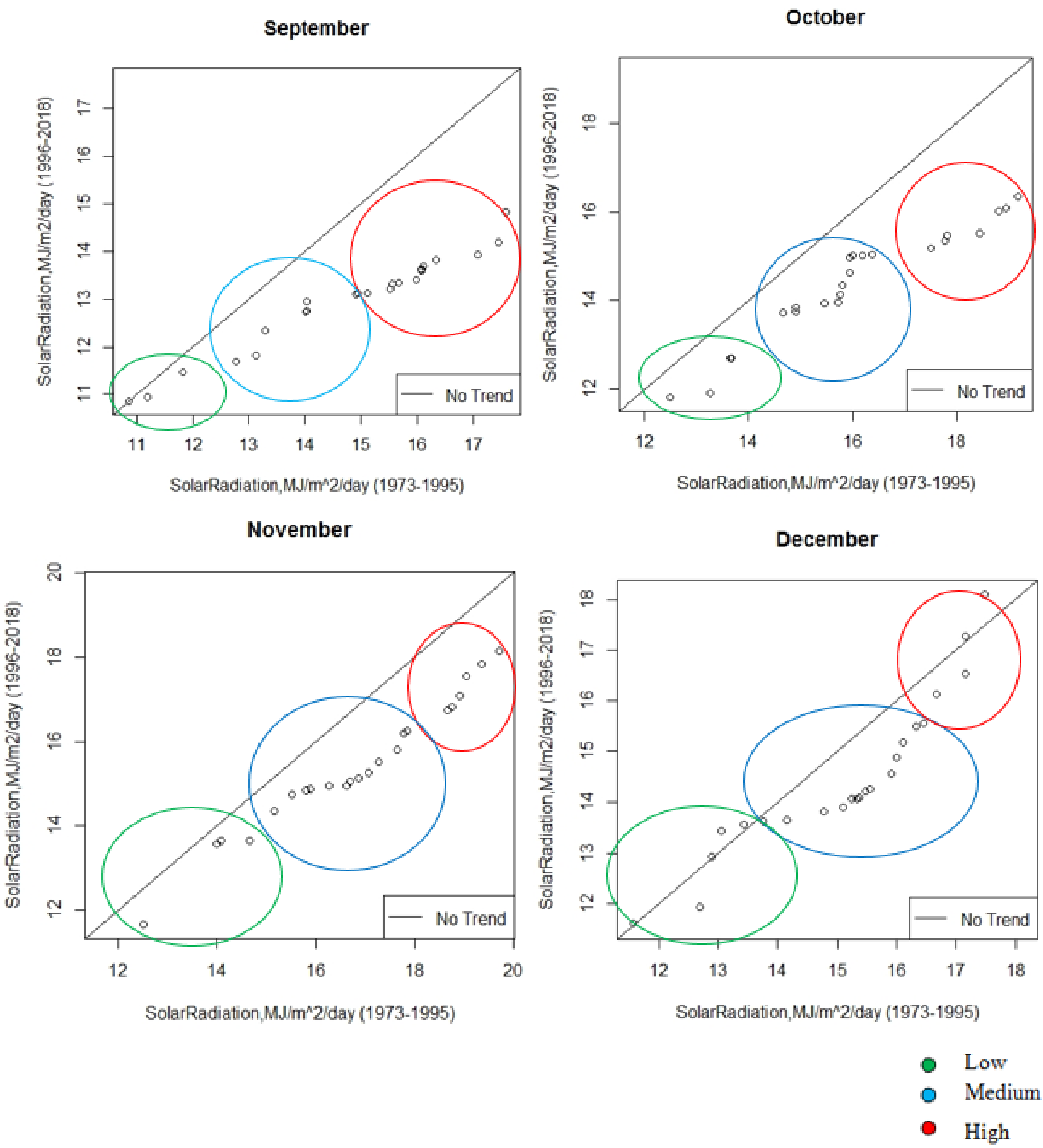


Fig.2. ITAM result for monthly solar radiation

3.3. *Comparison of trend analysis methods*

In this paper, the reliability of the innovative trend analysis method (ITAM) was tested by comparing the Mann-Kendall test with ITAM. It is particularly necessary to do the comparison because Sen [33] showed that the application of trend analysis have increased unprecedented in the last years due to global warming. The results obtained by this study shown that the ITAM and Mann-Kendall test agreed to some extent, however, some contrasting results were obtained which showed that ITAM has certain advantages compared to other trend tests.

The monthly evaporation results of the ITAM are consistent with the trend analysis results performed by the MK test, in particular during the months of January, February, March, April and July. In fact, February and April shown a significant downward trend for the Mann-Kendall test which is consistent with the result obtained with ITAM. The months of March and June, on the other hand, indicated a downward (decreasing) trend in the MK test and this result differs from that obtained with ITAM which indicated no trend for the low cluster values, while medium and high values shown a declining (decreasing) property. The month of August, with decreasing trend properties for Mann-Kendall test shown a different result from that obtained from ITAM, where low cluster values imply an increasing trend and a decreasing trend for medium and high cluster evaporation values. In addition, the months of October and December showed an increasing trend for low and high values, with a decrease in trend for medium evaporation values. However, this result is different from that obtained from the MK test, which just show that there is a decrease in properties for October and an increase in properties for the month of December. Hence the ITAM show trend properties which cannot be detected by the Mann-Kendall test. Over the twelve months, only two months show a non-significant upward (increasing) trend with the remaining months indicating a decrease in trend, and this contrasts with the study of Oguntunde *et al.* [5] where evaporation trend was reported to have decreased over the twelve months. However, this difference in results may be due to the difference in the number of years of the climatic variable considered. Over the study area, evaporation trend result shown that 75% of the months indicate decreasing trend and this may be likely to occur as a result of decline in solar radiation and may also be due to pollution. In a similar study by Grimenes and Thue-Hansen [34], they also reported that the consequence of reduction in solar radiation has resulted to steady decrease in rate of evaporation from open pans of water over the past five decades. The diurnal temperature ranges and an increase in low cloud cover was attributed to decrease in pan evaporation. On the other hand, similar study by Oguntunde *et al.*, [5], reported an increase in Epan size of about 58% of the months for Bet Dagan in Israel which have a maximum relative increase of 7% per decade in the month of November. Nevertheless, there has been an increase in potential evaporation over the past hundred years (1901-2002) in the Volta Basin in West Africa [35].

As regards the monthly solar radiation, the results of the ITA method agreed with the results of the trend analysis carried out by the MK test in particular in the months of January to November. In fact, all the months from January to November indicated a significant decreasing trend for ITAM result and this is similar to the trend result obtained for the MK test. However, only the month of December out of the twelve months for ITAM result has a free trend for low, high and decreasing trend for medium solar radiation values. At Ibadan, a significant decrease was found in almost all the months (January to November). The trend is said to be significant has the values clusters at a distance away from the ideal 1:1 straight line. The result of this study agreed with the study of Oguntunde *et al.* [5] who observed that solar radiation was found to decrease in all the months over Ibadan city. Also, monthly and year to year solar radiation significantly reduced for the period examined. The reduction of global radiation in south-eastern Norway for the period of 50 years was also observed by Grimenes and Thue-Hansen [34]. However, there is a slight contrast to the work of Oguntunde *et al.* [5] as regards the month December where the ITAM results revealed free trend for low and high cluster values and this may be as result of the difference in the number of years of climatic variables considered. The decrease in solar radiation observed in this study agreed with the widespread decrease, termed 'global dimming', which has been reported in the study of Stanhill and Cohen [36]. This reduction in solar radiation trend must be due to atmospheric changes when increase in cloudiness and aerosol concentration occurred [36,37]. The burning of fossil fuels is partially connected to atmospheric changes which links global warming to the reduction in global radiation. Hence, global dimming could be seen as a negative feedback to the process of global warming. Furthermore, 'harmattan', a hot and highly dust-laden wind which blow from the Sahara Desert always occur in the month of December to February. During this period, Ogunjobi *et al*. [38] reported that the dust haze from the Northeast Trade Wind tends to prevent all possible solar radiation from reaching the soil surface since these months are known generally to have low clearness indices and this could cause decrease solar radiation over these months.

4. CONCLUSIONS

In this study, trends in monthly evaporation and solar radiation were examined using the innovative trend analysis method (ITAM) and also by Mann-Kendall with Sen's slope test in Ibadan metropolis, Nigeria.

The monthly evaporation trend result shown that 75% of the months indicate decreasing trend with the month of January, February, March, April, May, June, August, October and November having a trend magnitude which decreases at the rate of 0.011 mm / year, 0.035 mm / year, 0.012 mm / year, 0.015 mm / year, 0.011 mm / year, 0.008 mm / year, 0.008 mm / year, 0.007 mm / year and 0.012 mm / year respectively. This decrease in evaporation conforms with previous studies over the study area and this has been linked to decrease in solar radiation over the decades. As regards solar radiation all the months indicates decreasing trend with the months of January, July and October shown a decreasing trend at 5% significant level. February, April, May and June shown a decreasing trend at 0.1% significance level while March, August, September and November have a decreasing trend at 1% significance level. The decreasing in solar radiation observed in this study conform with the widespread decrease, termed global dimming which occurred as a result of increase in cloud and aerosol concentration.

The results obtained from the ITAM for evaporation and solar radiation is similar to the ones obtained through the Mann-Kendall test except in some months. For instance, as regards solar radiation in the month of December, the MK test shown only decreasing trend for the month while ITAM signifies decreasing trend for medium cluster values with no trend for low and high values. Therefore, its apparent that the ITAM indicated trends that could not have been detected by the Mann-Kendall test and this gave the innovation trend analysis method some advantages over the other trend analysis methods. Some of the advantages includes that: it excludes all hypotheses (such as: test number, serial relationship and non-normality, etc.) in relation to the Sen's and MK trend test and also that the trends of high, medium and low data can be represented graphically and effectively distinguished by ITAM. This new method can therefore be applied in climate change scenarios and can provide a priori views to engineers, authorities and designers.

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