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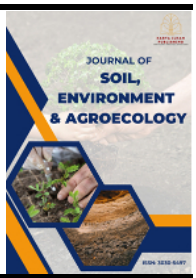
Journal of Soil, Environment & Agroecology

Journal homepage:
https://karyailham.com.my/index.php/sea/index
ISSN: 3030-5497



Emerging Trends in Agro Climatic Parameters in Malawi: Has Rainfall Changed?

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ARTICLE INFO

Article history:
Received 30 November 2024
Received in revised form 20 January 2025
Accepted 14 February 2025
Available online 15 March 2025

Keywords:
Rainfall; dry spell; trend; climate; Malawi

ABSTRACT

Climate change and variability in Malawi have had a wide impact on rain-fed agricultural production. The recent climatic events suggest new trends in agro-climatic parameters such as dry spell length, total annual rainfall, and planting dates. However, there is dearth of understand the emerging trends on the agro-climatic parameters in Malawi. Both parametric and non-parametric trend tests were used to quantify the strength of trends on a 49-year series of historical rainfall data from eight meteorological stations across Malawi. The results show that, while there is no change in dry spell length across the country, there is an increase in the number of dry spells and a decrease in the number of rainy days per growing season. Thus, there is a slight decrease in total annual rainfall with high variability. Suitable planting dates have also shifted towards later days in the season, resulting in a shorter growing season accompanied by high- intensity rainfall. This study indicates significant changes in the rainfall pattern in Malawi in specific areas, especially in the north. Therefore, it is imperative to consider early maturing varieties, in-field water harvesting structures, efficient irrigation systems, and extension services to farmers to adapt change of agricultural calendar.

1. Introduction

Being a southern African country, Malawi has a relatively dry sub-tropical climate, which is seasonal. The warm-wet season lasts from November until April and it is responsible for the majority (95%) of the annual precipitation that falls during this time period. Its economy is based on rain-fed agriculture in which crop production and the choice of crops that can be grown are primarily determined by climatic and soil factors. Both these factors they determine crop production, including the choice of crops can be grown. Thus, the amount and distribution of rainfall significantly affect crop production. For this reason, having a comprehensive understanding of the precipitation pattern

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https://doi.org/10.37934/sea.4.1.110 a

in Malawi is a necessary precondition for agricultural planning and economic development [1]. Furthermore, in order to effectively plan and manage water resources, agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling, water resource assessments, climate change impacts, and other environmental assessments, it is essential to have a comprehensive understanding of the temporal and spatial characteristics of rainfall [2]. Henceforth, it is important to check the trends of agro-climatic patterns.

This research has focussed on rainfall which has been described as the primary limiting factor for crop production in most parts of the tropics [3,4] and also a critical climatic variable that underlies both droughts and floods [5]. Across the course of history, numerous investigations on the temporal and spatial aspects of rainfall have been carried out all across the world as well as in southern Africa. For instance, Fauchereau *et al.,* [6] reported there have been notable changes in rainfall patterns in southern Africa, particularly in the last few years. Droughts, in particular, have increased in severity and distribution. Reportedly, there was a reduction in the average intensity of precipitation and an escalation in the length of dry spells from 1961 to 2000 [7]. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) documented an upward trajectory in the volume of precipitation from 1901 to 2005 from the equator towards tropical eastern Africa, and conversely, a downward trajectory in Africa south of 20o S latitude. The IPCC also observed an escalation in the duration and severity of dry spells in southern Africa [8]. Various researchers have conducted studies examining the rainfall patterns in Malawi [9-11]. These studies focussed more on the rainfall variability and its impact on the catchments in Malawi.

The Department of Climate Change and Meteorological Services has recently stated that there are signs indicating a shift in precipitation patterns, leading to more frequent extreme weather events such as droughts and floods. The occurrences of floods and droughts in Malawi during the 2014/15, 2015/16, and recent seasons highlight the necessity for a comprehensive study to comprehend the evolving trends in agro-climatic variables. This understanding is crucial for assessing the impact of any alterations in rainfall patterns, particularly on agricultural crops. Therefore, this study presents the trends of agro-climatic indices for selected stations in Malawi.

2. Materials and Methods

2.1 Study Site and Meteorological Data

The study was conducted in Malawi, where 8 meteorological stations (Figure 1) across all the regions in the country were used. The stations cover a wide range of climatic zones as categorized by the Department of Climatic Change and Meteorological Services (DCCMS). A 50-year series of daily rainfall data from each of the selected 8 stations was collected from the DCCMS (Table 1) and checked for completeness. All the stations had complete data sets.

The stations cover a wide range of climatic zones as categorized by the Department of Climatic Change and Meteorological Services (DCCMS). The agro ecological zones as demarcated by DCCMS are as follows. CZ1 is Shire valley. This covers areas along Shire River, Lake Chilwa and Lake Chiuta including valleys surrounding these lakes. CZ2 is Southern highlands. This covers areas in the Shire highlands, Kirk range up to Dedza. CZ3 is a central area. This covers Lilongwe, Mchinji, Dowa, Ntchisi, Kasungu and part of Mzimba Districts. CZ4 is Lakeshore areas. This covers all areas along Lake Malawi. CZ5 is Northern areas. This covers all areas north of Mzimba. A 50-year series of daily rainfall data from each of the selected 8 stations was collected from the DCCMS (Table 1) and checked for completeness. All the stations had complete data sets.

Table 1
Detailed description of the locations of the meteorological stations that were utilized in the research

Station	Longitude (°S)	Longitude (°E)	Altitude (m.a.s.l)	Agro-ecological zone
Bvumbwe	35.06	-15.91	1146	Southern highlands
Chitedze	33.63	-13.98	1149	Central areas
Karonga	33.88	-9.95	529	Northern areas
Kasungu	33.46	-13.01	1015	Central areas
Mzimba	33.61	-11.88	1351	Northern areas
Mzuzu	34.01	-11.45	1253	Northern areas
Ngabu	34.95	-16.5	102	Shire valley
Salima	34.58	-13.75	513	Lake shore areas

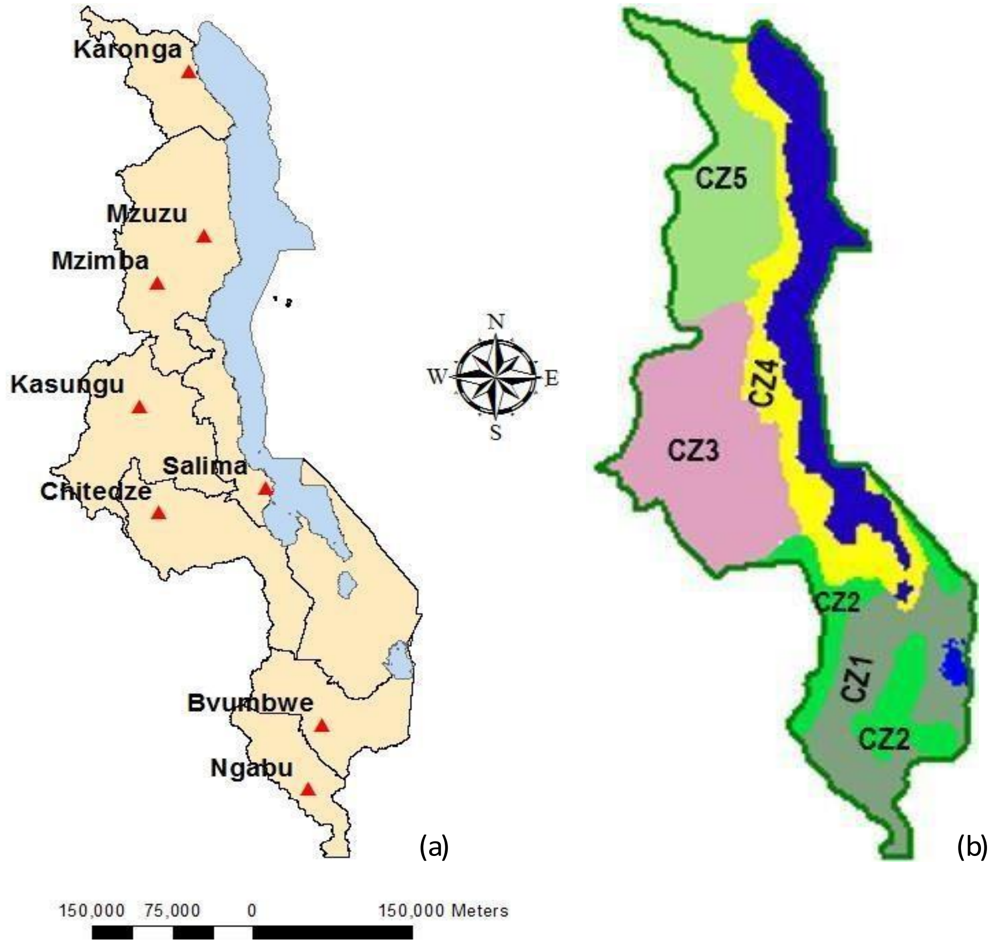

Fig. 1. (a) Map of Malawi showing the stations used in this research, (b) different agro-ecological zones as described by Department of Climatic Change and Meteorological Services. CZ1: Shire valley; CZ2: Southern highlands; CZ3: Central areas; CZ4: Lakeshore areas; CZ5: Northern areas

2.2 Total Annual Rainfall, Number of Rainy Days in a Growing Season, Planting Date, Number of Dry Spells, and Duration of Dry Spell (Dry Spell Length)

Total annual rainfall for each station was calculated as a sum of all rainfall recorded from 1st July in the current year to 30th June the next year. The calculation period was set on these dates to depict the peak rainfall months easily. Areas in the southern hemisphere with a unimodal rainfall pattern like Malawi, the peak period is usually around December and January.

The length of the growing season was calculated as the number of days between first and last agronomically important rainfall events. As advocated by the Ministry of Agriculture in Malawi, the date of the first agronomically important first rainfall event is the date of occurrence of the first day after 1st July with precipitation of over 20 mm. The date of last agronomically important rainfall event is the date of occurrence of last day with precipitation of more than 5 mm after 15th April [12].

Planting date was determined as date of start of any period in between 1st October and 15th February when crop specific conditions are met. The conditions set were that the first day within the growing season with a total rainfall of over 25 mm, on the condition that it is followed by a period of 13 or more days with at least accumulative precipitation of over 20 mm [12,13].

Number of rainy days in the agronomic growing season was calculated after determining the planting date as number of rainfall events in an agronomic season. For reference, the agronomic season in this paper was set at 120 days as most important crops in Malawi will have matured by the 120th day.

Number of dry days during the agronomic growing season was calculated after determining the planting date as number of days with rainfall of less than 2.5 mm in the growing season. This value was selected as rainfall less than 2.5 mm cannot significantly contribute/influence crop development in regions that experience pan evaporation of around 5 mm/day [14].

A dry spell was determined as any period of 5 or more consecutive days with precipitation of less than 2.5 mm per day during the agronomic growing season. This enabled the calculation of dry spell lengths within the growing season.

2.3 Trend Analysis

2.3.1 Test of randomness and persistence

When attempting to identify trends in time series, it is necessary to have data that is both random and persistent [1]. This test solves the effect of serial dependence when interpreting the results, especially in cases where the data contain positive correlations, the non-parametric test can give false results. The random effect of the data set can indicate a significant trend erroneously [15]. Therefore, in this study, an autocorrelation function was utilized to test the randomness and independence of the rainfall time series for each station. Additional information regarding this function may be found below [15]:

$$r_k = \frac{\sum_{i-1}^{N-k}(x_i-\bar{x})(x_{i+k}-\bar{x})}{\sum_{i-1}^{N}(x_i-\bar{x})^2} \tag{1}$$

where r_k is the autocorrelation coefficient for the lag–k interval, $\bar{x}$ is the mean value of a time series x_i, N is the number of observations, and k is the delay in time. Every time lag separation is accompanied by autocorrelations that are close to zero for random series, with the exception of the zero-lag coefficient, which is always 1. On the other hand, statistical tests are applied directly to the series in this scenario. Non-random series are characterized by autocorrelation values that are considerably non-zero and have a value of ≥1. In this particular scenario, statistical tests are done to a pre-whitened series in order to take into consideration the non-randomness.

2.3.2 Mann-Kendal test

It is recommended by the World Meteorological Organization [16] that the non-parametric Mann-Kendall (MK) test statistic [17,18] be utilized for the purpose of evaluating trends in meteorological data. The MK test is characterised by its simplicity, robustness, and reduced sensitivity to outliers and missing data [19]. When dealing with data series that do not follow a normal distribution, such as rainfall, the test is also recommended [20]. There have been several other trend-detection studies that have made extensive use of the MK test [1,12,13,19,21]. The MK test was utilized in this investigation at a significance level of 5% in order to identify temporal trends in a number of agronomic variables that were chosen. The test statistic is computed as follows:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if} \quad S < 0 \end{cases} \tag{2}$$

in which

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{3}$$

In the event that there is a possibility of ties (that is, equal values) in the x values, the variance of S can be expressed as follows:

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)] \tag{4}$$

that x_j and x_i represent the values of the sequential data, m is the number of groups that are tied together (a tied group is a collection of sample data that all have the same value), t_i is the number of data points in the ith group, n is the length of the data set, S is the MK test statistic, Z_{MK} is the normalized MK test statistic and $sgn(x_j - x_i)$ is equal to 1, 0, −1 if $(x_j - x_i)$ is greater than, equal to, or less than zero, respectively [19]. The presence of a statistically significant trend is evaluated using the Z_{MK} value. The positive (negative) values of Z_{MK} indicate increasing (decreasing) trends, and the value $Z_{1-\alpha/2}$ denotes a quantile of the standard normal cumulative distribution. The null hypothesis H_o should be accepted if $-Z_{1-\alpha/2} \leq Z_{MK} \leq Z_{1-\alpha/2}$ at a given level of significance (where α is a chosen level of significance).

2.3.3 Coefficient of variation

The coefficient of variation (CV) was calculated to evaluate the variability of the indices by dividing the standard deviation of the index by its mean.

3. Results and Discussion

3.1 Serial Correlation

The time series of rainfall and air temperature for each station did not exhibit any significant serial relationships at any of the lags that were examined. None of the stations are correlated to one another in any way (Table 2). Therefore, the time series were deemed random, meeting the independence distribution criteria. Consequently, the analysis of the trends of the agronomic indices did not require any further data manipulation, and the MK test was applied directly.

Table 2
Cross correlation between station (rainfall)

	Bvumbwe	Chitedze	Karonga	Kasungu	Mzimba	Mzuzu	Ngabu	Salima
Bvumbwe	1	0.12	0.21	0.28	0.02	0.18	0.09	0.15
Chitedze		1	0.19	0.34	0.23	0.06	0.17	0.29
Karonga			1	0.05	0.11	0.28	0.25	0.33
Kasungu				1	0.31	0.36	0.12	0.18
Mzimba					1	0.42	0.37	0.22
Mzuzu						1	0.24	0.07
Ngabu							1	0.14
Salima								1

3.2 Total Annual Rainfall

Most of the stations have high mean annual rainfall albeit Kasungu, Ngabu, Chitedze and Mzimba (Table 3). The standard deviation is high and coefficient of variation (>20%) in almost all areas. This reflects the fact that rainfall over Malawi is highly variable in each season, a result that fits the zone in which Malawi is located. This is in agreement with Tadross *et al.,* [22] also observed a high variability in rainfall in the south-eastern Africa where Malawi is located.

The high variability of rainfall in Malawi is not only caused by the geographical features, but also the air mass, which brings moisture over Malawi. The usual air masses which bring rainfall over Malawi are the Inter-Tropical Convergence Zone (ITCZ) and the Congo air mass. The movement of the ITCZ varies in its timing and intensity from year to year [23], hence the high variability. The MK test shows that there is an increasing trend in total annual rainfall Bvumbwe, Salima, Kasungu and Ngabu. In contrast, a decreasing trend is shown in Mzuzu, Chitedze, Karonga and Mzimba with as statistically significant trends in Karonga and Mzuzu. These results are in line with past observation [24] that reported a significant decreasing trend in Karonga. This observation means that there is a need for the immediate attention of water management options for agriculture. An example of the actions could be in-field water harvesting structures to take care of the dry periods during the rainy season. For the other stations or areas which have shown positive trends and a lot of rainfall, mostly the problem in these areas is the temporal distribution of seasonal rainfall and not the cumulative total and as a result, some crops may be affected as they tend to be sensitive to variations if they happen during critical periods of their growth.

Table 3
Statistical summary of total annual rainfall over the period 1961 to 2001

Statistic	Station							
	Bvumbwe	Salima	Mzuzu	Kasungu	Ngabu	Chitedze	Karonga	Mzimba
Mean (mm)	1141	1232	1221	773	779	876	1087	858
SD (mm)	255	362	246	168	198	178	296	160
Z_{mk}	1.33	0.80	-4.53*	0.53	1.41	-0.13	-10.29*	-1.62
CV (%)	22	29	20	22	25	20	27	19

Note: Zmk, Mann-Kendal trend test; *statistically significant trend (α = 0.05); SD, standard deviation; CV, coefficient of variation

3.3 Number of Rainy Days in the Growing Season

From Table 4, it can be noted that almost all stations have seasons with several rainy days greater than 30 with a standard deviation of around 10 days. The variability nature of the area is also depicted with CV values of >20% in most of the stations. There is a general decreasing trend in six stations in the number of rainy days with Karonga having a significant trend. However, a non-significant positive trend is observed in Bvumbwe and Ngabu.

This phenomenon was expected due to the variable nature of the rainfall over Malawi. The temporal distribution and intensity of the rains depend mainly on the geographical features of the area and the general characteristics of the rainfall in the study area [22,24]. The altitude at which these stations are located has an effect, a good example is Bvumbwe station is on a high altitude while Ngabu is at the low altitude and in a rain shadow behind the shire highlands.

Table 4
Statistical summary of number of rainy days in a growing season over the period 1961 to 2001

Statistic	Station							
	Bvumbwe	Salima	Mzuzu	Kasungu	Ngabu	Chitedze	Karonga	Mzimba
Mean (days)	47	43	51	38	30	41	46	44
SD (days)	10	10	8	9	7	9	8	9
Z_{mk}	0.08	-0.06	-0.09	-0.14	0.04	-0.10	-0.12*	-0.03
CV (%)	22	23	15	22	24	23	17	20

Note: Zmk, Mann-Kendal trend test; *statistically significant trend (α = 0.05); SD, standard deviation; CV, coefficient of variation

3.4 Number of Dry Spells

In all stations, there is a general observation of insignificant trends in the number of dry spells, with Mzimba having a negative trend (**Error! Reference source not found.**). The mean number of dry spells hover around 5 with a low (< 3 days) standard deviation.

The results suggest that the selected stations face similar phenomenon (as rain-bearing systems over Malawi) regardless of their geographical position. The ITCZ and the Congo air masses, which are the main rain-bearing systems that pass over Malawi, have similar effects in almost all meteorological stations in all agro-ecological zones. These results are in agreement with other observations [7,25], which have reported similar trends in southeastern Africa. The insignificant trends might be attributed to the el Niño and la Niña effects. The coefficient of variation in the number of dry spells is high >20%, which cements the fact that Malawi has a variable rainfall pattern hence not easily predictable. It has been reported that the problem in the study area is probably the temporal distribution of seasonal rainfall and not the cumulative total [24]. As a result, the yield of most of the cereal crops such as maize tends to be sensitive to variations in dry conditions such as length of dry spells.

Table 2
Statistical summary of number of dry spells over the period 1961 to 2001

Statistic	Station							
	Bvumbwe	Salima	Mzuzu	Kasungu	Ngabu	Chitedze	Karonga	Mzimba
Mean (days)	4	5	4	5	6	5	5	4
SD (days)	2	2	1	1	1	2	2	1
Z_{mk}	0.03	0.02	0.01	0.01	0.01	0.01	0.01	-0.01
CV (%)	38	31	42	27	22	37	36	35

Note: Zmk: Mann-Kendal trend test; *statistically significant trend (α = 0.05); SD: standard deviation; CV: coefficient of variation

3.5 Duration of Dry Spells

Similar as in the number of dry spells, the duration of dry spells follows the same pattern (See Table 6). Salima has a significant positive trend but has a high standard deviation on the duration and coefficient of variation. This indicates that farmers in Salima experience occasional dry spells due to the high variability of the rains. The rest of the stations report non-significant trends, but still higher CV values are observed.

These results confirm the behavioural patterns of the rains over Malawi, that the variability of the rains is the order of the day. Several studies [1,10,12,13,22] reported similar cases in terms of the rainfall variability in southeastern Africa.

Table 6
Statistical summary of duration of dry spells over the period 1961 to 2001

Statistic	Station							
	Bvumbwe	Salima	Mzuzu	Kasungu	Ngabu	Chitedze	Karonga	Mzimba
Mean (days)	8	9	7	8	9	9	7	7
SD (days)	2	5	2	3	3	4	2	2
Z_{mk}	0.01	0.06*	-0.04	-0.01	0.01	0.01	-0.01	0.02
CV (%)	28	54	33	32	31	42	29	23

Note: Zmk, Mann-Kendal trend test; *statistically significant trend (α = 0.05); SD, standard deviation; CV, coefficient of variation

3.6 Planting Dates

As shown by Table 7, all the stations are experiencing a forward shift of the planting dates from the expected late October to early and mid-December. The effect of the variability in the rainfall can be observed from the high standard deviation on the planting dates as well as high CV values.

Table 3
Statistical summary of planting dates over the period 1961 to 2001

Statistic	Station							
	Bvumbwe	Salima	Mzuzu	Kasungu	Ngabu	Chitedze	Karonga	Mzimba
Mean (date)	20 Nov	3 Dec	20 Nov	3 Dec	14 Dec	30 Nov	3 Dec	1 Dec
SD (days)	17	14	22	15	19	18	16	17
Z_{mk}	0.21	0.25	0.19	0.17	-0.14	0.39*	0.41*	-0.06
CV (%)	12	9	15	10	13	12	11	11

Note: Zmk, Mann-Kendal trend test; *statistically significant trend (α = 0.05); SD, standard deviation; CV, coefficient of variation.

Worth noticing are two stations, Chitedze and Karonga, showing significant positive trends in the planting dates. Farmers in these areas should revise their farming calendars in order not to miss out on the suitable planting period. The variability could also trigger the development of new cultivars, which can suit the short rainy seasons and heavy downfalls usually experienced during the past few years. The shifting of planting dates has been reported over central Malawi by other researcher [12], who looked at onset dates, cessation and length of the growing period. The study found out that the planting dates are shifting forwards, and these results confirming the same with an extensive data set. Other researchers got similar results in the region with the same climatic conditions: in Zambia [13] and South Africa [22].

6. Conclusion

The study indicates that significant changes in rainfall pattern in Malawi in specific areas, especially in the extreme north, and not all across the country. The differences in geographical features, including the altitude and location (leeward or windward side), including the huge lake in the eastern side of Malawi has an effect on the pattern. The extreme north of the country is experiencing decreasing trends in annual and seasonal rainfall and the number of rainy days per season. The area is also experiencing shifting of onset of rains to later dates while cessation of rains is shifting to earlier dates resulting in decreasing trends in length of the rainy season. No significant trends are observed in annual and seasonal rainfall or duration of the rainy season for the stations in the other parts of the country. Significant increasing trends in maximum daily rainfall and longest dry spells are being experienced in some areas in the centre of the country. In contrast, other parts of the country are unaffected. Other areas of the centre are experiencing significant decreasing trends in rainy days per season, just like extreme north, an indication of increasing trends in the frequency of dry spells. With these findings it is, therefore, imperative to for farmers to consider early maturing varieties although having low potential yields. Other suggested mitigating ways include in-field water harvesting structures, efficient irrigation systems, and extension services to farmers on change of agricultural calendar.

Acknowledgements
For the provision of data that was utilized in this investigation, the authors would like to express their gratitude to the Department of Climate Change and Meteorological Services.

Author Contribution
Lameck FIWA is the corresponding author of this publication as he made the paper to be publishable and organised all resources and contributions from co-authors. Therefore, his contribution is of paramount important to this research. Kenneth Alfred WIYO was the advisor in this publication and he contributed more in the scientific inference and discussion of the results. Kenneth is a seasoned water resources engineer whose ideas shaped this paper to be at this stage. Stanley PHIRI and Mwabuke NKHATA contributed much in the analysis of the data. The two are MSc students in the Agricultural Engineering Department. They are doing MSc Irrigation Engineering. Celray James CHAWANDA contributed in the methods of data analysis. He took a critical statistical analysis of the results and he organised the introductory part of this paper. Charles VANYA checked the quality of the data used in this research as well as the discussion of the results with the meteorological view. The authors believe that the contributions by each one of them are substantial and the paper could not be in this form if their contribution were not taken aboard.

Conflict of interest
None of the writers have any conflicts of interest to declare. It should be noted that the sponsors of the money did not play any part in the design of the study, the collection, analysis, or interpretation of the data, the writing of the paper, or the decision to publish the results.

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