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THE CHARACTERISTICS OF WET SPELLS IN TANZANIA

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In Tanzania where the bulk of economy depends largely on rain-fed agriculture, the study of daily rainfall patterns is of paramount importance. It is well known that wet or dry spells lasting for long duration may impose unbearable moisture stress on crops. The dry and wet spells will also influence the day-to-day agricultural operations which include seedbed preparations, weeding, fertilizer applications, harvesting and many others. These weather events also influence the occurrence and spread of many plants and animal diseases, and pests, together with the wind and water erosions. It is therefore important to investigate the spatial and temporal characteristics of wet and dry spells. The characteristics which should be investigated include:

(*a*) The length of dry/wet spell that can be expected in any given month or season.

(*b*) The chances of a dry/wet spell lasting for a given number of days.

(*c*) Persistence of the weather events. This will indicate whether the occurrences of dry/wet spells are functions of the rainfall events in the previous days.

(*d*) Statistical distribution of the wet/dry spells.

Spatial and temporal characteristics of the dry/wet spells have been investigated by many scientists. Some of these authors include Williams (1952), Gabriel and Neuman (1957, 1962), Longley (1957), Jorgenson (1964), Weiss (1964), Basu (1971), Feyerhem *et al.* (1965), Hopkins *et al.* (1964), Katz (1977), Swift *et al.* (1981), Kamte *et al.* (1979), Stern (1982) and Agnihotri *et al.* (1983). Results from these studies indicated the tendency for wet/dry spells to be followed by dry/wet spells in some regions of the world. Many statistical models have also been used to describe the temporal patterns of the wet/dry spells. The statistical distributions which have been used include geometric, gamma, log-normal, Markov-chain and SB models.

In East Africa Alusa and Gwage (1978) examined the frequency of dry spells during the rainy months for the whole of East Africa. In this study we will investigate the spatial and temporal characteristics of the wet spells in Tanzania during the months of November through to May.

MATERIALS AND METHODS

The daily rainfall data were obtained from Directorate of Meteorology (Dar es Salaam) and Kenya Meteorological Department (Dagoretti Corner, Nairobi). The daily rainfall data used covered the period 1950-80. The distribution of the stations used is given in figure 1. The choosing of the eleven stations were based on the homogeneous regional groups as provided by Ogallo (1980), and adequate availability of the daily records. The months included in this study were from November to May. This period includes all the rainy months in Tanzania. The rainy seasons in East Africa generally migrate with the Inter-Tropical Convergence Zone (ITCZ) which also move with the sun's positions. The southern regions of Tanzania generally have one rainy season, while two rainy seasons are dominant in the other parts.

A wet spell of length i was defined as a sequence of i wet days preceded and followed by dry day(s). This was also referred to as i runs of wet spells (days). A threshold value for a rainy day (wet spell) was 1 mm as defined by one of the meteorological standards.

The runs of wet spells were computed for each month using the daily rainfall records. These were used to compute the frequency, probability and persistence of the wet spells within the months and seasons. If f_{ij} is the requency of a wet spell of length i, then f_{ij} may be expressed in the form:

$$f_{ij} = \sum_{k=1}^{m} f_{ijk} \qquad (1)$$

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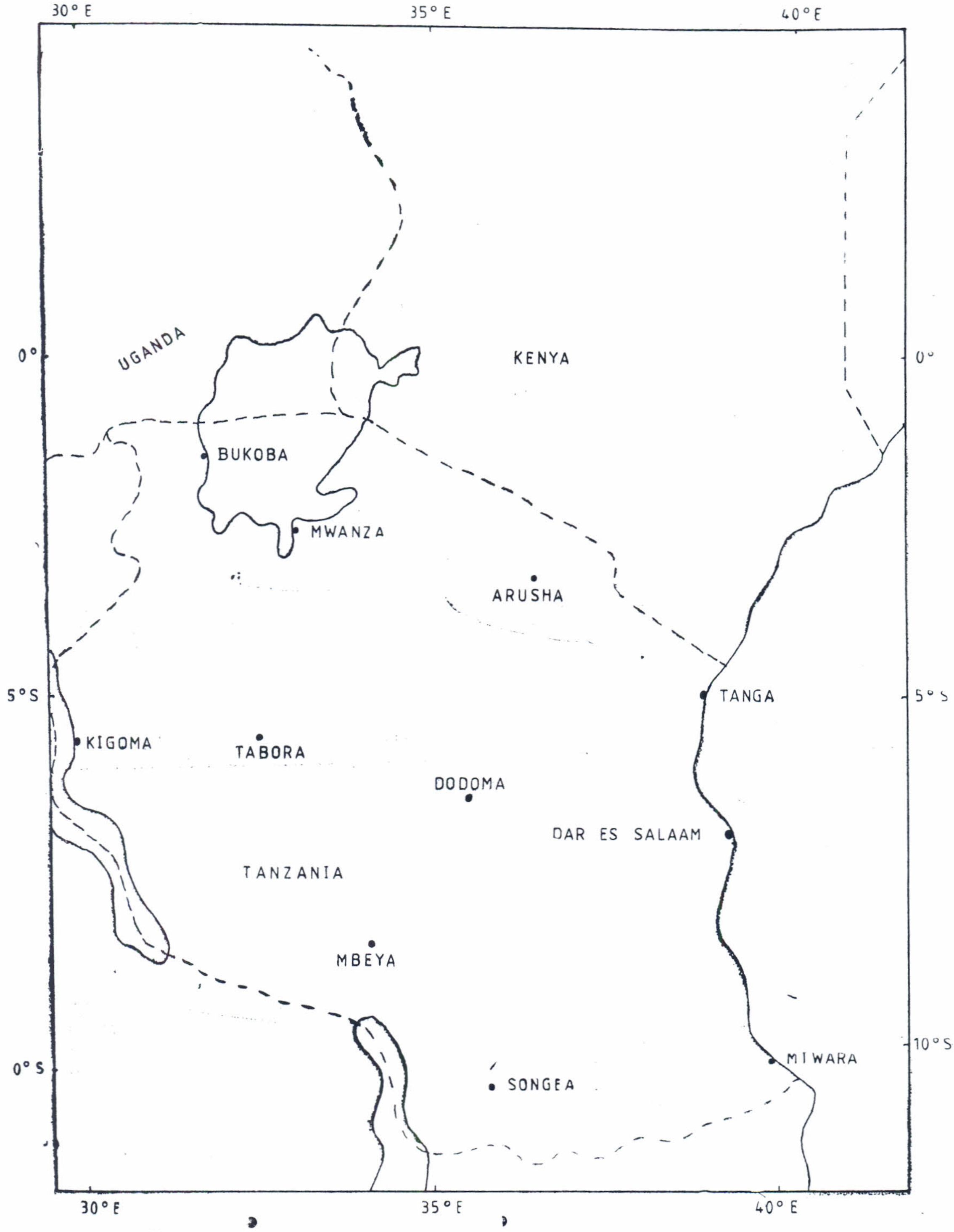

FIG 1 NETWORK OF THE STATIONS

Where m is the total number of years (31) and f_{ijk} is the frequency of i runs of wet spell during month j and year k. The frequency of all n wet spells in any month (F_j) or whole season (F_s) may be expressed as:

$$F_j = \sum_{i=1}^{n} \sum_{k=1}^{m} f_{ijk} \quad (2a)$$

$$F_s = \sum_{j=N}^{r} \sum_{i=1}^{n} \sum_{k=1}^{m} f_{ijk} = \sum_{j=N}^{r} F_j \quad (2b)$$

n is the total number of runs of wet spells, N the first of November and r the 31st of May.

The computed values of f_{ij}, F_j and F_s can be used to calculate cumulative frequencies within a month (C_{im}) or season (C_{is}). These cumulative frequencies may be used to describe the probability of at least i wet days within the month or season.

$$C_{im} = F_j - \sum_{i=1}^{i-1} \sum_{k=1}^{n} f_{ijk} \quad (3a)$$

$$C_{is} = F_s - \sum_{j=N}^{r} \sum_{i=1}^{i-1} \sum_{k=1}^{n} f_{ijk} \quad (3b)$$

The probability of a wet spell lasting at least i days for monthly or seasonal data may be obtained from the ratios C_{im}/f_m and C_{is}/f_s, where f_m and f_s are the total number of observations for the month and season used respectively.

The computed values of the ratios C_{im}/f_m and C_{is}/f_s, together with the corresponding frequencies have been used here to study the spatial and temporal patterns of the wet spells. Geometric and chain-dependant (Markov Chain) models were also used to investigate the persistence in the wet spells. The Markov Chain models will be used to determine whether the wet spells are functions of the preceding rainfall events.

Geometric and Markov chain models

When fitting the wet spells to Markov Chain models, it is generally assumed that these events obey a geometric distribution. Detailed accounts of Markov Chain models have been discussed by Gabriel and Neuman (1957, 1962), Katz (1977), and many others; hence only a brief review of the model characteristics will be included here.

The parameters of the Markov Chain models are derived from conditional properties. The occurrence of the rains is assumed to depend on the occurrence or absence of the rains in the previous days, and independent of the events of the further preceding days. Gabriel and Neuman (1962) have represented S_k, the probability of a wet spell of length k as:

$$S_k = (1 - P_1) P_1^{k-1} \quad (4)$$

$$P_1 = P_r \text{ (Wet day/Previous day Wet)} \quad (5)$$

$$P_o = P_r \text{ (Wet day/Previous day Dry)} \quad (6)$$

The probability of rainfall i days after a wet day (P_w) or a dry day (P_d) can be represented as:

$$P_w = P - (1 - P)\, d^i \quad (7)$$

$$P_d = P + Pd^i \quad (8)$$

where $d = P_1 - P_o$ and $P = P_o/(1 - d)$.

The probability of a weather cycle of n days ($f(n, P_1, P_o)$) can be expressed as:

$$f(n, P_1, P_o) = P_o(1 - P_1) \frac{(1-P_o)^{n-1} - P_1^{n-1}}{1 - P_o - P_1} \quad (9)$$

The other parameters for the Markov models, together with tests of goodness fit based on χ^2 distribution are well documented by Gabriel and Neuman (1962).

In fitting the daily data for each month to the chain-dependent models, the conditional probabilities S_k and $f(n, P_1, P_o)$ were computed. These were used to determine the expected frequencies of wet-spells and weather cycles at each station. The computed χ^2 values were then used to compare the observed and expected frequencies.

Results and Discussions

It was observed from the frequency of the runs of wet spells that many rain storms lasted one day. Some examples of the observed patterns are shown in figures 2-5. These patterns indicated that the frequency of the wet spells fell off exponentially from the shortest to the longest duration. The observed run values indicated that longer runs were evident during the wetter years. In many of these stations, relatively longer runs of wet spells were recorded during the wet years of 1961-63, and in 1978. The maximum length of a wet

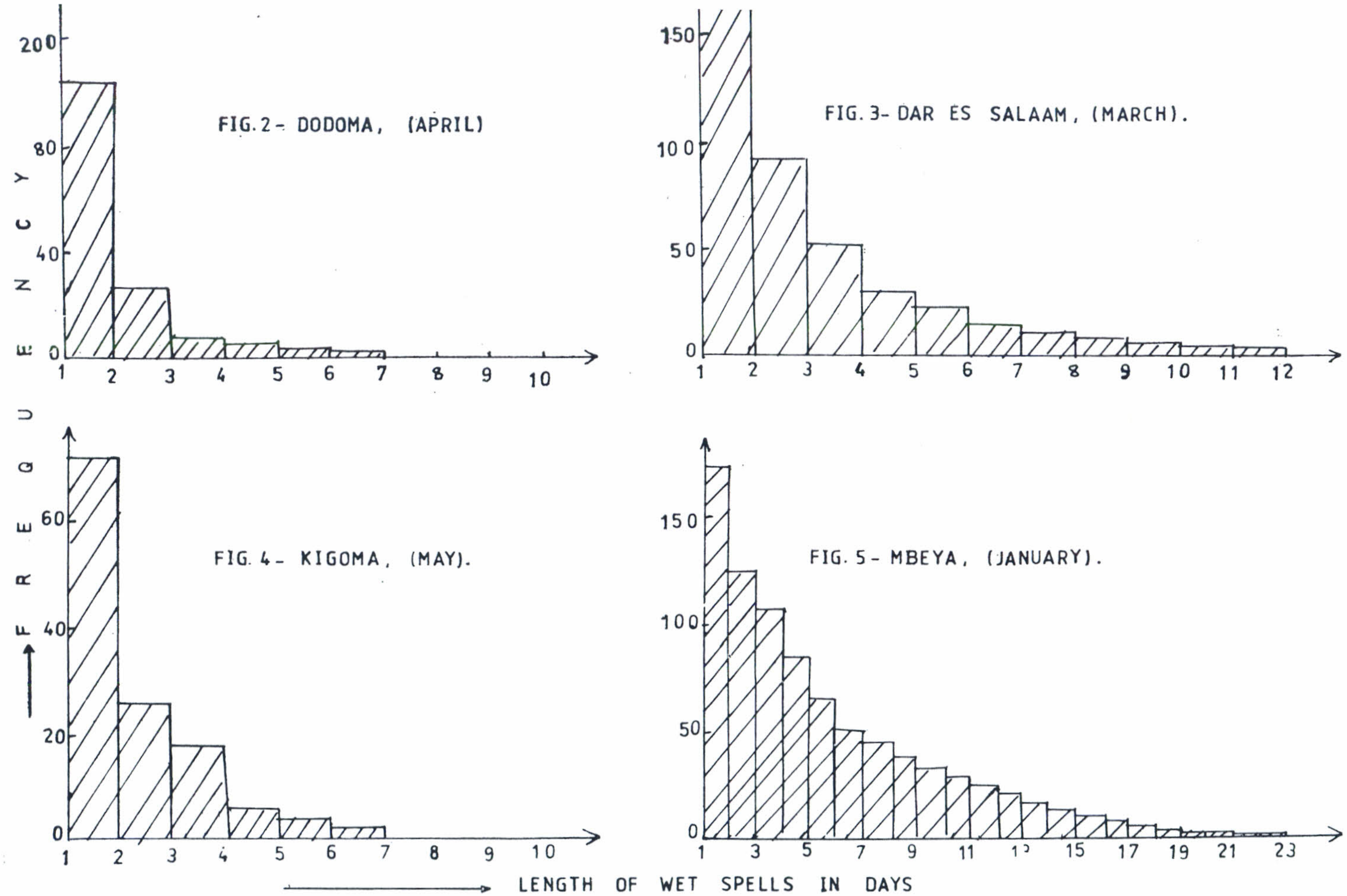

FIG. 2-5 : OBSERVED FREQUENCIES OF WET SPELLS

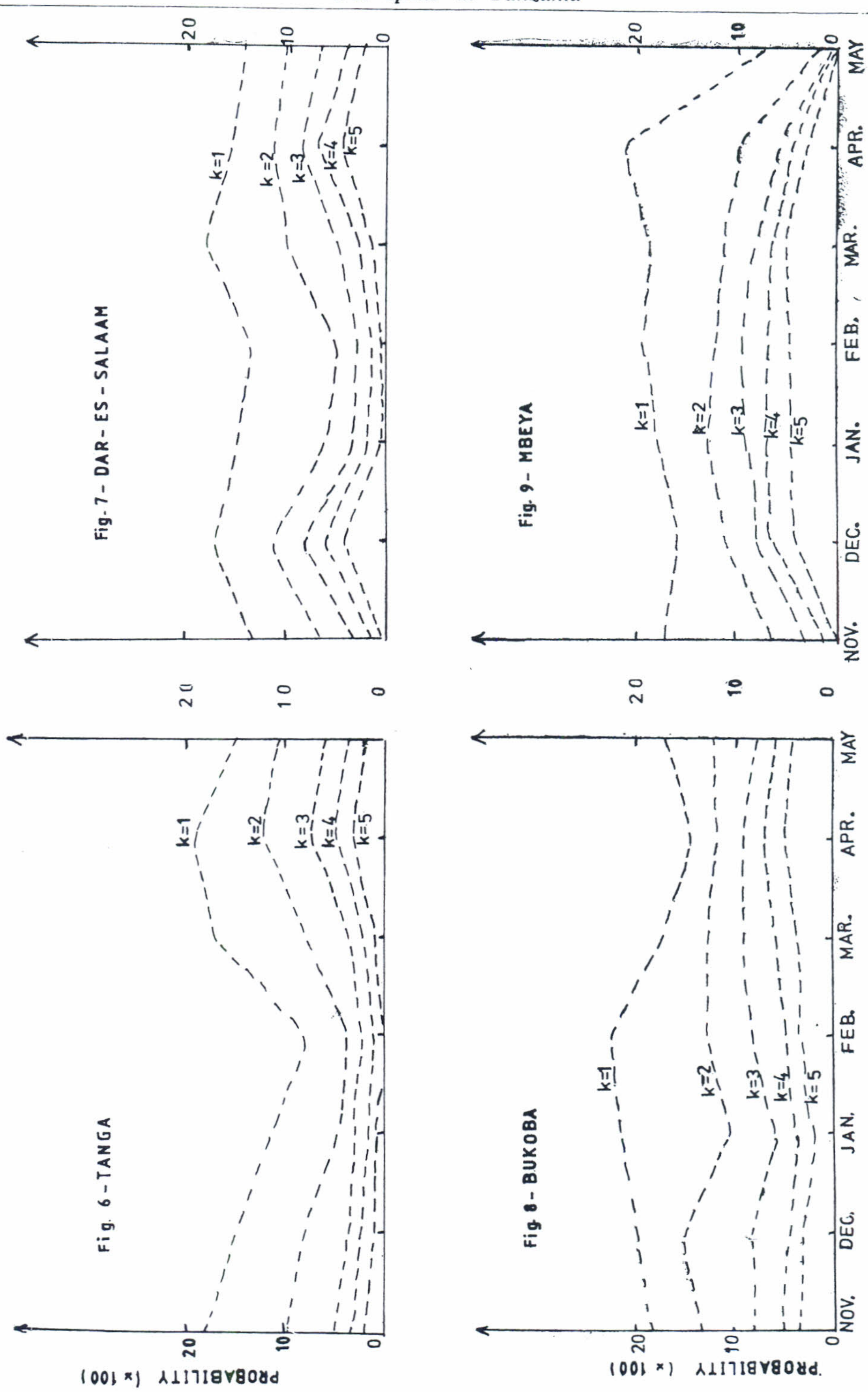

Fig. 6-9: Probability of at least k wet spells in a season

spell recorded during the period of study was 47 days. This was observed at Mbeya starting from 30th November, 1961, and ended on 15th January, 1962. Table 1 gives the observed maximum length of wet spells which was observed within a month at each station. It can be observed that longer runs of wet spells were observed in the southern highlands of Tanzania which receive most of their precipitation within a single rainy season. Mean annual rainfall records also indicate that this region of Tanzania is one of the wettest regions in East Africa. Long wet spells were also evident in Arusha and western areas of Lake Victoria region.

TABLE I—THE MAXIMUM LENGTH OF A WET SPELL OBSERVED WITH A SINGLE MONTH

Station Name	Days which longest spell per month lasted
Arusha	29
Bukoba	27
Dar es Salaam	20
Dodoma	16
Mbeya	31
Mtwara	21
Mwanza	19
Songea	30
Tabora	22
Tanga	18
Kigoma	16

Seasonal expectations of the wet spells are given in Table II, and figures 6-9. Seasonal trends are evident in these patterns, with the highest expectation values during the peak rainfall months as would be expected. In regions with two rainy seasons two maximum values are evident while only one appears in other regions. The influence of local factors like topography and large water bodies in enhancing the seasonal expectations of the wet spells can be seen through relatively high probabilities appearing throughout all of the months used at some shore stations.

TABLE II—P_{WS}: RELATIVE SEASONAL CUMULATIVE FREQUENCY OF WET SPELLS (x 100)

Station	November	December	January	February	March	April	May
Kigoma	13·4	15·9	15·4	15·2	15·6	14·5	10·0
Arusha	12·9	14·6	13·4	13·4	16·2	14·8	14·7
Bukoba	14·6	15·1	15·6	16·1	14·2	11·2	12·9
Dar es Salaam	14·3	15·1	14·0	13·5	14·3	14·9	13·9
Dodoma	6·4	17·1	19·0	19·1	21·1	12·9	4·0
Mbeya	14·5	13·6	15·5	16·5	16·1	17·2	6·6
Mtwara	10·1	10·9	16·3	18·4	17·4	17·1	9·8
Mwanza	13·3	14·7	14·6	14·4	13·6	15·4	14·0
Songea	9·4	16·2	16·1	16·0	17·6	18·0	6·7
Tabora	14·8	14·3	18·5	18·8	14·4	13·1	6·1
Tanga	17·2	14·4	10·8	8·0	16·6	18·5	14·5

P_{WS}: All wet days in month j/All wet days in the season.

The observed monthly frequency of the wet spells are given in Table III. It can be seen from this table that the patterns displayed in Table II were also evident here. As one would expert wet spells dominate during the peak rainy months. The chances of wet spells were however lower in the arid and semi-arid parts of Tanzania during most of the months.

TABLE III—RELATIVE MONTHLY FREQUENCY OF WET DAYS (Pwd)

Station	November	December	January	February	March	April	May
Arusha ..	0·32	0·38	0·29	0·28	0·41	0·64	0·46
Bukoba ..	0·65	0·58	0·45	0·51	0·61	0·75	0·58
Dar es Salaam	0·34	0·40	0·28	0·24	0·41	0·64	0·44
Dodoma ..	0·08	0·18	0·37	0·36	0·32	0·34	0·23
Mbeya ..	0·30	0·66	0·70	0·66	0·59	0·54	0·12
Mtwara ..	0·19	0·34	0·47	0·49	0·49	0·53	0·18
Mwanza ..	0·51	0·50	0·34	0·40	0·45	0·57	0·33
Songea ..	0·19	0·48	0·62	0·61	0·72	0·52	0·11
Tabora ..	0·49	0·57	0·53	0·52	0·46	0·42	0·12
Tanga	0·45	0·29	0·20	0·14	0·34	0·58	0·51
Kigoma ..	0·56	0·58	0·45	0·44	0·50	0·58	0·26

P_{wd} = All wet days in month j/f_m (all monthly observations).

Some examples of the conditional probabilities together with the parameters used in fitting the Markov Chain models are given in Tables IV-VI. Seasonal trends are also evident in the monthly patterns of these frequencies and probabilities. Table IV indicates a tendency for higher persistence during the peak rainy months as can be seen through larger P_1 values.

TABLE IV—MONTHLY CONDITIONAL PROBABILITY OF WET DAY WITH PREVIOUS DAY WET (P_1)

Station	November	December	January	February	March	April	May
Arusha ..	0·18	0·21	0·15	0·14	0·23	0·48	0·31
Bukoba ..	0·47	0·38	0·25	0·31	0·43	0·69	0·41
Dar es Salaam	0·19	0·21	0·13	0·09	0·22	0·49	0·29
Dodoma ..	0·03	0·03	0·21	0·19	0·17	0·19	0·10
Mbeya ..	0·14	0·51	0·56	0·53	0·47	0·35	0·06
Mtwara ..	0·08	0·22	0·30	0·27	0·31	0·35	0·07
Mwanza ..	0·32	0·28	0·15	0·21	0·25	0·37	0·15
Songea ..	0·10	0·32	0·47	0·45	0·55	0·34	0·05
Tabora ..	0·32	0·40	0·31	0·29	0·28	0·25	0·05
Tanga	0·25	0·14	0·09	0·06	0·17	0·38	0·36
Kigoma ..	0·34	0·32	0·23	0·22	0·27	0·36	0·11

The P_1 and P_0 values used in calculating the parameters for Markov Chain models are given in Tables IV and V. χ^2-tests indicated that the first order Markov Chain models fitted the sequences of wet spells well, especially near the larger water bodies. In other areas poorer fi\ were generally indicated during the drier months.

TABLE V—MONTHLY CONDITIONAL PROBABILITY OF A WET DAY WITH PREVIOUS DAY DRY (P_0)

Station	November	December	January	February	March	April	May
Arusha ..	0·14	0·16	0·15	0·15	0·17	0·16	0·16
Bukoba ..	0·19	0·19	0·20	0·21	0·17	0·15	0·17
Dar es Salaam	0·15	0·16	0·15	0·14	0·18	0·17	0·15
Dodoma ..	0·06	0·15	0·18	0·17	0·15	0·15	0·04
Mbeya ..	0·16	0·16	0·15	0·15	0·17	0·17	0·07
Mtwara ..	0·11	0·12	0·17	0·20	0·18	0·18	0·04
Mwanza ..	0·17	0·19	0·19	0·19	0·19	0·20	0·07
Songea ..	0·09	0·16	0·17	0·16	0·17	0·17	0·11
Tabora ..	0·18	0·18	0·23	0·23	0·18	0·16	0·08
Tanga	0·18	0·15	0·11	0·08	0·17	0·19	0·17
Kigoma ..	0·20	0·24	0·23	0·23	0·23	0·22	0·17

The computed frequencies of the weather cycles indicated peak values around 2-5 days. Cycles within this range have also been observed from spectral analysis of daily rainfall of some river basins in Tanzania (Kato, 1983).

The fitting of the first order Markov Chain models to the sequences of wet spells indicate some persistence in the daily rainfall events, especially during the peak rainy months. The relative frequencies of two runs of wet spells expressed as fractions of the total number of wet spells observed within the months are given in Table VI. These conditional probabilities indicated that many wet spells preceded wet spells, especially during the peak rainy months.

TABLE VI—CONDITIONAL PROBABILITY P_1 AS A RATIO OF RELATIVE OCCURRENCE OF ALL WET DAYS IN THE MONTH (x 100)

Station	November	December	January	February	March	April	May
Arusha ..	56	68	52	50	56	75	67
Bukoba ..	72	66	56	61	71	92	71
Dar es Salaam	56	53	46	38	54	77	66
Dodoma ..	40	17	57	53	53	56	45
Mbeya ..	47	77	80	80	80	65	50
Mtwara ..	42	65	64	55	63	65	39
Mwanza ..	63	56	44	53	56	65	45
Songea ..	53	67	76	74	76	65	45
Tabora ..	65	70	58	56	61	60	42
Tanga	56	48	45	43	50	66	71
Kigoma ..	61	55	51	50	54	62	42

SUMMARY

In this study daily rainfall records for eleven Tanzanian stations were used to study the spatial and temporal characteristics of the wet spells during the rainy months of 1950-80. The months included in the study were November through May.

The results from the study indicated that although many rain storms lasted for one day, there was a tendency for a wet spell to precede a wet spell, especially during the peak rainfall months. It was observed that the seasonal expectations of the wet spells generally migrated with the seasonal patterns of the rain belts. These patterns were however, modified near large water bodies.

The results from χ^2 test indicated that first order Markov Chain models fitted the sequences of wet spells adequately, especially during the peak rainfall months.

Conclusion

The results from the study indicated that although many rain storms lasted one day, there was a tendency for a wet spell to precede a wet spell, especially during the peak rainy months. The seasonal expectations of the wet spells were noted to follow the seasonal migration patterns of the rain belts. These seasonal patterns were however modified near the large water bodies.

The first order Markov Chain models fitted the sequences of wet spells well, especially during the peak rainy months. The good fit of the chain dependent models during rainy months may be due to the prevailing meteorological conditions during the rainy seasons. These conditions are generally stable once formed, and often last for more than one day. High autocorrelations between daily rainfall records together with cycles within 2-5 days have also been observed by Kato (1983) in some areas of Tanzania using correlograms and spectral analysis.

It should be noted that the fitted Markov Chain models together with the conditional probabilities which were used to compute their parameters were formulated entirely in terms of the sequences of rainfall events. No account was taken of the amount of precipitation or any other meteorological parameters which control the daily weather events.

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