Rainfall Variability and its Implications for the Transferability of Experimental Results in the Semi Arid Areas of Tanzania

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Abstract

Most of agricultural activities in semi-arid areas of Tanzania depend on direct rainfall. Consequently, any significant variation in the temporal and spatial distribution of rainfall usually results in serious shortage of soil-water available to plants and thus poor crop and livestock production. In this paper the variability and reliability of rainfall in four representative areas of the semi-arid lands in Tanzania namely Hombolo (Dodoma); Morogoro (Morogoro); Kisangara (Kilimanjaro) and Ngudu (Mwanza) is examined. The start and end of the rains and the occurrence of long dry spells within the seasons are also analysed. The result showed that during the long rainy season, the seasonal rainfall for Kisangara and Morogoro were only 525 mm and 445 mm respectively. During the short rains, the seasonal average rainfall was 359 mm and 327 mm for Kisangara and Morogoro respectively. For Hombolo which ha monomodal rainfall, the seasonal mean was 592 mm. Apart from seasonal mean rainfall being low, the seasonal rainfall variability expressed by the coefficient of variation (CV) was also observed to be high. Kisangara and Morogoro had CV's of 20% and 50% during long rainy season respectively. During short rainy season the CV's were 49% and 42% respectively. Hombolo had a CV of 24%. Analysis of long-term rainfall characteristics for Morogoro and Kisangara revealed that these areas experience dry spells of various lengths during the seasons. At Kisangara for example, dry spells of 15 days with 30% probability may occur during short rainy season, while in long rainy season dry spells of more than 14 days at 30% chances do occur in the rest of the months except April. These results form a good basis for explaining the performance of soil-water conservation measures including rainwater harvesting in the semi-arid areas of Tanzania.

Key words: Rainfall variability, dry spells, transferability, rainwater harvesting, agrometeorology

Introduction

Rainfall in the semi-arid areas of Tanzania is variable with respect to both time and space. Long term cycles or cyclic swings in climate are often important. Consequently, probability studies or computation of long term means are very likely to lead to erroneous conclusions, unless consideration is given to the position of the period of record in the cycle or swing. Likewise, the marked variation, in semi-arid climates, among the seasons of the year may require segregation of data by season. A combination of factors common in one season of the year may be virtually non-existent during another season. In addition, a particular combination of factors may exist for only a few days in several years and may render the computations based on average values grossly erroneous. Rainfall also varies greatly among different parts in the semi-arid areas of Tanzania, and indeed even within a catchment.

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For example, a high elevation zone may be the only part of a catchment in which rainfall is received regularly. In such a catchment, as much as 90 percent of the runoff may originate from 10 percent of its area.

Studies on rainfall variability in the semi-arid areas of Tanzania are limited. Ngana (1990) modelled and analysed the periodic features in seasonal rainfall and its implications to water resources and agricultural planning in central regions of Tanzania. He observed that in some parts of the semi-arid central Tanzania, there is a 5-year cyclic phenomenon in the seasonal rainfall series. He further observed that in some localities there was an additional 2.5-year cycle superimposed in the 5-year cycle. He concluded that the basic pattern of the seasonal rainfall could, to some extent be predicted by a periodic function /model although the model did not adequately predict the peaks or lows of the seasonal rainfall series. Studies by Ndorobo (1973), Patton (1971), Ngana (1983) have reported on frequency of famines in many parts of central semi-arid Tanzania. Generally, the above studies showed that occurrence of famines was not only related to years of low rainfall but to several other factors such as low acreage accomplished by each farmer, incidences of pests and crop diseases. Prins and Loth (1988) carried out an analysis of rainfall patterns in northern Tanzania using sixteen stations within the area. They found out that amounts of rainfall were unpredictable and the deviations of long-term mean annual rainfall were without cyclic trends for the individual stations. However, they further reported that pooled rainfall data of the different stations showed series of alternating wet and dry years.

Some studies carried out by Rodhe and Virji (1976) and Ogallo (1982) to examine the rainfall characteristics in some parts of East Africa revealed that there are multiple peaks in the annual rainfall and there were spatial variations on this phenomenon. Beltrando (1990) analysed the space-time variability of rainfall over East Africa. He reported that the spectral analysis of the time series associated with the space component revealed peaks around 5 – 6 years that appeared to be the major periodicity over East Africa. Tyson and Dyer (1978) in South Africa obtained similar results, and Masson (1980) in Swaziland, by identifying trends in rainfall data which characterised periods of dry and wet spells over selected periods of study. In these studies, the observed or predicted trends indicated that the decades of the 1970's were generally wetter than normal for the summer rainfall as a whole; the 1980's were much drier and the 1990's were expected to be much wetter. These predictions should however, be taken cautiously because they have their own shortcomings analytically, and they can present numerous problems to decision-makers.

Venalainen and Mhita (1998) analysed the variability of rainfall in Tanzania using six stations (Moshi, Mwanza, Songea, Dodoma, Dar es Salaam and Tabora). They reported that in single peak areas such as Dodoma and Tabora, the main onset of rains is between mid-November and early December while the mean end of the seasonal rains is between mid-April and mid-May. In these areas there is about a 10% probability of a long dry spell. For the double peaked areas, the short rains start by 25 October and end by mid-January, while the long, rains start by mid-March and end by early June in 75% of the years. The analysis of the occurrence of dry spells revealed that there is a very high variability of rainfall during the short rains. For Moshi, the probability of dry spells of 15 days or more during long rains ranged from 70% in mid-February to zero in mid-April. However, during the short rains the probability is about 50%.

The analysis by Venalainen and Mhita (1998) also revealed variability within and between seasons. For example, the calculated 20, 50 and 80% values of ten-day rainfall indicated that for Dodoma, rainfall is not reliable. In 20% of the years, ten-day rainfall amounts do not exceed 15 mm. In half of the years, the amounts exceed 15 mm from 1 December to 9 March. Tabora exhibited almost the same unreliability of rainfall as Dodoma. In 80% of the years the amounts of ten-day rainfall reach 15 mm only from early December to mid-March, and in half of the years from early November to early April.

The purpose of this paper was to analyse the rainfall variability in the study areas and look into its implication in the semi-arid areas of Tanzania.

Materials and Methods

Long-term rainfall data for four stations namely Hombolo [5° 55′ S, 35° 50′ E; altitude 1,100 m.a.s.l] (Dodoma Region); Kisangara [3° 43′ S, 37° 35′ E; altitude 870 m.a.s.l] (Kilimanjaro Region); Morogoro [6° 50′S, 37° 42′E; altitude 920 m.a.s.l] (Morogoro Region) and Ngudu [2° 57′ S, 33° 09′ E] (Mwanza region). were used. The data used was collected for periods of 34, 20, 34 and 33 years for Kisangara, Hombolo, Morogoro and Ngudu, respectively. Analysis carried out included the following:

- Descriptive statistics (mean, standard deviation and coefficient of variation.)
- Determination of trends or cycles by use of moving averages.
- Determination of start, and end of growing season.
- Probabilities of minimum and maximum length of dry spells.

The start and end of growing season was analysed using daily rainfall based on the method outlined by Alusa and Mushi (1974).
The start of growing season was defined as the first period with running total of at least 20 mm of rain in four consecutive days with at least two days being wet and no dry spell of more than ten days in the next thirty days. The end of growing season was defined as the first occasion after an earliest possible ending date on which fifteen consecutive dry days occurred.

The length of a dry spell within the growing season was obtained using the method outlined by Stern *et al.* (1982). A dry day was defined as a day with less than 0.85 mm of rain. This is reported by Nieuwolt (1989) to be of little value as much of it evaporates and does not contribute to the moisture requirements of crops.

In almost all the stations, data had gaps and these discrepancies in one way or another must have affected the description of events like annual rainfall amount, start and end of rain and risk of dry spells.

The INSTAT computer package (Stern *et al.*, 1990) was used to analyse the data.

Results and Discussions

Long term rainfall analysis

The descriptive statistical analysis of the long-term seasonal rainfall for Kisangara, Morogoro, Hombolo and Ngudu is shown in Table 1. Kisangara and Morogoro sites receive bimodal rains (*Masika* and *Vuli*) while the rainfall at Hombolo and Ngudu is unimodal. During *Masika* season, the mean seasonal rainfall was 525 mm and 445 mm for Kisangara and Morogoro, respectively. In the case of *Vuli* season, the mean was 359 mm and 327 mm for Kisangara and Morogoro, respectively. The values even for *Masika* are quite low in meeting the seasonal requirements for a crop like maize, which requires about 750 mm. A similar situation is observed for Hombolo (592 mm). This amount may be sufficient for a crop like sorghum but it is common to find farmers planting maize.

As already pointed out in the introduction, in the semi-arid areas, the total rainfall figures may be misleading. Variability of the seasonal rainfall is therefore an important parameter. In Table 1, the variability is represented by the coefficient of variation (CV). In *Masika*, the CVs are 20% and 50% for Kisangara and Morogoro stations respectively. During *Vuli* the CVs are 49% and 42% respectively. For Hombolo, the CV is 24%. These are large variations and to a great extent they contribute to crop failures. Therefore, the coefficient of variation over the growing period implies a high uncertainty in crop yields. Similar results were reported by Ngana (1990) for Farkwa (Dodoma), Singida (Singida), Manyoni (Singida), and Maswa (Shinyanga) stations.

Rainfall trends

When data for Ngudu was plotted on a 5-year moving average, (Figure 1), a weak cyclic wave or swing every ten years was observed. A similar trend was observed for both *Vuli* and *Masika* seasons at Morogoro (Figure 2(a) and 2 (b).

For Kisangara, both *Masika* and *Vuli* had distinct cyclic trends every 10 years (Figure 3(a) and Figure 3(b). These cyclic waves were more distinct during the 1960s and 1970s especially for Kisangara. At Hombolo, a similar trend was observed. Ngana (1990) observed similar results in central Tanzania and concluded that there was a cyclic or periodic feature in the data series.

Table 1: Descriptive statistical analysis of long term seasonal rainfall (mm) at Kisangara, Morogoro, Hombolo and Ngudu.

	Masika		*Vuli*		Unimodal	
	Kisangara	Morogoro	Kisangara	Morogoro	Hombolo	Ngudu
Mean	444.9	525.1	359.3	327.2	592.0	864.2
Standard Deviation	224.5	106.5	174.7	136.7	139.5	182.1
Coefficient of variation (%)	50.0	20.0	49.0	42.0	24.0	21.0

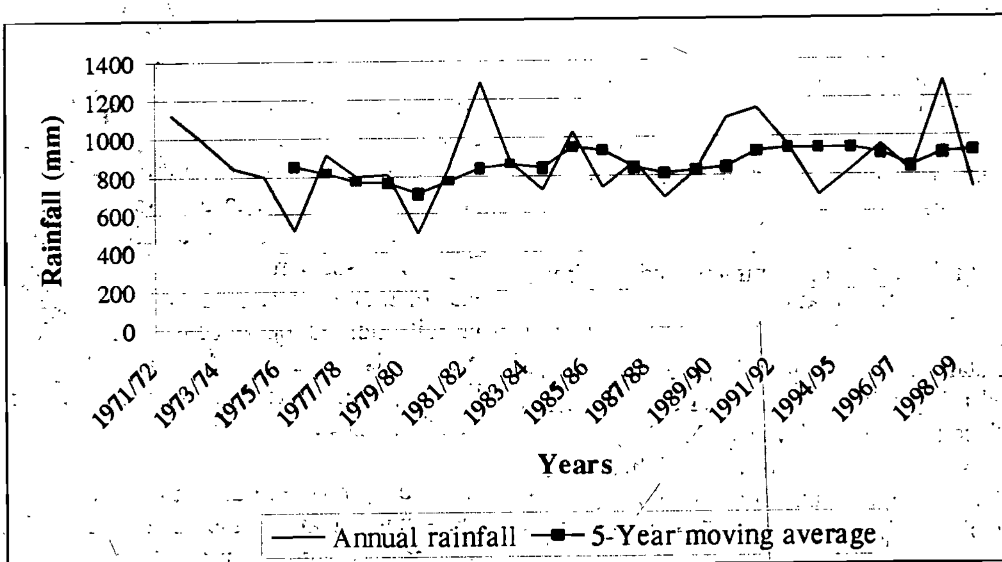


Figure 1: Annual rainfall and 5-year moving average for Ngudu

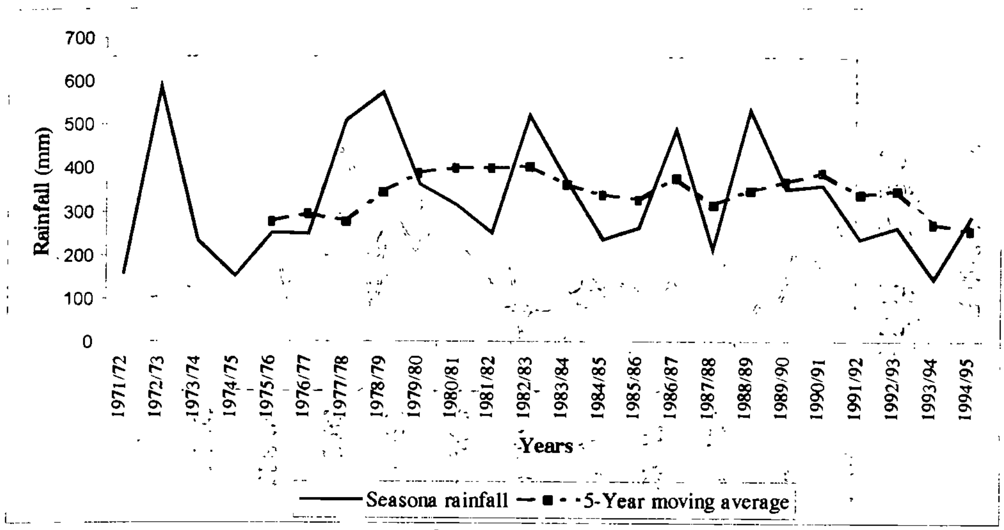


Figure 2 (a): ***Vuli* seasonal rainfall and 5-year moving average for Morogoro**

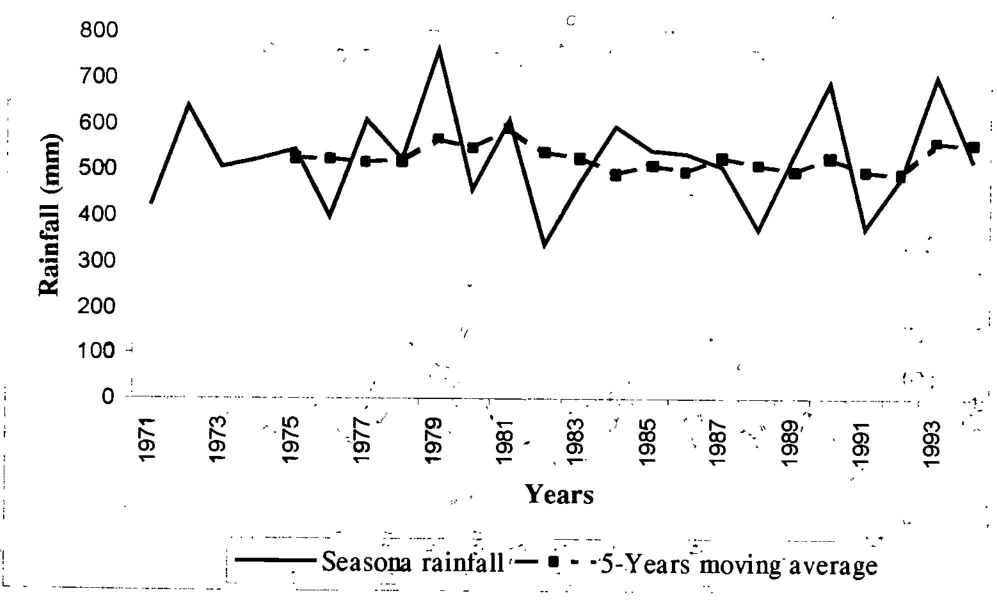


Figure 2 (b): ***Masika* seasonal rainfall and 5-year moving average for Morogoro**

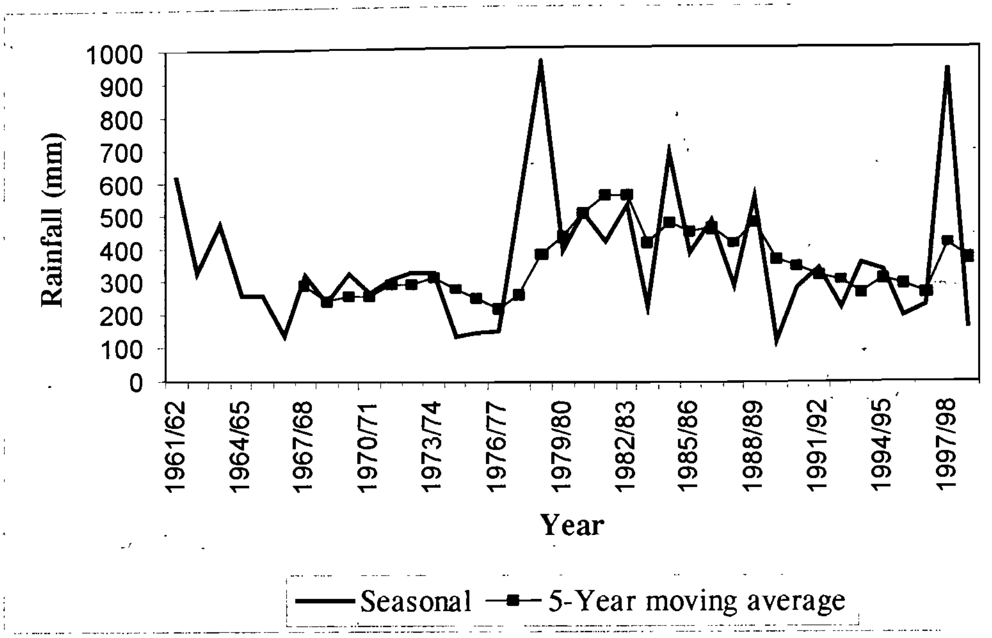


Figure 3 (a): ***Vuli*** **seasonal rainfall and 5-year moving average for Kisangara**

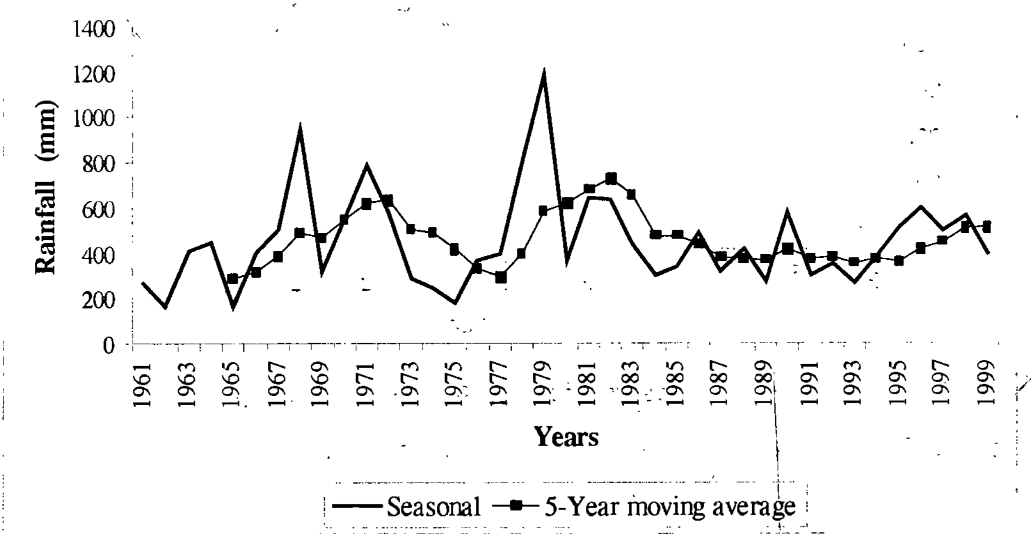


Figure 3 (b): ***Masika*** **seasonal rainfall and 5-year moving average for Kisangara**

Long-term rainfall characteristics

Hombolo

A summary of the long-term rainfall characteristics for Hombolo is shown in Table 2(a). Rainfall variability at Hombolo is very high and varies from 326 mm to 882 mm. The long-term mean rainfall is 591 mm, whereas the 70% probability rainfall is 518 mm. The rains are always received in the months of December, January, February and March.

Morogoro and Kisangara

Rainfall for *Vuli* in these stations is both unreliable and variable from season to season. For Morogoro, the rains may start in October and end in January. The situation at Kisangara is that, for *Vuli*, the season starts in November and ends in January. During *Masika*, the season may start in early March and stop by the end of May in Morogoro (Table 2 (b)). While the *Masika* season starts in March and ends by the end of May in Kisangara (Table 2 (c)).

In all the two stations, dry spells of various lengths do occur during the seasons. For example, at Kisangara the month of November may receive at least 18 mm of rainfall during *Vuli* and the length of the longest dry spell with 30% probability of occurrence is 15 days. During *Masika*, at Kisangara, dry spells of more than 14 days at 30% chance are experienced in the rest of the months except April. In all these situations, there is a high possibility of crop damage by water stress during the season.

Planting is usually successful if it is not followed by a long dry period. From the preceding analysis, the distribution of the start and end dates for the rain can be used successfully to select the best planting or harvesting dates, although other limiting factors like soil water holding capacity, variety of crop, length of growing season may have to be taken into account. Due to the uncertainty of the start of rainfall, many farmers in the semi arid areas have resorted to dry planting. This practice is highly risky because, although emergence may be good, the crop die due to prolonged dry spells during this growth stage. Farmers are therefore forced to do second or even third planting which may lead to low and poor yields.

Table 2(a): Summary of long term rainfall characteristics for Hombolo

Month		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Season
Rainfall (mm)	Min	0.0	0.0	0.0	35.7	39.7	7.0	0.8	0.0	326.3
	Mean	3.8	33.9	113.5	133.7	121.7	111.4	61.6	5.9	591.9
	70%[1]	0.0	9.6	60.8	83.8	81.8	82.0	20.8	2.8	518.0
	Max	43.6	88.5	290.5	293.7	253.1	180.0	212.2	24	881.6
Wet days	3mm +	2	2	6	8	7	7	5	0	37
	5mm+	1	1	5	6	6.4	5	3	0	22
	10mm+	1	1	3	4	4	2	2.2	0	18
Longest Dry spell (days)	Min	21	5	5	4	3	4	1	8	
	30%[2]	31	27	19	11	17	20	15	31	
	Mean	31	19	17	8	12	14	13	29	
	Max	31	30	41	17	25	27	34	48	

1=Probability of exceeding; 2= Risk of occurrence

Table 2(b): Summary of long term rainfall characteristics for Morogoro and Kisangara (*Vuli*)

	Parameter		Aug	Sep	Oct	Nov	Dec	Jan	Season
Morogoro	Rainfall (mm)	Min	0.1	0.0	0.0	1.4	0.8	10.8	124.3
		Mean	8.7	9.5	30.5	65.9	109.9	96.8	321.7
		70%	3.7	4.8	10.0	36.7	58.9	48.3	230.9
		Max	31.2	22.4	105.0	175.7	262.4	287.7	572.0
	Wet days	3mm+	1	1	2	4	6	6	20
		5mm+	0	1	2	3	5	5	16
		10mm+	0	0	1	2	3	3	9
	Longest dry spell	min	13	12	10	6	7	3	
		30%	31	30	25	20.5	14	19.5	
		Mean	24	24	20	16	12	15	
		Max	31	30	31	30	21	28	
Kisangara	Rainfall (mm)	Min	0.0	0.0	0.0	18.0	0.0	0.0	121.3
		Mean	5.0	9.5	35.3	138.3	106.4	65.1	354.9
		70%	0.0	0.0	8.5	78.5	50.5	22.0	258.6
		Max	32.0	55.0	130.0	424.0	385.0	211.8	950.0
	Wet days	3mm+	1	1	3	7	6	3	21
		5mm+	1	1	2	6	5	3	16
		10mm+	0	0	2	4	3	2	11
	Longest dry spell	Min	10	14	4	5	4	9	
		30%	31	30	27	15	14	20	
		Mean	26	26	20	11	13	17	
		Max	31	36	31	30	35	31	

Table 2(c): Summary of long term rainfall characteristics for Morogoro and Kisangara (*Masika*)

			Feb	Mar	Apr	May	Jun	Jul	Season
Morogoro	Rainfall (mm)	Min	0.7	41.2	87.1	12.7	0.0	0.0	348.0
		Mean	85.4	126.4	188.4	87.0	17.2	15.2	504.9
		70%	42.6	106.8	161.2	67.3	9.5	7.0	498.2
		Max	257.9	229.1	296.4	157.7	61.4	61.1	757.6
	Wet days	3mm+	4	8	13	8	2	1	36
		5mm+	3	6	11	7	1	1	29
		10mm+	3	4	7	3	0	0	21
	Longest dry spell	min	3	3	2	5	11	11	
		30%	18	12	8	13	30	31	
		Mean	16	9	6	10	23	22	
		Max	28	22	12	22	30	31	
Kisangara	Rainfall (mm)	Min	0.0	28.0	31.7	0.0	0.0	0.0	163.7
		Mean	44.7	165.5	162.3	64.5	6.8	12.0	449.9
		70%	23.5	76.7	101.0	35.2	0.0	0.0	327.45
		Max	161.3	451.0	423.0	203.0	47.0	33.0	1185.0
	Wet days	3mm+	2	5	8	5	1	1	20
		5mm+	2	4	7	4	1	0	17
		10mm+	1	3	5	3	0	0	12
	Longest dry spells	Min	11	8	4	5	13	14	
		30%	24	17	14	15	30	31	
		Mean	20	15	11	13	26	24	
		Max	30	31	30	21	33	39	

Start and end of rainy season and the occurrence of dry spells

The start and cessation of rainfall in the different areas is given in Table 3. For Hombolo, rain may start as early as November to as late as December, while the end of rain is more certain and occur in April (Figure 4). In Ngudu the rain may start as early as late October to as late as November and end as early as late April to as late as end of May. For the other sites, the probable start of rain varies from 15 to 25 days and end of rain varies from 13 to 18 days.

For Hombolo, dry spells occurring between December and April have significant influence on crop growth and yield. There is a 30% risk (i.e. 3 years out of 10) of dry spells of 11, 17, 20 and 15 days, for January, February, March and April respectively. (Table 2(a)). Maximum lengths of dry spells for these months vary between 17 and 34 days. Except for April and December, the rest of the months suffer a dry spell of more than 14 days at 30% chances at Kisangara and Morogoro. Thus there is high possibility of crop failure/damage by stress during the seasons.

Table 3: Probable dates for which the rainy season can be expected to start and end at given probabilities

Station	Onset Date at Different Probabilities				Cessation Date at Different Probabilities			
	20%	50%	80%	s.d	20%	50%	80%	s.d
Hombolo	18 Nov	3 Dec	19 Dec	14	15 Apr	19 Apr	27 Apr	9
Ngudu	24 Oct	4 Nov	30 Nov	18	28 Apr	11 May	23 May	13
Morogoro (*Vuli*)	23 Oct	12 Nov	1 Dec	23	6 Jan	18 Jan	29 Jan	13
Morogoro *Masika*)	2 Mar	15 Mar	27 Mar	15	4 May	19 May	2 Jun	17
Kisangara (*Vuli*)	23 Oct	11 Nov	1 Dec	23	18 Dec	2 Jan	19 Jan	18
Kisangara (*Masika*)	27 Feb	20 Mar	10 Apr	25	2 May	15 May	29 May	14

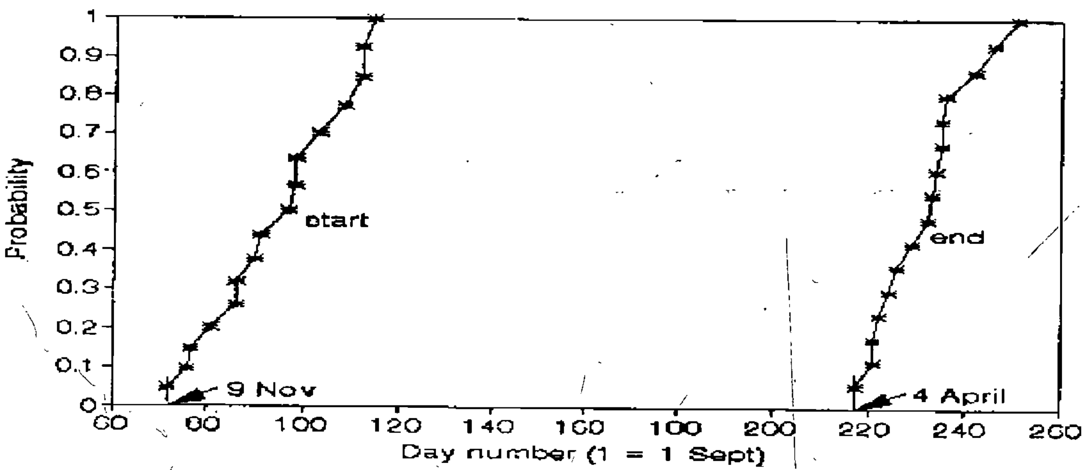


Figure 4: Cumulative probability of start and end of rains in Hombolo, Dodoma

Table 4: Effective length (days) of growing season at three levels of probability (rainfall criterion)

Station	sd	Length (Days)		
		20%	50%	80%
Hombolo	35	150	115	90
Morogoro - *Masika*	20	86	67	47
Morogoro - *Vuli*	23	86	67	47
Kisangara - *Masika*	26	81	57	35
Kisangara - *Vuli*	20	70	53	31
Ngudu	38	156	147	123

Effective length of growing season

The length of the season mainly depends on the starting date. The effective length of the rainy season at Hombolo, which has a unimodal pattern of rainfall, was found to vary between 90 days at 80% probability to 150 days at 20% probability. The effective length of growing season during both *Masika* and *Vuli* season for Morogoro and Kisangara does not exceed 47 days in 80% probability (four years out of five) (Table 4). For Ngudu the effective length was found to vary between 123 days at 80% probability to 156 days at 20% probability. It has the longest effective growing season (147 days at 50% probability) as compared to the other areas.

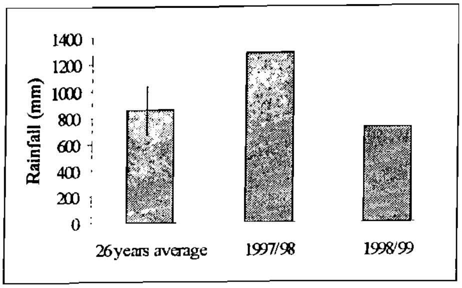
Seasonal rainfall during the experimental period

A plot of the long-term mean rainfall and the mean seasonal rainfall for the four stations indicate that for Ngudu, the seasonal rainfall for the two experimental years were both above the minimum (Figure 5 a). However, for 1997/98, the seasonal amount was above the long-term mean while 1998/99 season, it was below the long term mean.

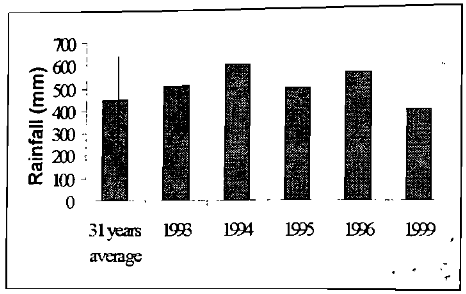
For Kisangara site, during *Masika*, with the exception of 1999, the seasonal total rainfalls were all above the long term seasonal mean during the experimental period (Figure 5b). During this time, no seasonal mean rainfall was in the minimum range. On the other hand, during *Vuli*, with the exception of 1997/98, the amount of rainfall was within the minimum range (Figure 5c). The El Nino rains explain the 1997/98 situation.

At Morogoro site, during *Vuli*, all seasonal rainfall during the experimental period were less than the long term seasonal mean (Figure 5 d), and more of them covered the maximum range. However, the 1993/94 seasonal rainfall was within the minimum range.

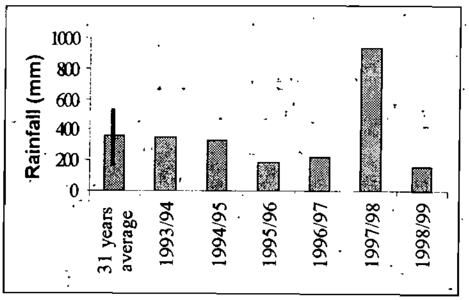
During *Masika*, only two years, 1993 and 1994 had seasonal rainfall greater than the long-term seasonal mean rainfall and were within the maximum range (Figure 5 e). None of the seasonal rainfall fell within the minimum range during the experimental period. From the above discussion, the *Vuli* rains at both Kisangara and Morogoro are quite low and this explains the frequent crop failure during this season. The same case explain the situation in Hombolo (Figure 5 f).



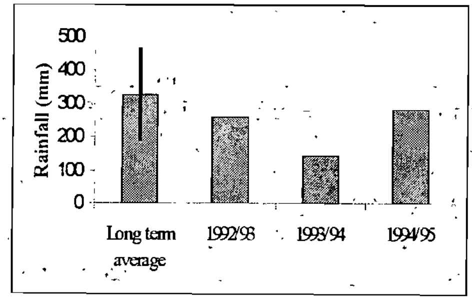
a: Ngudu



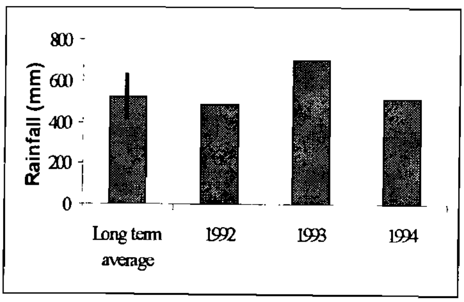
b: Kisangara during *Masika*



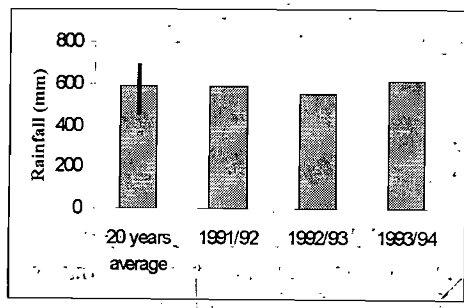
c: Kisangara during *Vuli*



d: Morogoro during *Vuli*



e: Morogoro during *Masika*



f: Hombolo

Figure 5: Comparison of seasonal totals with long term average at Ngudu, Kisangara, Morogoro and Hombolo

Conclusions

1. The analysis of the rainfall pattern though limited to a few stations shows very high variability in both the *Masika* and *Vuli* seasons. The coefficient of variation, which ranged from 20 to 50% over the growing period, implies a high uncertainty in crop yields.

2. In almost all the stations studied, the rainfall pattern shows that many of the early starts of rainfall, are in effect false starts as far as plant establishment and growth is concerned. A good example is Hombolo, where the rains may start as early as October and November but the growing season effectively starts after 15 December.

3. The rainfall pattern showed some cyclic wave for a few stations (e.g. Kisangara during *Masika*) while in the majority of the stations trends were weak or did not exist. The absence of trend in some of the data series may be linked to gaps in the raw data. This raises the issue of data quality, an issue that is often times neglected by planners and project implementers.

4. The analysis in this paper has shown that trends may serve as a basis for extrapolating future rainfall patterns in the area and provide evidence of existing differences. When such information is to be applied in a different area, but of similar climatic characteristics, physiographic factors have to be considered.

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