The most important questions about rainfall from the farmer's point of view are concerned with the onset, cessation and length of the rainy season, including the risk of dry spells within the growing season. The timing and distribution of rainfall determine both the length and quality of the growing season, and hence have important implications for agricultural production and food security.

Definitions of what constitutes a growing season abound. At times the term 'rainy season' is used loosely to define a growing season. However, a growing season is defined in terms of the probability of obtaining a favourable period for non-irrigated crops between two given dates of the year. It consists of the period when soil water, resulting mainly from rain, is freely available to the crop. This occurs when the water consumed by the crop is in equilibrium with rainfall and water stored in the soil (Frère & Popov, 1979). In general, the start and end of the rains characterize the growing season. In the tropics though, to define an event to mark the start and end dates is not easy due to the intermittent and patchy nature of tropical rainfall. According to Stern *et al* (1982), a definition of the start and end of rains should be flexible and designed for the circumstances of the weather system, soil and crop.

Discrimination between rainfall patterns and an estimate of the earliest possible onset and cessation dates can be obtained from a plot of cumulative mean daily rainfall against time (Kingamkono, 1993). Points of maximum positive and negative curvatures on the cumulative rainfall curve are taken as the mean onset and cessation dates respectively. A unimodal rainfall pattern will result in two such curvatures, i.e., one positive and the other negative, while a typical bimodal rainfall pattern will depict four well-defined curvatures representing the two rainfall seasons. Other workers have used grouped data to derive earliest possible start and end dates (Ilesanmi, 1972; Alusa and Mushi, 1974; Kassase, 1992). However, Stern *et al.* (1982) and Kingamkono (1993) cite a number of advantages of using daily rather than grouped data for such an analysis.

The quality of a growing season is determined to a large extent by the distribution of rainfall within the season. An area having high rainfall may not necessarily have an even distribution of the rainfall such as to render it unsuitable for certain crops which would otherwise have done well in another area with less rainfall but more evenly distributed. Hence, the quality of a growing season is influenced by the magnitude of intervening dry spells. A 'dry spell' does not necessarily mean a period without rainfall, but could also denote a period over which rainfall stays below a certain limit. This limit is often taken to be 1.0mm of rainfall.

There are various methods of determining the occurrence of dry spells, all based on the statistical processing of rainfall events in the past. The more simple methods identify the occurrence of dry spells of a certain length over a certain period at the start of the rainy season, and statistically assess the chance that such dry spells materialize. Limitations in the approach notwithstanding, several workers have been able to derive meaningful information using such methods (Stern *et al.*, 1982; Kassase, 1992; Kingamkono, 1993). The more complicated of these methods try to determine the chance that 1, 2, 3 or more dry days follow after a period of 1, 2, 3 or more rainy days, which ultimately results in the assessment of the chance for a crop to survive for varying planting dates.

A commonly applied approach for predicting seasonal climate is a statistical one, which consists of finding the predictors that better explain the predictand(s) by correlation analysis, then choosing predictors with significant correlation to be used for production of models to produce monthly rainfall for the respective seasons. The global sea surface temperatures (SSTs) are the predictors commonly used, while standardized rainfall indices are used as predictands. Such forecasts are, however, limited to the prediction of rainfall at seasonal time scales for relatively large areas. At a local scale, farmers are interested in the quality of the upcoming growing season. Probabilistic expressions such as 'normal to above normal rainfall' may not be quite helpful to the farmer, and may be considered somewhat esoteric. 'Above normal' rainfall may be poorly distributed within the season. Kingamkono *et al.* (1994) have proposed the use of an aridity index (AI), defined as the product of the ratio of number of rainy days within the growing season to the length of growing season and the seasonal rainfall total. Such an index describes the quality of a growing season better, and if used as a predictand, it could make forecasts more meaningful. Ironically, indigenous knowledge seems to suggest the existence of traditional indicators for forecasting the quality of a growing season (Kihupi *et al.*, 2002).

Materials and Methods

Study area and Data Collection

Over 30 years daily weather data for 51 stations were collected from the Tanzania Meteorological Agency in Dar es Salaam and from other sources. The stations represent the three main rainfall patterns in Tanzania, namely the bimodal, unimodal and transitional rainfall patterns. In bimodal areas, there are two rainy seasons, while in the unimodal regions only a single rainfall peak exists. Between these two regions, lie the transitional areas, which have essentially two peaks but with no discernible dry season between the short and long rains (Venäläinen and Mhita, 1998).

Determination of Onset, Cessation and Length of Growing Season

This study adopted the definition of start and end of growing season given by Stern et al. (1982), and used by Kassase (1992) and Kingamkono et al. (1994). According to the definition, the start of the growing season was taken as the first occasion after the earliest possible date (obtained graphically from a plot of the cumulative mean daily rainfall against time) on which a running total of at least 20mm of rain was reached in four consecutive days, with at least two days being wet; and that no dry spell of 10 days or more occurred in the next 30 days. The end date for the growing season was taken as the first occasion after the earliest possible date on which 15 consecutive dry days occurred. The water balance approach for the determination of the cessation date, though more realistic, is more demanding in terms of data requirements. Simplified assumptions and generalizations may lead to unrealistic results. Hence this approach was not used. The length of the growing season was taken as the duration between the onset and cessation dates of the growing season.

The INSTAT statistical computer package (Stern, 1991) was used for the analysis. Results of computations were crosschecked physically by viewing the raw data in spreadsheet format, and making adjustments where necessary.

Determination of Growing Season Quality Classes

Surface analysis of growing season quality patterns in the study area was done based on integrating aridity index values and sample input rainfall stations location using ArcView GIS (ESRI, 1996a), and Spatial Analysis (ESRI, 1996b). The spatial analysis used Spline interpolator for surface generation, and the generated surface was presented as contour lines. The generated contours were then classified in ranges and colours used to indicate the value range classes for each quality zone of growing season.

Trend of Growing Season Characteristics

Both linear and polynomial trend lines were fitted to the data for onset date, cessation date, seasonal rainfall total, number of rainy days within the growing season and aridity index. Long dry spells within the growing season were also analyzed for various temporal periods to see if there was any trend.

Results and Discussion

Figures 1 and 2 show typical curves of cumulative distribution of annual rainfall derived from mean daily values for bimodal and unimodal rainfall patterns respectively. Curves for some stations tend to be rather obscure with no clear-cut distinction between the end of the short rains and the start of the long rains. Examples of such stations are Mwanza (Fig. 3), Biharamulo, Loliondo, and Ngara. These are areas with a transitional rainfall pattern (Fig. 4). From such curves, points of maximum curvature depict mean onset (positive slope) and mean cessation (negative slope) dates of rains. Fourteen days prior to the mean onset and cessation dates can be taken to represent the earliest possible onset and cessation dates of rains. These dates represent the starting points for the search for the onset and cessation dates for the respective years according to the selected definition.

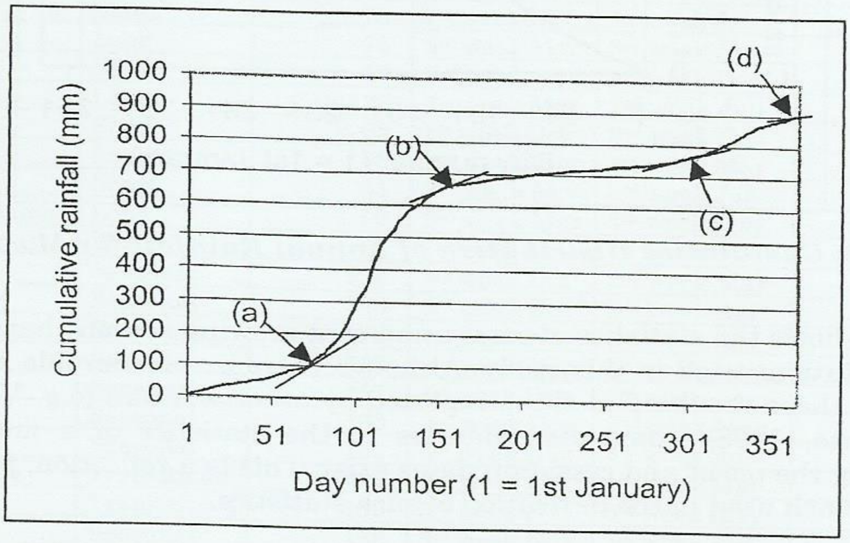

Figure 1: ***Cumulative distribution of annual rainfall for Moshi with points of maximum curvature: (a) onset of long rains, (b) cessation of long rains, (c) onset of short rains, (d) cessation of short rains***

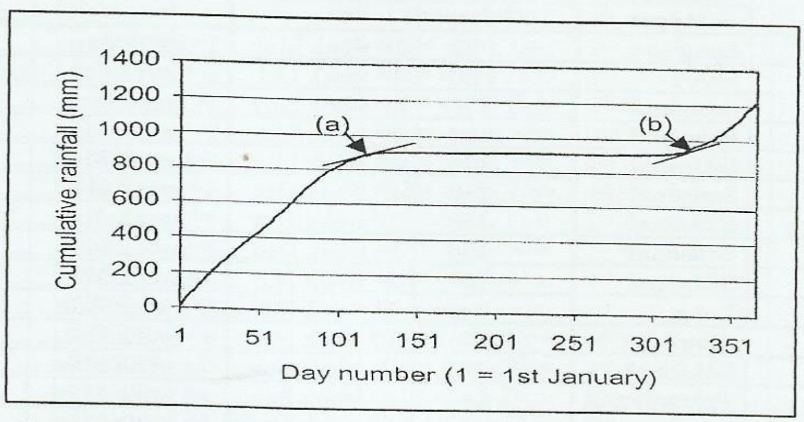

Figure 2: ***Cumulative distribution of annual rainfall for Songea with points of maximum curvature: (a) cessation of rains, (b) onset of rains***

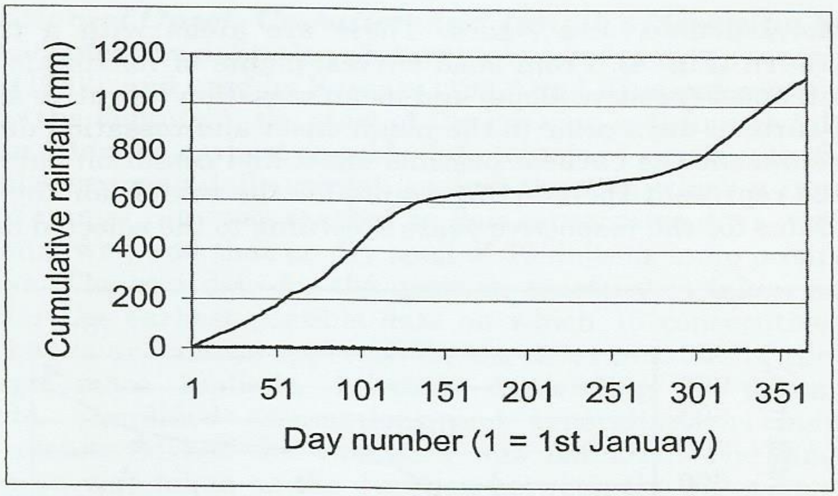

Figure 3: ***Cumulative Distribution of Annual Rainfall for Mwanza***

Table 1 shows the statistics of some important growing season characteristics for the stations used in this study. Although there is considerable agreement between these results and those reported by other workers (e.g. Venäläinen and Mhita, 1998), some discrepancies in the statistics of a few stations regarding the onset and cessation dates exist. This is a reflection, perhaps, of the approach used in the derivation of such statistics.

Table 1: Mean Values of Growing Season Characteristics for Various Stations

Station	Rainfall season type	Length (days)	Onset date	Cessation date	No. of rainy days	AI (mm)
Zanzibar	Long	82	1st week Mar	1st week Jun	115	1198
	Short	80	4th week Oct	2nd week Jan		
Mbeya	Seasonal	156	4th week Nov	1st week May	87	475
Shinyanga	Seasonal	194	4th week Oct	2nd week May	75	332
Njombe	Seasonal	174	4th week Nov	2nd week May	95	637
Kigoma	Seasonal	210	4th week Oct	4th week May	82	351
Sumbawanga	Seasonal	168	3rd week Nov	4th week Apr	77	413
Lindi	Seasonal	164	1st week Dec	3rd week May	49	213
Mpwapwa	Seasonal	167	4th week Nov	3rd week May	70	331
Lyamungo	Long	142	4th week Mar	2nd week Aug	122	913
	Short	71	3rd week Nov	4th week Dec		
Maswa	Seasonal	184	1st week Nov	3rd week May	74	337
Ngara	Transitional	247	4th week Sep	4th week May	89	374
Bagamoyo	Long	71	4th week Mar	4th week May	69	527
	Short	64	4th week Oct	2nd week Jan		
Ifakara	Seasonal	177	1st week Dec	4th week May	77	600
Tukuyu	Seasonal	230	2nd week Nov	2nd week Jul	138	1474

Lushoto	Long	110	2nd week Mar	4th week Jun	112	654
	Short	73	4th week Oct	2nd week Jan		
Bukoba	Long	155	1st week Feb	4th week May	160	1326
	Short	105	4th week Sep	4th week Dec		
Musoma	Long	101	1st week Mar	4th week May	94	444
	Short	85	4th week Oct	4th week Dec		
Moshi	Long	75	4th week Mar	4th week May	73	484
	Short	59	2nd week Oct	2nd week Dec		
Arusha	Long	101	2nd week Mar	3rd week May	83	398
	Short	78	1st week Nov	1st week Jan		
Same	Long	75	3rd week Mar	3rd week May	60	273
	Short	53	2nd week Nov	4th week Dec		
Tanga	Long	127	4th week Mar	2nd week Jun	108	655
	Short	92	1st week Oct	2nd week Dec		
Morogoro	Long	93	2nd week Mar	3rd week May	83	502
	Short	53	2nd week Nov	3rd week Jan		
Dar es Salaam	Long	92	2nd week Mar	4th week May	95	750
	Short	53	1st week Nov	1st week Jan		
Mwanza	Seasonal	226	4th week Oct	2nd week May	96	470
Singida	Seasonal	146	3rd week Dec	2nd week Apr	53	248
Tabora	Seasonal	174	3rd week Nov	3rd week Apr	87	490
Dodoma	Seasonal	133	2nd week Dec	1st week Apr	44	189
Iringa	Seasonal	151	1st week Dec	3rd week Apr	63	267
Mtwara	Seasonal	163	2nd week Dec	2nd week May	87	607
Songea	Seasonal	165	4th week Nov	4th week Apr	91	635
Biharamulo	Transitional	229	2nd week Oct	4th week May	95	401
Loliondo	Transitional	182	3rd week Nov	3rd week May	63	335
Nzega	Seasonal	158	3rd week Nov	4th week Apr	63	337
Kilwa	Seasonal	166	1st week Dec	2nd week May	68	363
Nachingwea	Seasonal	146	1st week Dec	4th week Apr	55	302
Mbambabay	Seasonal	155	4th week Nov	1st week May	95	754
Tunduru	Seasonal	139	1st week Dec	3rd week Apr	66	439
Newala	Seasonal	146	1st week Dec	4th week Apr	68	449
Manyoni	Seasonal	116	2nd week Dec	2nd week Apr	40	183
Lupatingatinga	Seasonal	149	4th week Nov	3rd week Apr	72	430
Monduli	Long	87	3rd week Feb	4th week May	64	338
	Short	64	2nd week Nov	2nd week Jan		
Olmotonyi	Long	107	2nd week Feb	4th week May	79	492
	Short	40	2nd week Nov	4th week Dec		
Selian Coffee	Long	104	3rd week Feb	4th week May	69	525
Estate	Short	17	3rd week Nov	1st week Dec		
Dolly Estate	Long	70	2nd week Mar	3rd week May	45	479
	Short	Unreliable				
Kondoa	Seasonal	156	4th week Nov	1st week May	56	238
Babati	Seasonal	174	2nd week Nov	2nd week May	59	264
Igawa	Seasonal	134	1st week Dec	3rd week Apr	54	246
Rujewa	Seasonal	124	2nd week Dec	2nd week Apr	45	204
Kimani	Seasonal	132	1st week Dec	3rd week Apr	56	283
Igurusi	Seasonal	137	1st week Dec	4th week Apr	64	314
Matamba	Seasonal	172	3rd week Nov	2nd week May	91	516

Whereas this study employed daily values, Venäläinen and Mhita (1998) used decadal values. There is a danger of using grouped data in analyses of this nature because with aggregated data, the distribution of wet and dry days within the lumped period is completely masked. For example, a 40-mm rainfall in the first day of a decade (ten-day period) might allow that period to be classified as wet; if the following decade has also a 40-mm event but on the last day of the decade, the 18-day dry spell between these two events would be completely missed. This gives rise to false starts of growing seasons.

The length of the growing season shows considerable variability among stations. Results indicate that the total length of the growing season for unimodal and bimodal stations is more or less the same, i.e., unimodal seasons last as long as bimodal's short and long seasons combined. These findings are in agreement with those of other researchers, notably Alusa and Mushi (1974). Even though some stations appear to have longer growing seasons, they are not necessarily recipients of larger amounts of rainfall (e.g. Shinyanga and Ngara), nor do they indicate a better rainfall distribution. Length alone cannot, therefore, be used as a criterion to judge the quality of a growing season.

Four zones have been delineated according to the magnitude of the aridity index (Fig. 4). Zone I (AI<300) stretches longitudinally across the country covering much of the Central Plateau and parts of Lindi, Kilwa and Kisarawe Districts with an estimated area of about 268,000km^2. It includes stations with the poorest growing season representing areas that are quite arid. To some extent it follows the general rainfall distribution as shown in various maps. Some stations in this region show significant trends in growing season characteristics. Figures 5 and 6 depict such trends in the onset and cessation dates for Dolly Estate in Arumeru District, Arusha Region. Rains appear to progressively start late and end earlier than before, resulting in a shorter growing season. It should be noted though that there is much less variation in the cessation date for most stations compared to the onset date. Dolly Estate also shows a discernible increase in the occurrence of long dry spells with time during the growing season (Fig. 7). Similar trends exist in the southern part of this region, notably in the Usangu Plains, where even the quality of the growing season appears to be getting poorer, and also where the seasonal rainfall also appears to be declining. This has serious implications on the options for adaptability, where the main coping strategy is irrigation. However, the sustainability of this strategy is questionable, bearing in mind the increasing demands for water by competing sectors and decreasing dry season river flows (Tarimo *et al.*, 2002). Nevertheless, current policies appear to address this concern (MWLD, 2002), although the necessary legislation and institutional issues are yet to be implemented.

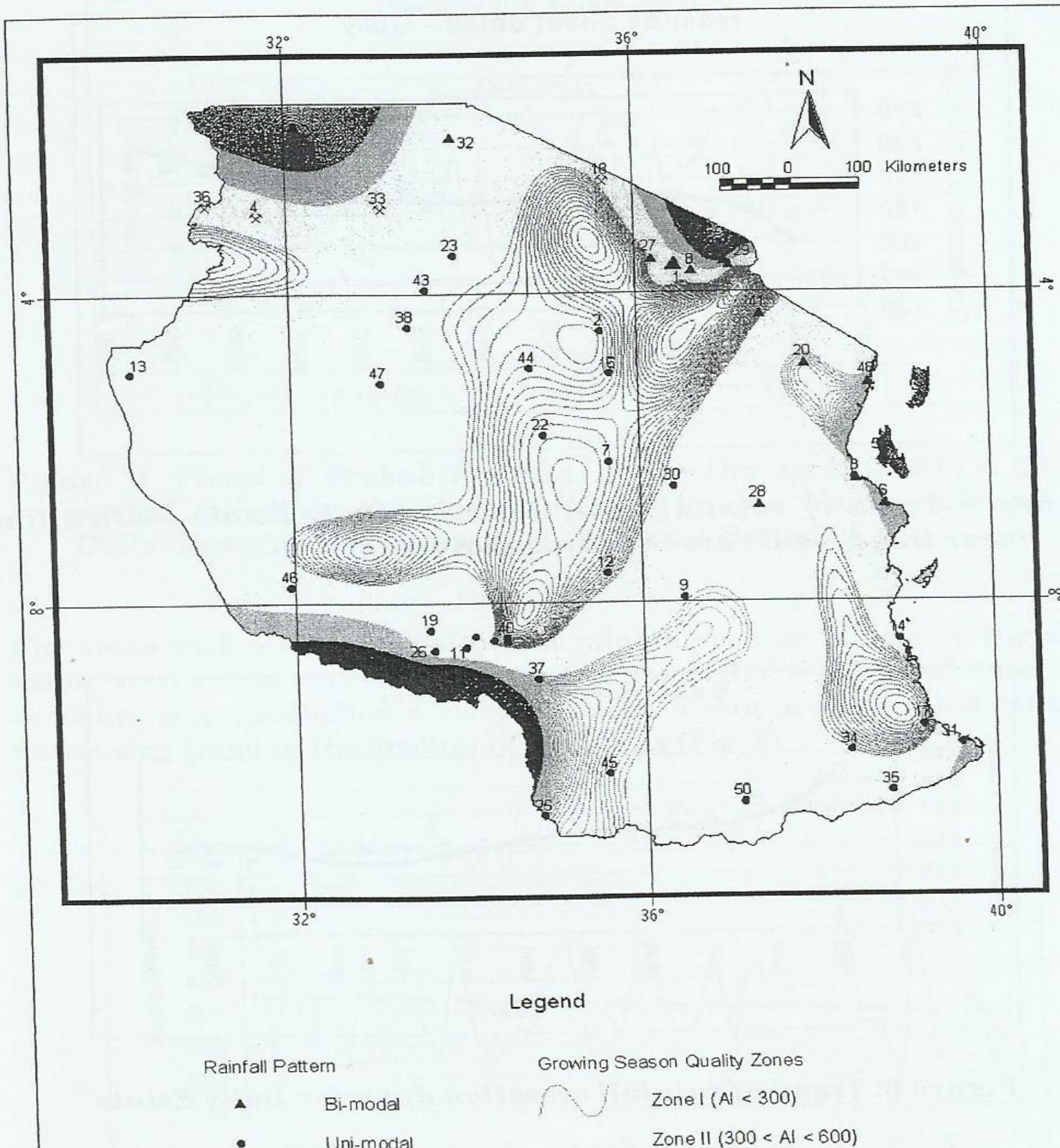

Figure 4: ***Growing Season Quality Zones (The numbers Represent the Station ID shown in Appendix I)***

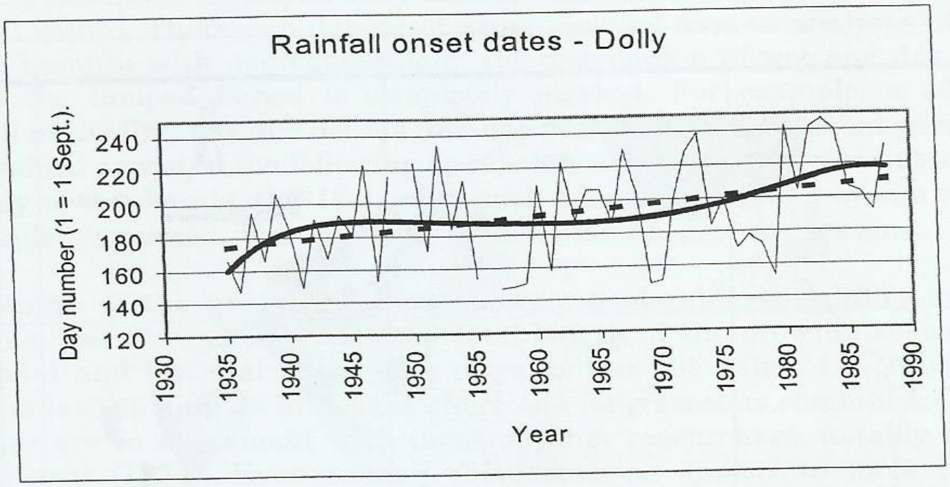

Figure 5: ***Trend of rainfall onset dates for Dolly Estate (dotted line linear trend, bold curve =polynomial trend)***

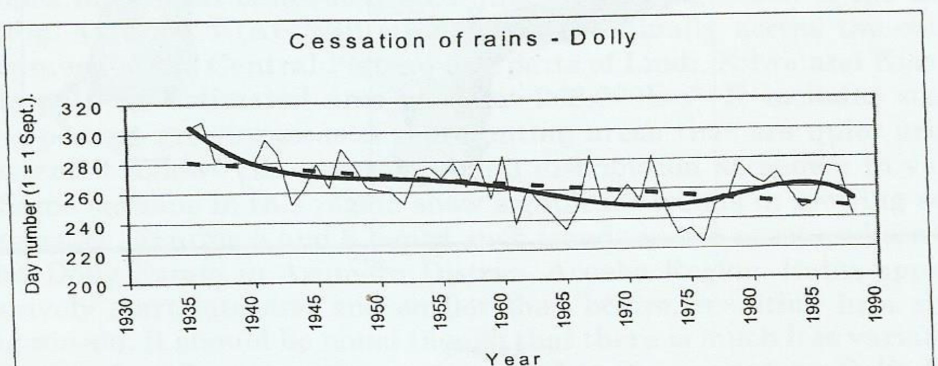

Figure 6: ***Trend of rainfall cessation dates for Dolly Estate***

Zone II (300<AI<600) is the largest in terms of coverage (about 515,000km^2). It occupies much of the central and western parts of the country; and parts of Mtwara, Lindi, Ruvuma, Morogoro and Coastal Regions. This is the area that can be described as semi-arid with a growing season that is not quite reliable. Although most stations in this zone do not show any trend in growing season characteristics, it is worth noting the very unreliable nature of the growing season.

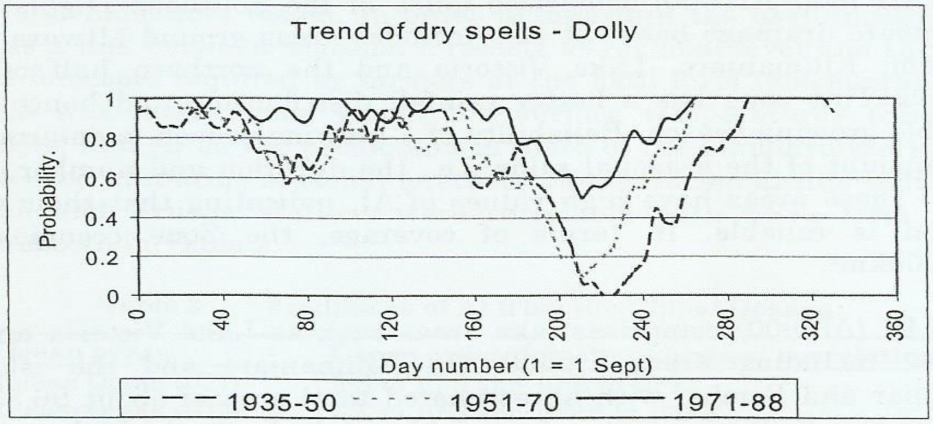

Figure 7: ***Trend of Probability of a 10-day Dry spell within a 30-day period following the date Indicated on the Horizontal axis for Dolly Estate for the Respective Temporal Periods***

For areas with a bimodal pattern of rainfall such as Morogoro, the short rains (*vuli*) are so variable in terms of amount (CV = 50%) and onset that it makes crop production a risky business. There is also an indication of decreasing trend in the amount of *vuli* rains (Fig. 8).

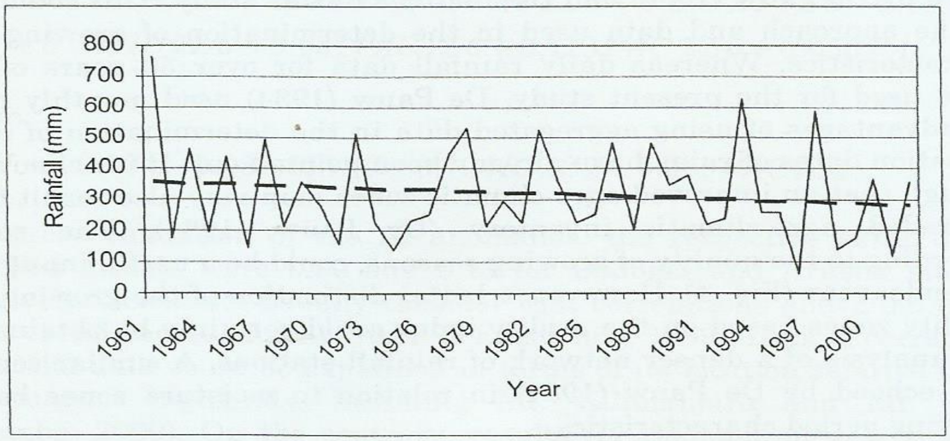

Figure 8: ***Trend of 'vuli' rainfall amount for Morogoro (dotted line = linear trend)***

Zone III (600<AI<900) comprises much of the Southern Highlands and Kilombero drainage basin. It also includes areas around Mtwara, Dar es Salaam, Kilimanjaro, Lake Victoria and the northern half of Tanga Region. This zone has a better rainfall distribution, and hence a more reliable growing season. Reliability of a growing season is determined by the amount of the seasonal rains, i.e., the duration and number of rainy days. These areas have high values of AI, indicating that their growing season is reliable. In terms of coverage, the Zone occupies about 114,000km^2.

Zone IV (AI>900) comprises lake areas such as Lake Victoria and Lake Nyasa, including areas around Mt. Kilimanjaro and the islands of Zanzibar and Pemba, with an estimated total area of about 96,300 km^2. These areas have very high values of AI mainly due to the high amounts of rainfall received at these places. Mountain effects play a role in the distribution of rainfall especially at Lyamungo (Jackson, 1989). Bukoba owes its abundance of rainfall to the lake breeze mechanism coupled with the general easterly airflow (Lumb, 1970). The growing season in this Zone is almost continuous. Stations in Zones III and IV show no discernible trends in growing season characteristics. This agrees with the findings of other workers (e.g. Kassase, 1992).

There are a number of differences between the agro-climatic description of certain areas with regard to the reliability or quality of the growing season given by De Pauw (1984) and the findings in this study. This could be due to the approach and data used in the determination of growing season characteristics. Whereas daily rainfall data for over 30 years of record were used for the present study, De Pauw (1984) used monthly rainfall. Disadvantages of using aggregated data in the determination of onset or cessation dates of rains have already been pointed out. It is acknowledged though that an improved agro-climatic zones map may also result from an upgraded agro-climatic inventory (De Pauw, 1984). The zonation, according to the quality of growing seasons, could be a useful input in such an endeavour (Fig. 4). However, a better distinction of the growing season quality zones based on the aridity index could certainly be obtained from the analysis of a denser network of rainfall stations. A similar sentiment was echoed by De Pauw (1984) in relation to moisture zones based on growing period characteristics.

In a study on the promotion and integration of indigenous knowledge in seasonal climate forecasts, Kihupi *et al.* (2002) found AI to correlate better with temperature for the months preceding the growing season than the other local indicators tested. In order to ascertain the usefulness of this index as a link between seasonal forecasts at regional level and the more refined forecasts required by farmers at the local level (downscaling), an analysis was made using global sea surface temperatures (SSTs) as predictors, and AI as the predictand in place of the standardized rainfall indices used in routine seasonal forecasts. Standardized aridity indices for Dodoma and Arusha stations were correlated with SSTs from global oceans shown in Table 2.

Table 2: Predictors of AI from the Global Oceans

Ocean areas	Ocean areas domain of highest correlation
Indian Ocean (IO1)	5°S to 15°S and 40°E to 60°E
Indian Ocean (IO2)	5°S to 10°S and 100°E to 120°E
Atlantic Ocean (AT1)	Equator to 5°N and 60°W to 40°W
Atlantic Ocean (AT2)	Equator to 10°S and 60°W to 40°W
Atlantic Ocean (AT3)	15°N to 5°N and 60°W to 40°W
Pacific Ocean (PAC1)	10°S to 20°S and 150°E to 160°E
Pacific Ocean (PAC2)	10°S to 20°S and 160°E to 170°E
Pacific Ocean (PAC3)	20°S to 25°S and 150°E to 160°E

The respective models derived for Dodoma and Arusha are as follows:

Dodoma

$$AI = 0.251 + 0.261\,AT1Z6 + 0.238\,AT2Z6 + 0.277\,AT3Z6 - 0.153\,IO1Z6 + 0.348\,IO2Z6 - 0.081\,PAC1Z6 + 0.123\,PAC2Z6 + 0.056\,PAC3Z6$$

Arusha

$$AI = -0.004 - 0.089AT1Z2 - 0.104IO2Z2 + 0.069PAC1Z2$$

Upon cross validation of the AI anomalies, the respective skills of the developed models were 0.60 and 0.13 for Dodoma and Arusha stations respecively. Scientists usually consider that correlations above 0.5 or 0.6 offer a useful degree of skill (Stern & Easterling, 1999). Lack of correlation for Arusha data could be explained in terms of its location relative to the north-eastern highlands, including Mt. Kilimanjaro and Mt. Meru (Kanemba, 2000). On the contrary, results for Dodoma suggest that AI, though computed from point data, could be used as an index for predicting not only the seasonal rainfall but also the degree of reliability of the growing season. This is the kind of information a farmer may find useful.

Conclusions

Results obtained from this study indicate the importance of using appropriate data in analyses involving growing season characteristics. One such characteristic, i.e., the quality of a growing season appears to provide useful information upon which an area can be characterized and forecasts made.

Generally, many of the stations in Zones III and IV do not show discernible trends in growing season characteristics. However, some stations in Zones I and II show disturbing trends, which could be attributed to environmental degradation.

A further improvement to the zonation arrived at in this study could be obtained from the analysis of a denser network of rainfall stations.

Acknowledgements

The authors are greatly indebted to the Tanzania Meteorological Agency for the climatic data used in this study. Financial support, albeit for part of the study, came from NOAA/OPG and USAID/OFDA through DMC Harare for which we are deeply appreciative. Lastly, we would like to express our thanks to Mr. R.A. Ludovic from the Department of Agricultural Engineering and Land Planning for the generation of the growing season quality zones map using GIS technology.

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Appendix I

Table I.1: Station ID for the growing season quality zones map

Station	Rainfall pattern	ID No.
Arusha	Bimodal	1
Babati	Unimodal	2
Bagamoyo	Bimodal	3
Biharamuro	Transitional	4
Bukoba	Bimodal	5
Dar es Salaam	Bimodal	6
Dodoma	Unimodal	7
Dolly	B-modal	8
Ifakara	Unimodal	9
Igawa	Unimodal	10
Igurusi	Unimodal	11
Iringa	Unimodal	12
Kigoma	Unimodal	13
Kilwa	Unimodal	14
Kimani	Unimodal	15
Kondoa	Unimodal	16
Lindi	Unimodal	17
Loliondo	Transitional	18
Lupatingatinga	Unimodal	19
Lushoto	Bimodal	20
Lyamungo	Bimodal	21
Manyoni	Unimodal	22
Maswa	Unimodal	23
Matamba	Unimodal	24
Mbamba Bay	Unimodal	25
Mbeya	Unimodal	26
Monduli	Bimodal	27
Morogoro	Bimodal	28
Moshi	Bimodal	29
Mpwapwa	Unimodal	30
Mtwara	Unimodal	31
Musoma	Bimodal	32
Mwanza	Transitional	33
Nachingwea	Unimodal	34
Newala	Unimodal	35
Ngara	Transitional	36
Njombe	Unimodal	37
Nzega	Unimodal	38
Olmotonyi	Bimodal	39
Rujewa	Unimodal	40
Same	Bimodal	41
Selian	Bimodal	42
Shinyanga	Unimodal	43
Singida	Unimodal	44
Songea	Unimodal	45
Sumbawanga	Unimodal	46
Tabora	Unimodal	47
Tanga	Bimodal	48
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Zanzibar	Bimodal	51