DETERMINATION OF HUMIDITY-REFERENCED POTENTIAL AREAS FOR CROP PRODUCTION IN TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURAL ENGINEERING) OF SOKOINE UNIVERSITY OF AGRICULTURE

1999

ABSTRACT

The study sought to determine the potential areas for production of maize, sorghum, groundnuts and beans based on humidity levels. The specific objectives were; to determine monthly humidity grades of the meteorological stations, to demarcate humidity zones, to establish potential areas for cultivation of the crops and to compare the established areas with those where selected crops are currently grown.

Rainfall and evapotranspiration data of 97 stations were collected from the Directorate of Meteorology while the maximum water holding capacity, the growing periods and the crop coefficients of the selected crops were estimated from those available in the literature. Data analysis was based on hydrologic budget balancing model for stations and the computer packages; Microsoft Excel for Windows 95 Version 7.0 and QUATRO PRO Version 4.00 were applied for determination of humidity levels. Potential areas were delimited by grouping of stations of the same humidity levels. The areas were then compared to those under current production.

The study found that the approach seems to provide basic information on potentials and can therefore be used for agricultural planning purposes. A fairly large percentage of areas established through this method, especially for maize and sorghum, coincide with the current production areas. Among the three crops, beans have shown the greatest potential over the country's total area and only 20% of it is utilized while groundnuts have the highest percentage of its potential area being unutilized.

Recommendations from the study include: Mapping out of crop potentials as related to other factors to improve the predictability of the method for agricultural planning. Similar studies on specific crops be carried out in smaller areas and later on be combined to cover the whole country. Zonal research centres be involved to establish more meteorological stations so that each portion of the country is well covered.

DECLARATION

I, Juma Mohammed Ikingu Mande, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own work and has never been submitted for a degree in any other University.

Signature: ____________________

Date: 5/7/1999

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ACKNOWLEDGEMENT

I wish to express my special gratitude to my Supervisor: Prof. Benedict Kayombo for his extensive advice and direction which enhanced the success of this work. I also acknowledge with deep appreciation the help, constructive criticism and tireless guidance of Dr. H.O. Dihenga, Dr. N. Kihupi, Dr. S.T.A.R. Kajuna and Dr. A.K.P.R. Tarimo that came at such a very crucial moment.

I am indebted to the staff of the Directorate of Meteorology in Dar es Salaam and of the Morogoro Meteorological station for their assistance in the data collection.

Friends and Colleagues are also acknowledged here for the help I enjoyed in many forms during the course. Particular mention must be made of Mr. P.M. Ntella, R.I. Rushomesa, A.N. Kituli, O.R.B. Mziray and G. Daudi for their laughter and company.

I wish also to mention the tolerance of my wife and children who have had to suffer inconveniences attributed to the cause of this work.

DEDICATION

This work is dedicated to the one who bought me the first pencil I ever used in my life: My mother, Zainab.

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1 INTRODUCTION

The humidity of a given region is greatly influenced by the amount of rainfall and evapotranspiration. In general terms, evapotranspiration is a measure of the water demand of growing plants, and rainfall can fully or partially supply the plant water requirements (Nieuwolt, 1973). Examination of evaporation on a land surface with a dense cover of plants has revealed that transpiration accounts for more than 95% of evapotranspiration. Thus, for such conditions evapotranspiration can be assumed to be equal to transpiration. This leads us to compare the known crop coefficients (as they are related to transpiration) of some crops to the ratios of the calculated actual evapotranspiration over the potential evapotranspiration (Schmiedecken, 1981).

When rainfall and evapotranspiration are balanced and prevail for periods of more than three months, agriculture is possible (Nieuwolt, 1973). In the driest parts of Tanzania like Dodoma, conditions are marginal for most forms of farming. Proper use of meteorological data can be of great assistance in making the right decision on crop selection, timing of planting and harvesting (Conyers, 1973).

Humidity plays a significant role in agriculture due to the fact that it determines the type of natural vegetation as well as living conditions of most crops grown in the tropics and subtropics (Schmiedecken, 1981). For example, the length of the growing period for annual crops is determined by the number of humid months, and aridity is a limiting factor for growing perennial crops. Humidity conditions are produced by precipitation and an interplay between water availability and evapotranspiration requirement (Jatzold, 1977).

Developing countries (including Tanzania) are mostly located in the tropical region of the world. In this region temperatures show little or no seasonal variation and rainfall is the major limiting factor in agricultural production (Nieuwolt, 1973). For instance, in the humid tropics, in particular, temperature does not rise sufficiently high or fall sufficiently low to seriously limit plant growth for any prolonged time throughout the year (Williams and Joseph, 1973). Also rainfall and evapotranspiration are the two major elements in the host of variables which impinge on successful crop production. Therefore, there is a basic need to determine the influence of the two parameters on crops in order to identify potential areas for crop production as a tool for agricultural planning (Baier, 1983). In this regard, humidity which is affected by both rainfall and evapotranspiration, is an important and adequately available weather parameter for analysis.

There are several studies currently available on agro-ecological zoning which have been done in Tanzania (Conyers, 1973; De Pauw, 1984; Food Studies Group, 1992). The study conducted by Conyers (1973) was based on sufficiently homogeneous agricultural conditions to warrant the adoption of a single agricultural policy at the district level. Other studies based on soil surveys, rainfall and length of the growing season also emerged in early eighties (Food Studies Group, 1992). Most classifications are not crop-specific although they have been used to describe areas where various crops can possibly be cultivated. In this respect, a study based on mapping out potentials of specific crops is necessary for effective agricultural planning.

The success of the crops grown in an area depends on the environment and on how they adapt to it. Before attempting any crop production in a given area, therefore, many questions have to be answered. What crops can be grown and what are their potentialities? Why one crop is grown in that area and not in another? etc. The answers to these questions depend on, among others, a thorough understanding of the ecologic conditions of the area.

Many agricultural projects undertaken with little or no knowledge of crop ecologic requirements in relation to the climatic conditions of an area have resulted in disastrous failures (Slater, 1983). For example, the failure of a mechanized large scale groundnut production in Kongwa (Dodoma region), an area which is ecologically suited to natural pastures, is evidence of such shortfalls (Eldin, 1983). Establishment of crop priorities presupposes a measure of agro-economic information which is still insufficient in relation to farm-size and extent of coverage in the country (Conyers, 1973). But little effort has been made to address this inadequacy and that is why cases just mentioned still occur.

The significance of this study is based on the fact that agriculture is the most important sector in Tanzania's economy. It employs about 85% of the population workforce and contributes about 75% of foreign exchange earnings. It is also the main source of food supply and raw materials for the industrial sector (Ministry of Finance, 1996). The production potential in this sector is greatly influenced by rainfall (Gommes and Houssiau, 1982; Kassase, 1992; Kingamkono, 1994) which is also a major factor that influences humidity level in an area. A study of humidity levels is, therefore, essential in understanding the spatial distribution of the potentials of an area for growing different crops.

Although both rainfall and evapotranspiration influence humidity, neither of the parameters alone can be used in agro-ecological zonification. This is because not many, if any, quantitative studies on relationships between the two parameters and crop water requirements have been conducted (Mavi, 1986). However, the ratio of water availability to potential evapotranspiration (determined by both parameters) can be compared to crop water requirement. Also, as will be seen later in the methodology, the same ratio expresses humidity grade of an area and hence a relation between humidity and crop water requirements.

It is worth-noting that delineation of humidity zones is useful for mapping out suitable areas for growing specific crops. Other alternatives like soil surveys, aerial photograph and satellite imagery interpretation would serve a similar role but they are more expensive as compared to humidity zoning especially when they are to be applied over a vast country like Tanzania. There is also one big advantage with humidity zoning method, that is, records of past years are available in many meteorological stations. Therefore, humidity information is readily available and can be used for agricultural planning.

Maize, sorghum, groundnuts and beans form a major source of food in Tanzania and are widely produced in the country (Ministry of Agriculture, 1995). Yet their potential areas are not well demarcated. Maize and beans are high water demanding annual crops while sorghum and groundnuts adapt well to drought conditions (Doorenbos and Kassam, 1979). A comparison between the so established optimal areas of the above-mentioned crops and those in which the crops are currently grown will facilitate investigation of other factors influencing the performance of the crops in the respective zones.

The main objective of this study was to determine optimally suitable areas for production of selected crops, namely, maize, sorghum, groundnuts and beans in Tanzania, according to prevailing humidity levels.

The specific objectives of the study were:

i) to determine monthly grades of humidity for selected meteorological stations in Tanzania;

ii) to demarcate humidity zones;

iii) to establish optimal zones for cultivation of maize, sorghum, groundnuts and beans based on prevailing humidity levels; and

iv) to compare the established optimal zones with those where the selected crops are currently grown.

2 LITERATURE REVIEW

2.1 Introduction

This section reviews the importance of agroecological classification, especially in the tropics where there is a great potential for agriculture. Different attempts in Tanzania for agroecological classification are also comparatively reviewed. Different methods for determination of essential parameters of humidity zoning are critically reviewed. Emphasis is also made on different alternatives for determining or estimating the potential evapotranspiration (pEt) and its relation to crop water requirements, grading of humidity of stations and finally its coding which is useful for the later cartographic work. Finally, the crop ecologic requirements are briefly reviewed to highlight their adaptability to different humidity conditions and the length of growing periods.

2.2 Importance of Agroecological Classification in the Tropics

The world food is supplied by two distinctly different regions which are shaped by climate. There is the temperate region where climate is seasonal and weather patterns are often manageable. There is also the tropics region where climate is less predictable, particularly rainfall. The former is characterized by modern, mechanized and usually high productive farming while in the latter agricultural production is manual, small-scale and subsistence oriented (Slater, 1983). Despite all this difference, it is believed that tropical agriculture could become the most productive in the world with the use of technology of which agroecological classification is an integral part of this new science (Kamarch, 1979).

Agroecological classification presents a considerable problem in that numbers and distribution of stations are often inadequate to represent spatial relations in variables (Jackson, 1989). Tanzania has over 600 rainfall, 13 agroclimatological and 55 climatological stations throughout the country (Deckers *et al*, 1991). This number of stations, though inadequate, can provide a pool of information for the evaluation of the agricultural potentials.

2.3 Agroecological Classification in Tanzania

Several attempts have been made to classify Tanzania into different agroecological zones. The methods used were based on types of soil, rainfall and length of growing season (FAO, 1978; 1980a,b). Some authors, for example, De Pauw (1984) classified the country into eight zones based on physiographical divisions and constituent production systems. Others classified it into twenty zones based on soil types, annual rainfall, rainfall pattern, length of growing season and altitude (Food Studies Group, 1992). Rombulow-Pearse and Kamasho (1982) conducted a study which was aimed at evaluating and grouping of different physical resources of Mbeya region into rural development zones. The region was divided into four major development zones.

As noted earlier the above classifications are not crop-specific (De Pauw, 1984). The Ministry of Agriculture (1991) prepared maps specifically for some crops based on percentage of the total area of each administrative region which is cultivated with those crops. Jackson (1989) pointed out that approaches for agroecological classification were available based on a particular crop by grouping stations with similar characteristics. Gadgil and Joshi (1983) used monthly rainfall and humidity index (the ratio of rainfall to potential evapotranspiration) and minimum temperature for classification of climate. They found that climatic grouping so obtained in India closely corresponded to the vegetation pattern. Oldeman and Frere (1982) obtained similar results of agroclimatic classification for rice-based cropping pattern. They used water balance approach to show the validity of a wet month defined as having more than 200mm and a dry month with less than 100mm of rainfall as criterion to delimit climatic classes.

Schmiedecken (1981) developed an approach whose results indicated a possibility of identifying potential areas for cultivation of crops in the tropics. The method calculates the ratios of the actual water availability to the potential evapotranspiration (aWA/pEt) and uses them to categorize humidity zones. The ratios are then compared to the crop coefficients (kc) for the purpose of determining optimal areas for production of the crops by grouping of related stations.

The crop coefficient values over the growth periods of the crops are calculated or estimated based on monthly measurement of the crop water requirements (ET_{crop}) using lysimeters (Schreiber, 1981). A ten-day period has also been used in the related studies, for instance, in developing a crop yields forecasting method. Some countries prefer to work with weekly periods or five-day periods (Frere and Popov, 1979). The basis for the choice of these periods is that they correspond to the time during which the total water reserve of the soil can assure a good water supply to the crops before further rainfall (Eldin, 1983).

Satellite imagery interpretation technique is now being used for evaluation of land resources for development planning (Earth Satellite Corporation, 1976). De Pauw (1984) applied satellite imagery interpretation to fill the blanks in a soil map that resulted from compilation and transfer of soil data sources onto a base map. The interpretation was, particularly, easy in the northeastern, drier part of Tanzania but it was also of a considerable assistance in other parts of the country.

2.4 Essential Parameters for Humidity Zoning Method

2.4.1 Potential evapotranspiration

The effects of climate on crop water requirements is expressed in terms of potential evapotranspiration or, sometimes, called reference crop evapotranspiration. According to Penman (cited by Frere and Popov, 1979), potential evapotranspiration is defined as the maximum quantity of water which may be lost by a uniform cover of dense, short grass when the water supply is not limiting. Wilcox and Sly (1975), Doorenbos and Pruitt (1977), and Jones (1981) defined the term as the rate of evapotranspiration from an extensive surface of 8 to 15cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. Papadakis (1966) briefly defined it as the water needed for optimum growth of plants. It is a term which refers to potential water consumption (Wilson, 1975; Schmiedecken, 1981).

Potential evapotranspiration is the most useful and central concept in agrometeorology. It is a measure of evaporative power of the atmosphere. As such, being based on meteorological parameters only, it does not express exactly the water needs of the crops, which have their specific physiological requirements (Gommes, 1983). The soundest method of determining potential evapotranspiration is by actual measurements in the field. In the more developed regions of the world, measured values are available and they form a basis for calculation of irrigation requirements. In the remaining regions, however, experimental data on potential evapotranspiration are non-existent or of too short a period, and are often related to irrigation projects. Indirect methods based upon different climatic parameters are, therefore, used for estimation (Doorenbos and Kassam, 1979; Critchley et al., 1991).

There are at least 30 formulas for determination of potential evapotranspiration reported in the literature, covering a wide variation in complexity of calculation and nature of climatic data required. These methods provide estimates of pEt which are reasonably similar to lysimeter values of a standard or reference crop (full cover of grass) under unlimited water supply (Linsley *et al.*, 1982). Four methods reviewed here are the Penman, Pan evaporation, Blaney-Criddle and Radiation method. The choice of a method will normally be based on climatic data available and accuracy required (Doorenbos and Pruitt, 1977).

2.4.1.1 Penman method

Most agrometeorologists agree that the Penman's method yields realistic estimates under most climates, provided appropriate coefficients are used (Gommes, 1983). The method can give the results with possible error of plus or minus 10 percent in summer and up to 20 percent under low evaporative conditions (Doorenbos and Pruitt, 1977). It relates pEt to a number of climatological parameters, such as, the mean air temperature, dew point temperature, wind speed, and incoming solar radiation (Nieuwolt, 1973).

The disadvantage with the Penman method is that it requires data on climatological parameters which can only be obtained from a particularly well-equipped climatical station. This precondition is rarely met in developing countries (Stewart and Mills 1967; Schreiber, 1981).

2.4.1.2 Pan evaporation method

The Pan evaporation method gives results with possible errors of about 15 percent (Doorenbos and Pruitt, 1977). With this method, pan evaporation readings are needed for calculation of pEt values. Pan evaporation (E_{pan}) is, usually, higher than potential evapotranspiration and has to be multiplied by a pan coefficient (K_{pan}) (Wilson, 1975). Thus,

$$pEt = E_{pan} \times K_{pan} \tag{1}$$

Many types of pans are in use, but the US Weather Bureau Class A pan is, perhaps, the most widely used (Jackson, 1989). For Class A pan, the coefficient ranges from 0.35 to 0.85, depending on relative humidity, wind speed and vegetation conditions (Doorenbos and Pruitt, 1977; Critchley *et al.*, 1991; Critchley *et al.*, 1992). If the precise pan factor is not known, the average value of 0.70 can be used for approximation. For higher accuracy, a detailed table of pan factors has been made available from Irrigation Water Management Training Manual (Critchley *et al.*, 1991). There are difficulties in using the pan for direct measurement, but actual field measurements should form an important part in any studies of evapotranspiration (Wilson, 1975).

In practice pan evaporation measurements of one area can often be estimated for another adjacent area. Thus, the relationship between this evaporation and crop water requirements can also be transposed from another area whose climate bears resemblance to that of the area under study (Withers and Vipond, 1988).

2.4.1.3 Blaney-Criddle method

The Blaney-Criddle method is straight-forward and perhaps the best known and widely used as it requires only the mean daily temperatures and approximate geographical latitude of the area for the corresponding value of the mean daily percentage of annual daytime hours. However, with this method, only approximations of potential evapotranspiration are obtained which can be inaccurate in extreme conditions (Critchley *et al.*, 1992). The formula is:

$$pEt = p(0.46\, T_{mean} + 8) \qquad (2)$$

where:

pEt = potential evapotranspiration (mm/day)

T_{mean} = mean daily temperature (°C)

p = mean daily percentage of annual daytime hours

In order to calculate the mean daily temperature (T_{mean}), the daily minimum and maximum temperature are to be measured. Thus,

$$T_{max} = \frac{\sum_{i=1}^{n} T_{max_i}}{n} \qquad (3)$$

$$T_{min} = \frac{\sum_{i=1}^{n} T_{min_i}}{n} \qquad (4)$$

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \qquad (5)$$

where:

n = number of days of the month.

The values of p are obtained based on the approximate latitude of the location (Appendix A).

2.4.1.4 Radiation method

The radiation method is considered more reliable than others, especially in tropical zones, small islands, and regions of high altitude. The method is based primarily upon radiation and air temperature, with additional correction made for relative humidity and daytime wind speeds (Critchley *et al.*, 1991). The formula is:

$$pEt = f + gWR_s \qquad (6)$$

where:

pEt	=	average daily evapotranspiration (mm)
f & g	=	adjustment factors made graphically on WR_s using estimated values of relative humidity and daytime wind speed.
R_s	=	incident solar radiation (mm/day)
W	=	temperature and altitude dependent weighing factor

2.4.2 Hydrologic budget of a station

The climatic hydrologic budget of a station is defined as the difference between rainfall and potential evapotranspiration at a given location (Schmiedecken, 1981). The factors of hydrologic equation include rainfall and part of the stored soil water which is available for evapotranspiration (Robertson, 1989). The monthly total rainfall is used, instead of effective rainfall, to determine the hydrologic budget.

Effective rainfall (p) is defined as the fraction of total rainfall that is effectively intercepted by the vegetation or stored in the root zone and used by the plant-soil system for evapotranspiration. It is opposed to that part which evaporates in the atmosphere, lost as surface run-off or as groundwater flow through infiltration, and is not available for evapotranspiration (Abdulmumin and Bastiaansen, 1991). It is not practical to measure run-off and deep percolation for all meteorological stations as these measurements are complicated, time consuming and expensive. Only total rainfall records are available in the meteorological stations and can be used for approximation purposes (Eldin, 1983).

Schmiedecken (1981) suggested the following procedure for balancing of the hydrologic budget:

The available soil moisture (St) is calculated differently in two periods. In periods with deficit hydrologic budget the following equation is used:

$$St_n = \frac{St_{n-1}}{e^{\frac{(pEt-p)_n}{WC}}} \qquad (7)$$

where:

St_n or St_{n-1} = volume of water in the soil at month n or n-1 with St_o = WC

WC = water holding capacity in root zones of soil

p = mean monthly precipitation.

pEt = potential regional evapotranspiration.

In periods with surplus budgets (i.e, p ≥ pEt) calculation is carried out by adding the positive figures from p-pEt up to the maximum soil water holding capacity of a station.

The change in the soil water from month to month is determined using the following equation:

$$\Delta St = St_{n-1} - St_n \qquad (8)$$

where:

St_n or St_{n-1} = volume of water in the soil at month n or n-1

Thus, the actual evapotranspiration (aEt) is then calculated. It equals potential evapotranspiration for periods of surplus budget and is given by $p+\Delta St$ for periods of deficit budget. This is because in the periods of deficit budget, rainfall is less than evapotranspiration and can only partially supply the water demand. The stored moisture in the soil, therefore, has to supplement for the excess evapotranspiration (Schmiedecken, 1981).

Finally, aWA/pEt are calculated. These indicate the humidity status of a station in a given month.

The maximum water holding capacity of soils (WC) determines, to a great extent, the length of the growing period and the likelihood that a crop may overcome a dry spell within the growing period (De Pauw, 1984). The factor varies with soil type and depth of the root zone and it is, therefore, difficult to give a general estimate. The most economical solution is to input "blanket" values for the maximum soil moisture reserve into the waterbalance (FAO, 1979). Nieuwolt (1973) used a value of 250mm and found that this factor is, in most cases, not particularly critical with regard to the general type and consequences of the water balances in Tanzania.

Some efforts have already been made in Tanzania to obtain approximate values of the maximum water holding capacity of different soil units. De Pauw (1984) compiled estimates of the range of maximum water holding capacities that can be expected in broad areas that are subdivisions of the physiographic regions (Table 1). The work was based on numerous soil studies carried out at smaller areas in the country (Presant, 1974; Maggogo, 1982a, b, c). Similar compilations were made by Cook (1974, 1975), Hathout (1975) and Moore (1971).

Table 1: Physiographic regions/subregions and maximum water holding capacity (per metre depth) in root zone of soil

Physiographic Region or Subregion	Max. WC (mm)	Average WC (mm)
Coastal zone		
Coastal uplands	50-150	100
Coastal lowlands	150-350	250
Eastern plateau and mountain blocks		
Semi-arid plains	40-60	50
Semi-humid upland plains	150-300	225
Semi-humid lowland plains	200-350	275
Mountain blocks	200-400	300
Southern highlands		
Highlands covered by volcanic products	100-200	150
Highlands developed on basic metamorphic rocks	300-400	350
Highlands developed on acid metamorphic rocks	150-200	175
Lacustrine plains	300-350	325
Northern rift zone and volcanic highlands		
Plains developed on sodic volcanic ash	30-50	40
Volcanic ash plains & cones (I)	200-400	300
Volcanic ash plains	100-200	150
Volcanic ash plains & cones (II)	300-600	450
Rift depressions	0-50	25
Central plateau		
Predominantly well drained plains with sandy or loamy soils	150-300	225
Predominantly well drained plains on lacustrine sediments	200-250	225
Seasonally water logged plains with hardpan soils	15-50	33
Predominantly well drained plains on strongly weathered Sediments	100-200	150
Predominantly poorly drained plains	150-225	188
Ruaha riftzone		
(I)	150-350	250
(II)	150-300	225
Inland sedimentary plateaux	100-150	125
Ufipa plateau	150-300	225
Western highlands		
Highlands developed on basalts or argillaceous rocks	200-400	300
Highlands developed on sandstones	100-200	150

Source: De Pauw (1984)

2.4.3 Crop coefficients (kc)

Water requirements for agriculture are closely related to the potential evapotranspiration which depends on crop type and environmental conditions when water supply is not limiting. ET_{crop}/pEt, usually called crop coefficient (kc), has been worked out empirically (experimentally) for a variety of crops. It is a function of the crop (variety) and of its growth stages. Thus, at early growth stages, the ratio assumes low values around 0.5 and gradually increases to 1.0 or sometimes 1.2 for high water demanding crops, such as, maize (Gommes, 1983).

Reliable monthly kc values for some crops over their growth periods are now available in the tropics. Rijks (1978), for example, computed the kc values for some crops at Namulonge, Uganda.

2.4.4 Humidity grades of a station

Papadakis (1966) pointed out that, rainfall alone will not indicate whether a climate or a season is humid. In order to tell how humid or arid climate or a season is, the amount of water which is necessary to produce good crop that did not suffer from water stress should be known and compared to the actual rainfall. This leads to the need to measure or estimate pEt. The ratio of rainfall over potential evapotranspiration is, therefore, very important and can be applied to indicate humidity level of a given area.

On the other hand, aWA/pEt are used for characterization of a given location as humid or arid, based on predetermined limits of these values. The values are calculated according to the procedure suggested by Schmiedecken (1981), which uses monthly rainfall and evapotranspiration as input values.

Jatzöld (1977) suggested the following limits based on plant water requirements and potential evapotranspiration (pEt) for determining the grades of humidity. The water supply of over 1.2pEt is termed as perhumid; 0.8-1.2pEt as fully humid; 0.4-0.8pEt as subhumid; 0.2-0.4pEt as semiarid; 0.1-0.2pEt as fully arid and under 0.1pEt as extremely arid. In this case, the concept of isohygromenes as lines with the same number of humid months is supplemented by the specification on the physiology of the crops. Schmiedecken (1981) used a method based on aWA/pEt values alone. The quotient of 2.0 is used to separate between humid and semihumid zones. Further, between semihumid and semiarid the quotient of 1.0 is used and between semiarid and arid 0.5 is used.

The limits of a climatic region can also be given by humidity index (I) values computed according to Thornthwaite (1948). The criterion adopted is that the values greater than 40 represent superhumid; 20-40 represents humid; 0-20 subhumid; -20-0 dry subhumid; -40 to -20 semiarid; and less than -40 represent arid (Carrillo and Benacchio, 1983).

The methods discussed above are related in that they all take into consideration the two major parameters which are crop water requirements and potential evapotranspiration. Nevertheless, different approaches have been applied in determining the parameters and expressing the limits used for grading of humidity.

2.4.5 Humidity reference number

The monthly humidity situation of a station can be expressed in two ways (Papadakis, 1966). One way makes use of a 4-figure reference number system based on values of 2.0, 1.0, and 0.5, of aWA/pEt values calculated according to Schmiedecken (1981). The number of months with the same humidity grade is entered as follows: humid-subhumid-semiarid-arid. A 4-figure reference number of a station is, therefore, formed with respect to the number of months in each subdivision, entered in the above order. Thus, for instance, 4134 means a station has four humid months, one subhumid month, three semiarid months and four arid months. The sum of digits should be 12, corresponding to the number of months in a year.

The second way is to express the monthly humidity situation according to predetermined ratios of rainfall over potential evapotranspiration. For example, 4-7;10/12-2 means that the humid season includes April (4), May, June and July (7); October (10) is also humid; the dry season includes December (12), January, February (2); and the months not included in these two seasons (March, August, September, November) are intermediate (Papadakis, 1966).

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Formulating a reference number of a station represents the climatological characteristics of a station in the simplest form useful for cartographic purposes.

2.5 Crop Ecologic Requirements

The following are the crop ecologic requirements for the selected crops: Common beans (*Phaseolus vulgaris*) require medium rainfall, but not suited to the humid, wet tropics. Dropping of flowers and pod occurs due to excessive rainfall which is a characteristic in this region. The length of its growing period varies with the intended use of the crop and is 60 to 90 days for green beans and 90 to 120 days for dry beans (Doorenbos and Kassam, 1979; Ministry of Agriculture and Livestock Development, 1987).

Groundnuts (*Arachis hypogaea*) is very resistant to drought and, therefore, well adapted to the short humid season (Papadakis, 1966; Kassam *et al.*, 1975). Its growing period is 90 to 115 for the sequential, branched varieties and 120 to 140 for the alternately, branched varieties (Doorenbos and Kassam, 1979).

Maize (*Zea mays*) is an efficient user of water and, therefore, sensitive to drought. A humid season of four months is sufficient. Early grain varieties mature after 80 to 110 days and medium varieties 110 to 140 days (Doorenbos and Kassam, 1979; FAO, 1980c).

Sorghum (*Sorghum bicolor*) is adapted to drought conditions. It occupies the soil well and lowers potential fertility much less than maize (Papadakis, 1966; Kowal and Adrews, 1975). Early grain varieties take 90 to 110 days and medium varieties take 110 to 140 days to mature (Doorenbos and Kassam, 1979; Ministry of Agriculture and Livestock Development, 1987).

3 METHODOLOGY

3.1 The Study Area

Ninety seven climatological stations in Mainland Tanzania were used for this study. The criteria used for selection of the stations was the availability of adequate data to carry out the study.

Appendix B is an alphabetical index of the stations giving details of their geographical positions and altitudes. Figure 1 shows the location of the stations, the numbering in this case corresponds to that of Appendix D.

3.2 Data Collection

Monthly rainfall records of 30 years duration were collected from the Directorate of Meteorology in Dar es Salaam for all ninety seven stations. These were published by the Directorate for the period of 1931-1966 (East African Meteorological Department, 1966).

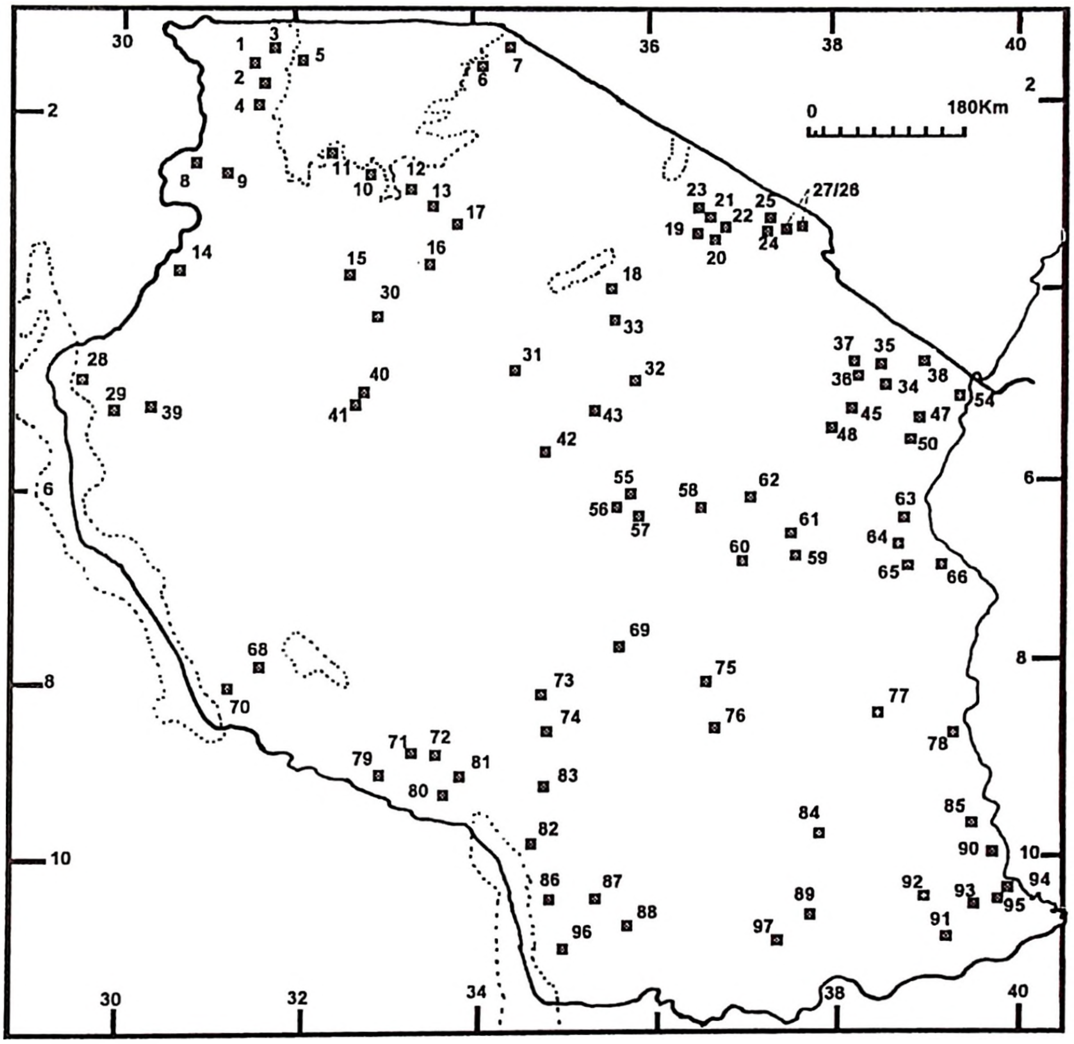

Figure 1: Stations used in the study

The monthly potential evapotranspiration data for all 97 stations were obtained by three different methods. The Penman method was considered first in the data collection for the reason that it has least error and considerable data are currently available in Tanzania based on the method (Woodhead, 1968). Pan evaporation method was applied to those stations where Penman data were not available. The Blaney-Criddle method was applied to the rest of the stations as the sum of stations from the above methods was still inadequate.

Data of 41 stations were those calculated by Woodhead (1968) using the Penman method. These were based on records for the period ranging from 1935 to 1966, each station taking into consideration the number of years in which data were available for the calculation. The Pan evaporation method was applied to 40 other stations with records ranging from 1976 to 1990. Records of 5 years in each station were collected according to the availability of data in that period and their monthly averages were determined. The pan coefficient value of 0.70 was used for correction of pan measurements as the values for each station where pan evaporation data was used were not available. The Blaney-Criddle method was applied for the remaining 16 stations. The daily maximum and minimum temperatures for a period of 5 years were collected. The mean daily percentages of daytime from Appendix A were used.

Maximum water holding capacity data were estimated from those published by De Pauw (1984). Reference was also made to the soil map prepared by the Ministry of Agriculture (1991). These were used for calculation of the available soil moisture (St) in periods with surplus budget.

The monthly crop coefficients (kc) for the selected crops were estimated from those published by Doorenbos and Kassam (1979) based on different growth stages. The beginning of the initial growth stage was taken as a starting point for the determination of the monthly intervals and hence the corresponding approximate kc values.

3.3 Data Analysis

Potential evapotranspiration (pEt) values for Morogoro Meteorological station (Table 2) from the three methods were used to correlate the Blaney-Criddle and Pan Evaporation to the Penman method before further stages of data analysis. The regression analysis was carried out by using the Microsoft Excel for Windows 95 Version 7.0 computer program.

Table 2: Monthly pEt values (mm) for Morogoro Metereological station (6° 51' S, 37° 40' E) used for regression analysis

Method	Penman	Blaney-Criddle	Pan evaporation
Duration	1947-1960 (Woodhead, 1968)	1981-1985	1981-1985
Jan	173	173	240
Feb	159	171	193
Mar	167	184	243
Apr	126	119	142
May	111	91	94
Jun	106	85	94
Jul	112	105	83
Aug	126	138	136
Sep	146	172	179
Oct	179	192	189
Nov	176	196	226
Dec	179	239	220

The values of monthly rainfall, potential evapotranspiration and maximum soil water holding capacity were then entered into a computer package, QUATRO PRO Version 4.00, for analysis.

3.3.1 Balancing of hydrologic budget of a station

The procedure suggested by Schmiedecken (1981) was employed in the calculation of hydrologic budgets of stations. The procedure involved the determination of the difference between rainfall and potential evapotranspiration which was then used to judge the deficit or surplus status of the budget for a given station. The status was in turn used in deciding for an appropriate means of determining the stored soil moisture available for use by plants. Also it involved further calculation of the change in the soil water from month-to-month and aWA/pEt values.

3.3.2 Humidity grades of a station and humidity reference number

The calculated aWA/pEt values were used in grading of humidity of stations. The ratios 2.0, 1.0 and 0.5 were used for separation among four subdivisions of humidity: humid, semihumid, semiarid and arid, respectively.

The system of 4-figure reference number was used to characterise stations. The number of months in each subdivision was entered in the order: humid-semihumid-semiarid-arid.

3.4 Establishing of Humidity Zones

In order to delimit humidity zones, reference numbers were located on the map according to their respective stations. Stations with the same number of humid plus semihumid months were then connected together to obtain isohygromenes. The same was done to obtain the boundaries between areas of various humid months and those with various arid months.

3.5 Selection of Length of Growing Season of the Crops

Only one variety of each of the selected crops was considered in this study on the basis of the average conditions. Selection of the length of growing periods for the crops was according to Doorenbos and Kassam (1979). The considered total length for beans was 120 days and for maize, sorghum and groundnuts was 140 days.

The monthly crop coefficients (kc) were estimated according to the growth stages: initial, development, mid-season, late season and at harvest, which constitute the length of growth period.

3.6 Parallelization of Humidity Zones and Cultivation Zones

A comparison was made between the ratios, aWA/pEt, of each month obtained from the calculations and the crop coefficients, ET_{crop}/pEt (or kc). The values of aWA/pEt represent degree of humidity of a station over twelve months in a year while those of ET_{crop}/pEt represent approximate water demand by the crop over its growing period. The values of ET_{crop}/pEt were assessed for each individual station by determining the range of months in a year which can host the growth period of a given crop. The stations satisfying the above condition were determined. The locations of these stations were, accordingly, delineated directly on the map. The final map which is a result of overlays of the zones of humidity and growing conditions of a crop determines the location of optimal areas for production of such crop. Similar procedure was done for other crops under this study.

3.7 Comparison of the Established Zones to the Current Growing Areas

The current areas for production of maize, sorghum, beans and groundnuts were delineated based on the survey conducted by the Bureau of the Resource Assessment and Land Use Planning (Conyers, 1973). The areas were then superimposed with those established by this study. Percentages of different areas were determined by using Planimeter for comparison purposes.

4 RESULTS AND DISCUSSION

4.1 Distribution of Stations

It was noted during plotting of stations that some large areas especially those occupied by large forest reserves, game reserves, national parks, swamps or plantations (Fig. 2) have no or very few meteorological stations. This presented some difficulties in the plotting of iso-humid lines and, therefore, extrapolations had to be done.

It is possible that more stations have recently been established in these areas but were not yet publicised. Therefore, they were not accessed during data collection for this study.

4.2 Regression Analysis Between Penman and Blaney-Criddle and Pan Evaporation

Table 3 shows the summary of the results of the regression analysis. On the basis of R-Square, both methods (Blaney-Criddle and Pan Evaporation) have shown a strong relationship to the Penman method. The following developed models were, therefore, used in determining Penman evapotranspiration from Blaney-Criddle and Pan Evaporation data:

$$pEt_{Penman} = 0.58\, pEt_{Blan\text{-}Crid} + 57.25 \quad (9)$$

$$pEt_{Penman} = 0.47\, pEt_{Pan} + 67.67 \quad (10)$$

where:

pET_{Penman} = Penman method pEt values;

$pET_{Blan\text{-}Crid}$ = pEt value obtained using Blaney-Criddle method;

pET_{Pan} = pEt value obtained using Pan Evaporation method.

Table 3: Summary of regression analysis for Morogoro Meteorological station (6° 51' S, 37° 40' E)

	Blaney-Criddle	Pan evaporation
Multiple R	0.946777	0.941896
R Square	0.896387	0.887168
Adjusted R	0.886026	0.875884
Standard Error	9.759504	10.184450
Intercept	57.251580	67.673070
Coefficient	0.575325	0.465170

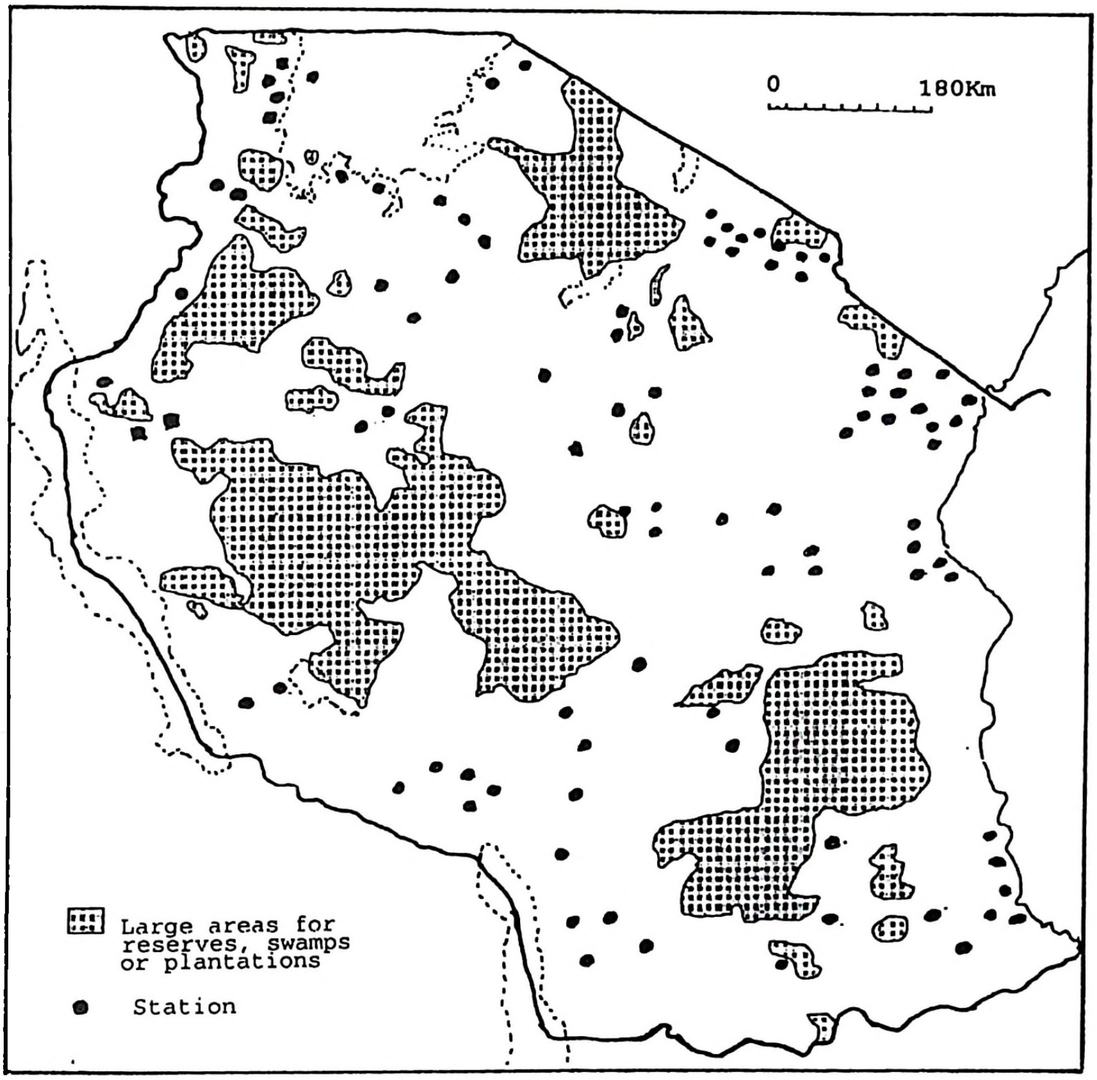

Figure 2: Large areas for forest reserves, game reserves, swamps or plantations

4.3 Monthly Grades of Humidity (aWA/pEt)

4.3.1 Highest and lowest values

The highest values for aWA/pEt of 7.27 was found in the northern highlands at Kibosho station. This was followed by other values in stations like Kilema and Marok forest, Ambangulu and Ngaraya stations. Similar results were observed in the southern highlands at Musekera and Tukuyu stations (Appendix D). The stations are located in areas reported to receive very high rainfall (Mhita, 1990) which is the major source of water available for evapotranspiration. It was also noted that the areas experience long period of about six months in which the values of aWA/pEt are greater than 1.00. This shows that water is sufficiently available for evapotranspiration during that period.

The lowest values of aWA/pEt less than 0.50 for about seven months in a year were observed in the central areas of Dodoma and Singida. Mwanza and Shinyanga also show similar conditions. Generally, the values in these areas are less than 1.00, an indication that there is no adequate water available for evapotranspiration.

4.3.2 Humidity reference numbers

It was found that the humidity reference numbers for some stations were the same. This occurred to some neighbouring stations where similar method for obtaining evapotranspiration data was applied, e.g. Korogwe, Sakura and Karimi stations in Tanga.

Another example is for Igabiro, Musoma and Tarime stations, although in this case different methods for evapotranspiration data were applied. These stations are at almost the same altitude. It is, therefore, possible to experience the same ecological condition as implied by humidity reference number.

However, there are other examples of Kondoa, Tabora, Morogoro, Tungi and Kilwa as one group on one hand, and Seliani, Narok, Ngurumahamba and Mikindani on the other. Although the two groups of stations have similar reference numbers they are far apart from each other and differ in altitude as well as in the methods applied for evapotranspiration data. This points out to the fact that one ecological condition can be experienced at different locations with differing altitudes.

4.4 Humidity Zones

It is worthwhile noting that the humidity zones discussed in this section may not necessarily correspond to the known climatological zones of the country although great discrepancy is not expected. The zones (humid, semihumid, semiarid and arid) are defined in this study according to the predetermined limits of aWA/pEt values.

4.4.1 Lines of humid plus semi-humid months (Isohygromenes)

It should be noted that at any given station, as the number of humid plus semi-humid months increases, the number of semi-arid plus arid months decreases.

The line of zero humid plus semi-humid months runs from north-west to south-east of the country. It passes through Mwanza, Shinyanga, Singida, Dodoma, Mbulu, Hanang and Lindi (Fig. 3). The line divides the country into two parts in which the number of months of humid plus semi-humid increases toward the respective highlands (Northern and Southern). The number increases to the highest value of 6 at Mbozi.

Humidity levels of the country differ largely from the areas passed by the line to the highlands. The central parts experience lower (zero) humid plus semi-humid months as compared to the northern and southern highlands which have three months.

However, there are areas like Same in Kilimanjaro region that experience dry conditions like those found in the central zone but they are included in the northern highlands climates. This may be due to the reason that there were insufficient stations that could be used to demarcate the area precisely.

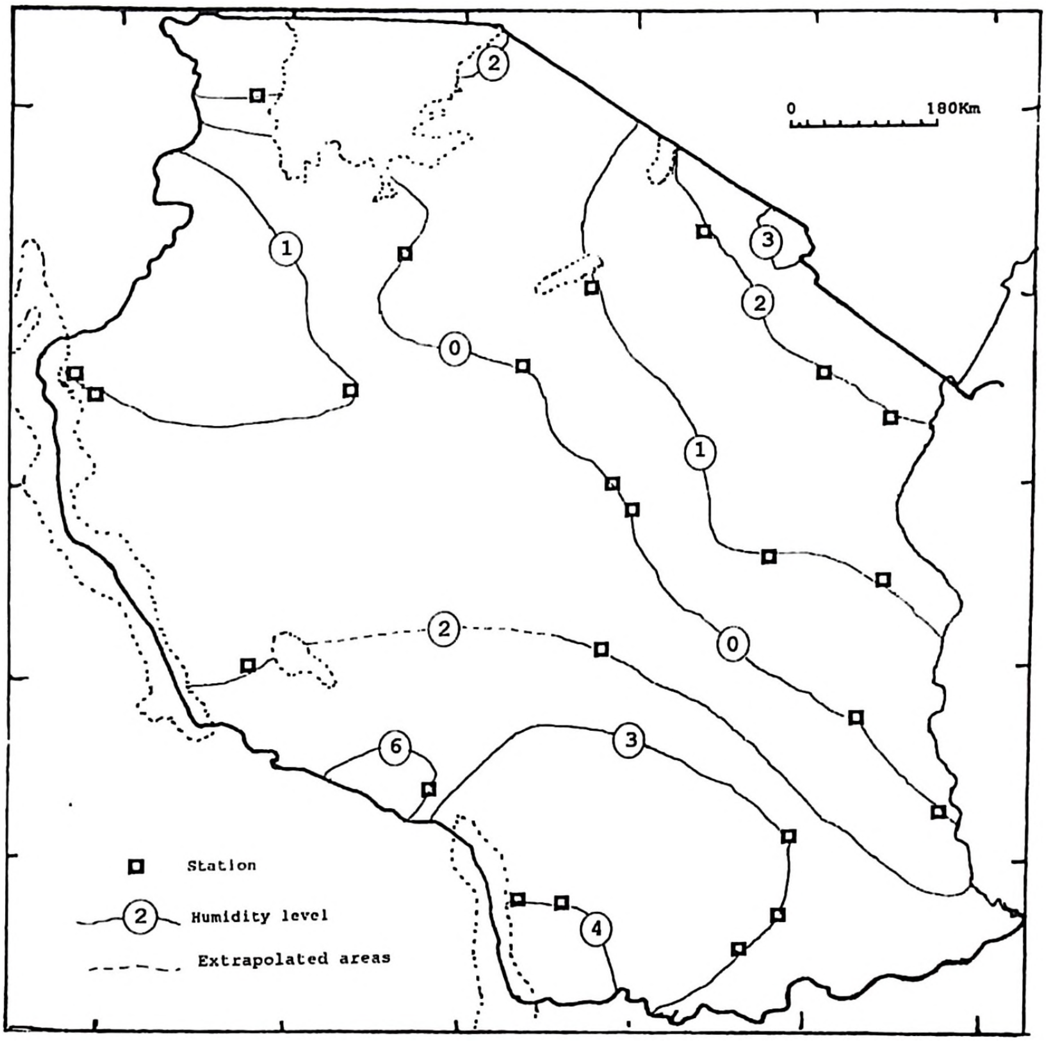

Figure 3: Boundaries between areas of the same number of humid plus semi-humid months

4.4.2 Humid areas

Figure 4 shows the boundaries between areas of the same number of humid months. As was the case for the humid plus semi-humid lines, the humid lines are concentrated in the two distinct areas, the northern and southern highlands. Two lines of zero humid months engulf the respective areas of the northern and southern highlands. The number of humid months is 3 in the areas around Mount Kilimanjaro and Chunya. It is 2 around Njombe and 1 around Bukoba. The above characteristics indicate that a small part of the country has humid months as compared to the remaining vast area which experiences generally semi-humid, semi-arid and arid conditions as can be seen from Figure 3.

Distribution of the humid boundaries (Fig. 4) compares closely to the patterns of the unimodal rainfall regime of October-April (Fig. 5) as established by Nyenzi et al., (1997). Relationship was noted also with the rainfall patterns according to Nieuwolt (1973). Ogallo (1980) categorised Tanzania into seven climatologically homogeneous regions (Fig. 6). The boundaries for these regions compare fairly well to the boundaries made by the zero humid lines. The comparison carried out between humid boundaries and evapotranspiration established by Woodhead (1968) could not, however, indicate a defined relationship.

The above situation suggests that perhaps humidity is more related to rainfall than to evapotranspiration. This can also be noted from both rainfall and evapotranspiration data that rainfall variation in a year is greater than evapotranspiration (Table 4).

Table 4: Range and variation of monthly rainfall and evapotranspiration in a year for sample stations

	Range		Variation	
	pEt	Rainfall	pEt	Rainfall
Musoma Met.	156-189	48-225	33	177
Mbulu	108-187	1-165	79	164
Seliani Coffee	111-183	3-276	72	273
Dodoma Met.	149-188	0-146	39	146
Lindi Met.	152-210	5-176	58	171
Ujiji Mission	128-200	0-144	72	144
Singida	138-214	0-149	76	149
Bagamoyo Agric.	137-203	23-241	66	218
Mbeya Boma	103-212	0-211	109	211
Malangali School	136-217	0-198	81	198
Rubya Mission	115-143	11-228	28	217
Olmotonyi Forest	99-161	4-264	68	260
Rombo Mission	111-192	22-290	81	168
Tungi Sisal	133-217	43-291	84	248
Pangani	106-179	11-191	73	180
Mean variation			68	193

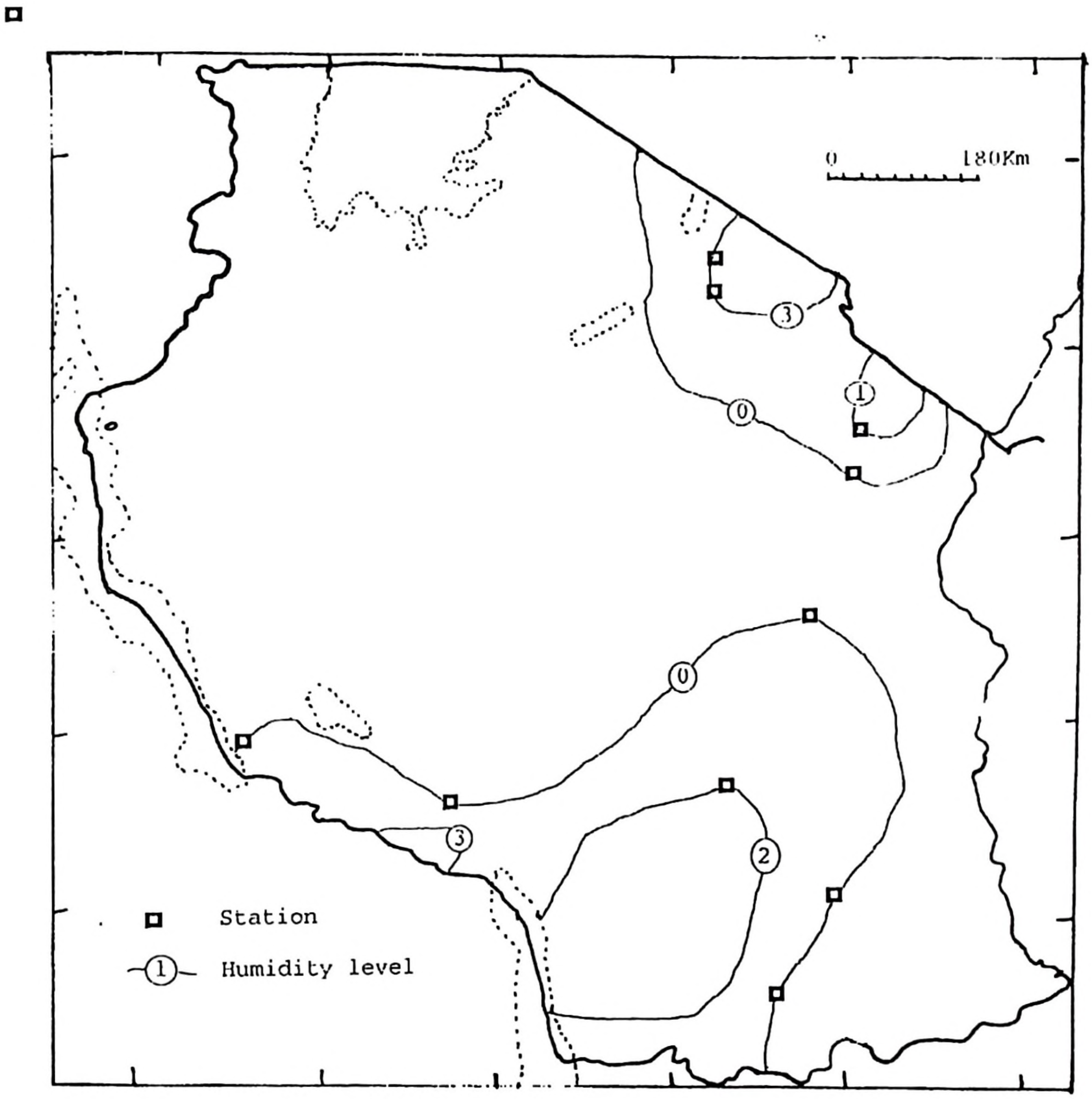

Figure 4: Boundaries between areas of the same number of humid months

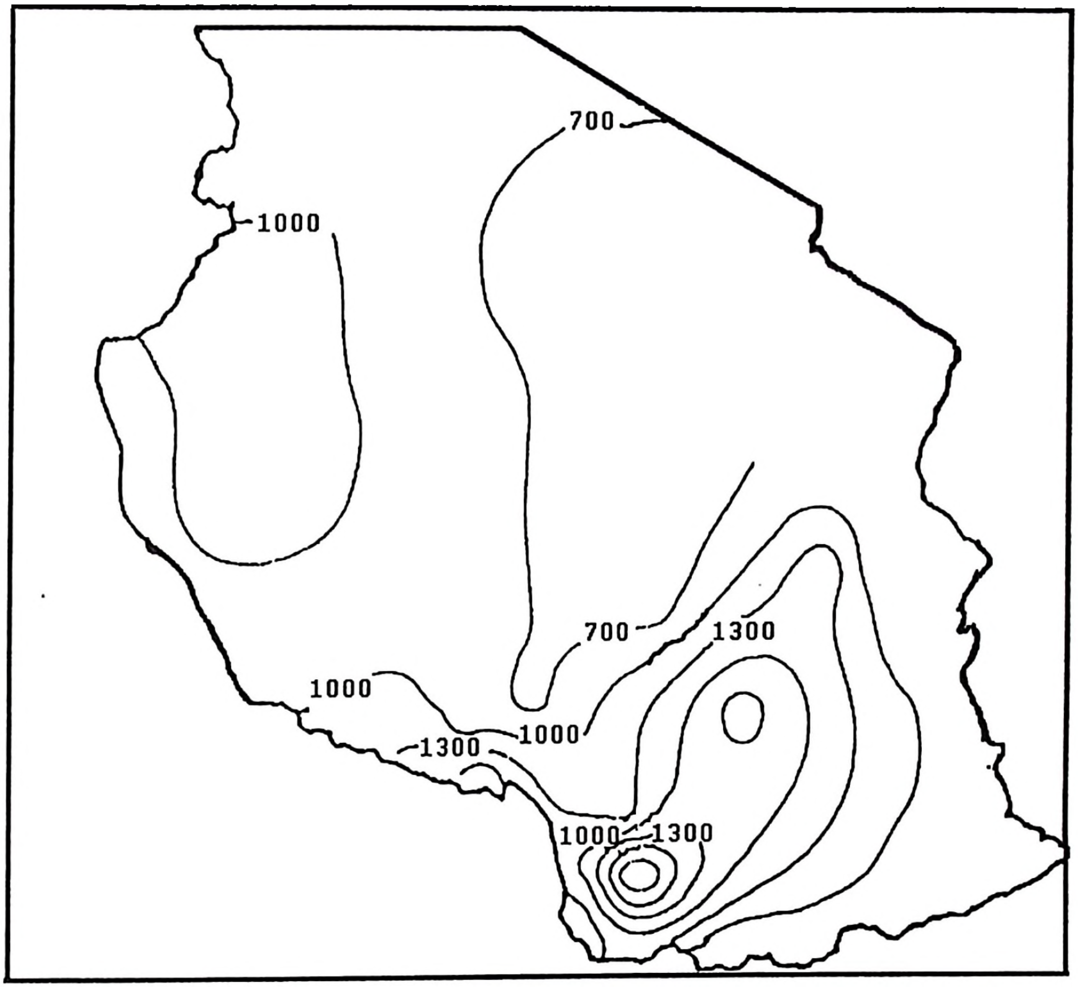

Figure 5: Patterns of unimodal rainfall regime of October-April

Source: Nyenzi, et al., (1997)

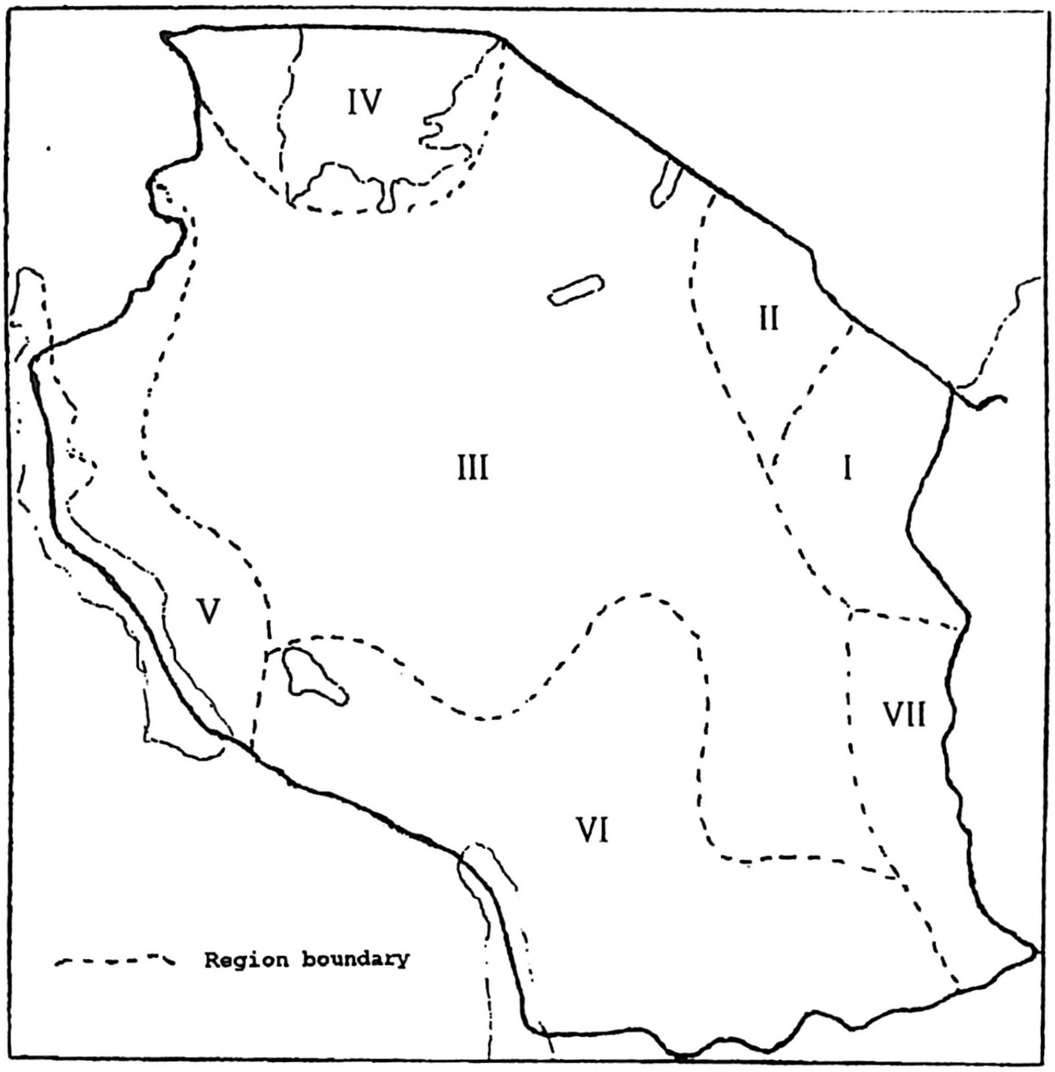

Figure 6: Climatological homogeneous regions of Tanzania

Source: Ogallo (1980)

4.4.3 Arid areas

Perhaps the most interesting humidity feature of the country is the large arid area. The highest number of arid months is found in the central part of the country. Contrary to the number of humid months, the number of arid months decreases from eight in the central regions toward the northern and southern highlands. It is 5 around lake Victoria and Mbinga and zero around Mount Kilimanjaro and Bukoba (Fig. 7). The lines discontinue at some areas especially the forest reserves, game reserves, large swamps and plantations.

It was observed that large parts of the country are dominated by arid conditions which last for up to eight months in the central areas. The situation changes slightly to the northern and southern highlands and lake zones where the number of arid months drops to zero. Very small areas over Lake Victoria in Kagera region and over the slopes of mount Kilimanjaro and Meru were found to exhibit zero arid months. The situation in these areas corresponds to the rainfall conditions as noted by Mhita and Venalainen (1992), who reported the highest mean annual rainfall in the country about 3000mm. Both

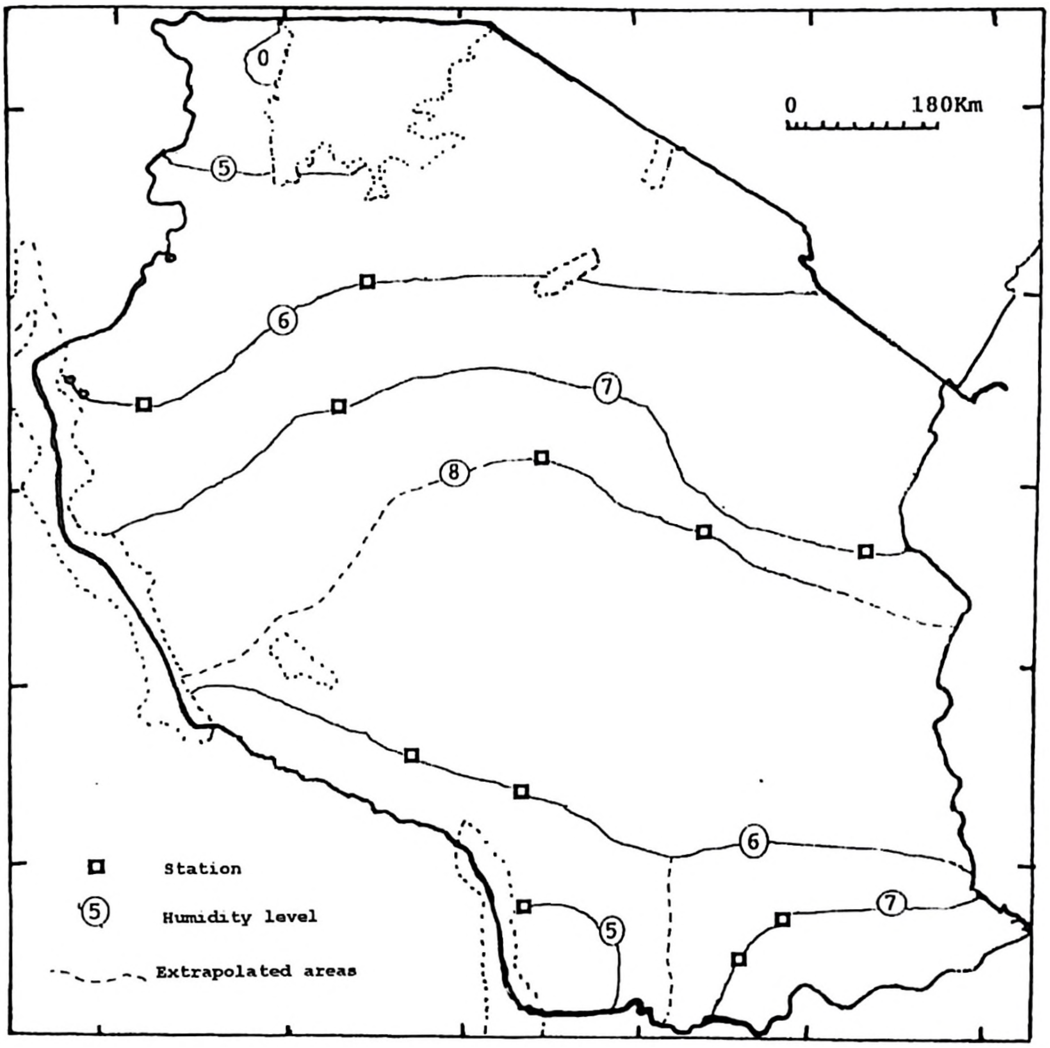

Figure 7: Boundaries between areas of the same number of arid months

long and short rains occur in these areas and constitute a long period over a year. Again as was for the case of humid lines, the above situation suggests a strong relationship between rainfall and humidity.

4.4.4 Combination of the three types of humidity boundaries

Figure 8 shows a combination of the boundaries between regions of humid months, humid plus semihumid months and completely arid months. It can be noted from the figure that the boundaries represent a continuous pattern of humidity zones in which the difference, when a boundary is crossed, can be only one month upwards to the next higher degree of humidity or downwards to the next lower degree of humidity. Similar implications were also pointed out in the study conducted for Nigeria by Schmiedecken (1981)

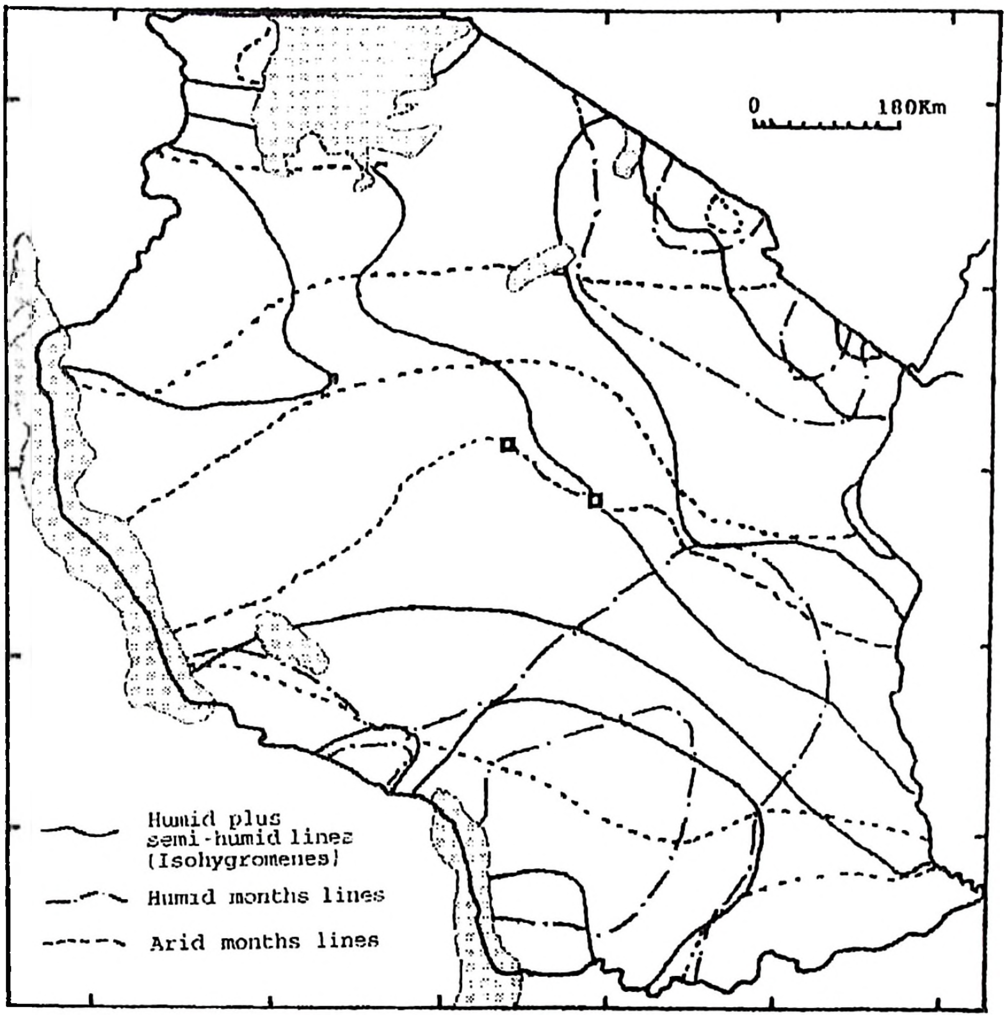

Figure 8: The combined three boundaries of the areas with similar humidity levels

4.5 Potential Areas for Production of the Selected Crops

Potential areas for production of the selected crops can be classified into two: optimal areas, where crops can be produced without suffering water shortage problem and marginal areas, where crops can suffer water stress. It was noted that there were large exclusions of the current growing areas in the potential areas for the crops. Based on crop water requirements, some of the current growing areas not covered by the derived potential areas, may not necessarily be reliable for production of the crops. Most of semi-arid areas of Dodoma, Singida, Mbulu, Hanang and Shinyanga, for instance, are included in the current growing areas though crop failures due to poor distribution and uncertainty of rainfall are quite pronounced (Ministry of Agriculture, 1995). This can be one of the reasons for the exclusion of some of the current areas in the potential areas.

It should also be realized that potential areas provide for the best crop growth requirements and that cultural preferences could partly explain production of crops on areas which are marginal. A good example is the staple preference of maize and sorghum in some cultures. Cassava and wheat can grow well at Dodoma and Singida but the respective Gogo and Turu tribes would prefer to produce maize and sorghum at any risk to the former crops.

4.5.1 Maize

It was noted that the kc values of the crops at different growth stages were approximately the same (Table 5). Since the growth duration considered in this study is the same for the three crops then on the basis of the crop water requirement and the data collected it was found that the three crops have the same potentials areas (Fig. 9).

Table 5: Approximate monthly crop coefficient (kc) for selected crops

	Month					
Crop	I	II	III	IV	V	VI
Beans	0.35	0.75	1.13	0.70	0.28*	
Groundnuts	0.45	0.75	0.88	1.10	0.75	0.58*
Maize	0.40	0.78	0.95	1.20	0.85	0.58*
Sorghum	0.40	0.73	1.00	1.15	0.78	0.53*

* = Crop coefficient at harvest stage

Source: Doorenbos and Kassam (1979)

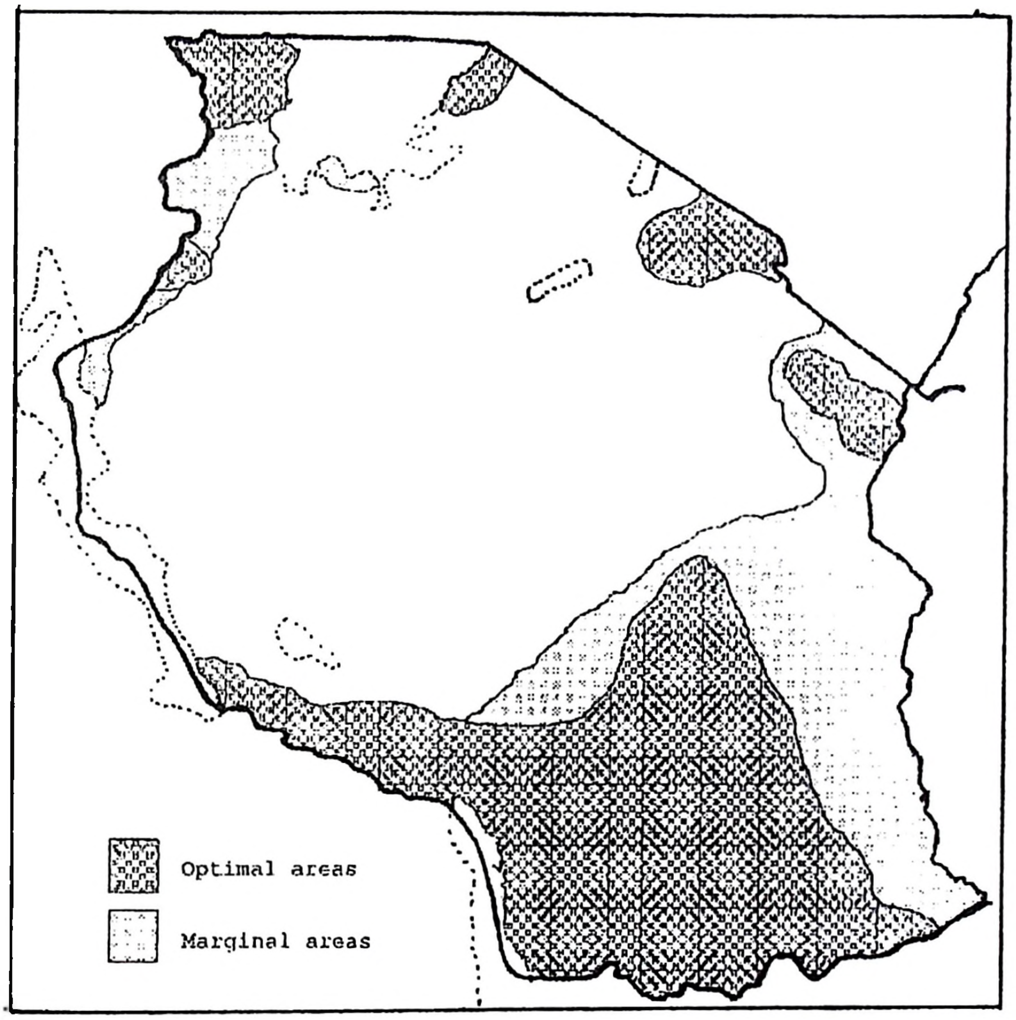

Figure 9: Potential areas for maize, sorghum and groundnut production

The results show that a fairly large number of stations fall under the optimal zone for maize production. The zone is formed by the southern and eastern region of the country including the highlands of Iringa, Mbeya, Morogoro and Rukwa. Other areas are the wet coastal parts of Tanga, the slopes of the volcanic mountains of Meru and Kilimanjaro and the northern parts of Kigoma, Kagera and Mara region. The marginal zone is formed by the coastal areas including Lindi, Coast and Tanga regions. Some parts of Mwanza region around Lake Victoria, south of Kagera region and the northern portion of Kigoma region are also included in this zone.

Conyers (1973) pointed out that maize is produced at almost every part of the country. However, this is with exclusion of a few areas occupied by forest reserves, game reserves and national parks. A narrow belt along the Indian ocean, Ukerewe and Mafia islands were also excluded from the production zone.

Comparison between the established areas and the current growing ones indicated that only a small region of the country has been represented by the study as potential for maize production (Fig. 10). The reason for this can

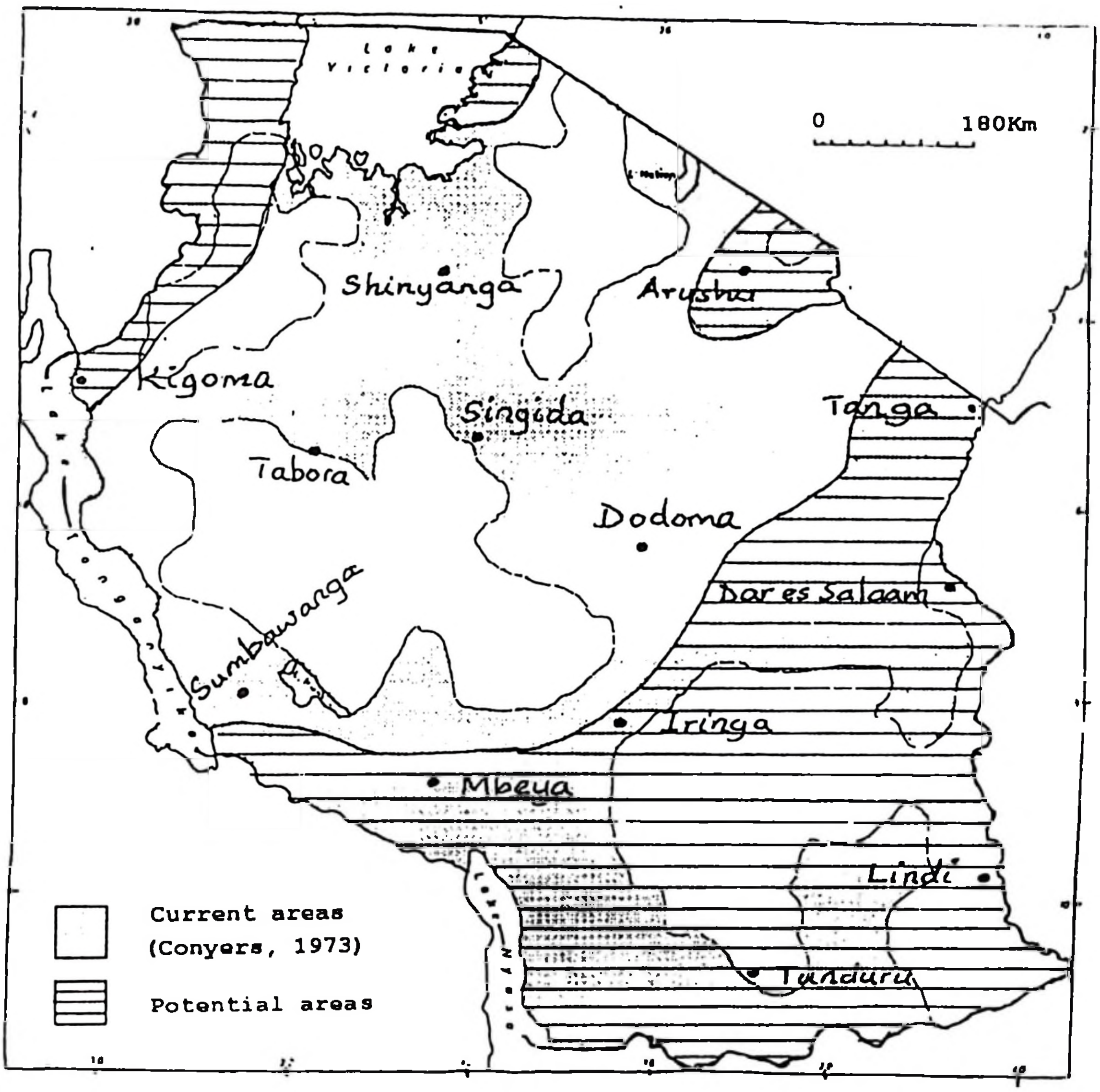

Figure 10: Current and potential areas for maize production

be the use of only one variety of maize and of longer growing season. This is hardly possible, for example, in the semi-arid areas. Also there are areas which were not shown by Conyers (1973) as suitable but have been shown in this study as maize potentials. Suitability of these areas is based on water requirements but other factors like soils may not favour maize production.

It was noted that regions (Ruvuma, Iringa, Mbeya, Rukwa and Morogoro) famous for maize production have been validated by the study as well as from the surveys. The areas experience reliable rainfall (Ministry of Agriculture, 1995) and can, therefore, support maize varieties of longer growing period.

4.5.2 Sorghum

As noted above, the potential areas for sorghum production as established in this study are the same as those for maize. Conyers (1973) located the following areas for sorghum cultivation which can be categorised into two parts. The northern and central part that includes Singida, Dodoma, Shinyanga and Mara regions. There is the southern and eastern part that includes

Morogoro, Lindi, Mtwara and small areas in Rukwa, Coast, Kigoma, Tabora and Kagera regions (Fig. 11). Similar areas were noted by the Ministry of Agriculture and Livestock Development (1987).

The southern and eastern part where sorghum is currently grown was also mapped out as a potential area for sorghum. The current production, however, covers only a small part of this region. This implies that sorghum production can still be extended to other areas of the region. The situation was different for the northern and central part where only a small portion was mapped out. Large areas of Singida, Shinyanga and Tabora were not included. Again this may have resulted from the use of a variety that requires longer growing period.

Sorghum production has not been extended to some areas of Ruvuma, Mbeya, Kagera, Tanga, Kilimanjaro and Arusha due to the following reasons. Sorghum demands higher labour inputs for weeding, bird scaring, harvesting and winnowing as compared to maize. Unpopularity of available improved varieties is also a constraint to this extension. Cultivation of improved varieties is still limited and is mostly undertaken in large scale

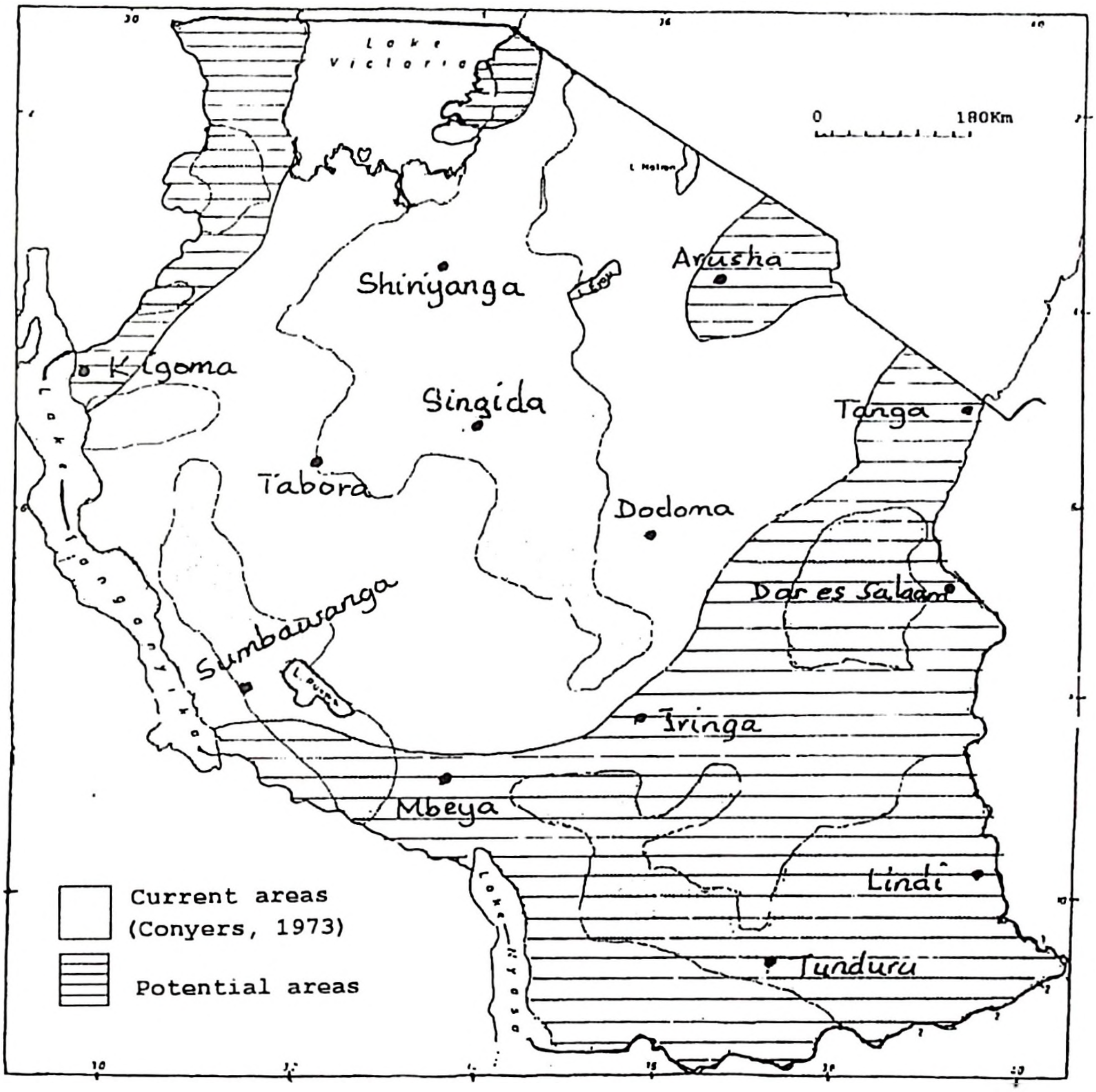

Figure 11: Current and potential areas for sorghum production

farms by public institutions (Ministry of Agriculture and Livestock Development, 1987).

4.5.3 Groundnuts

The largest production areas of groundnuts as identified by Conyers (1973) constitutes the Shinyanga, Kahama, Nzega and Manyoni areas. Smaller areas include some areas in Lindi and Mtwara regions in the southern limb of the country and, minor areas of Morogoro, Tabora, Kigoma and Mbeya regions. Dodoma, Mtwara and Rukwa regions were also pointed out by Bolton (1980) as well as Doto and Mwenda (1987) as the groundnuts producing areas.

It can be noted that only a small portion (Mtwara and Lindi) of the current growing area was delimited as potential for groundnuts production (Fig. 12). The results point out that large potentials for groundnuts production have not been fully utilised.

Possible reasons to this under-utilisation can be due to lack of agroecologically adapted cultivars for most areas of the country (Sibuga, *et al.*, 1989). Groundnuts

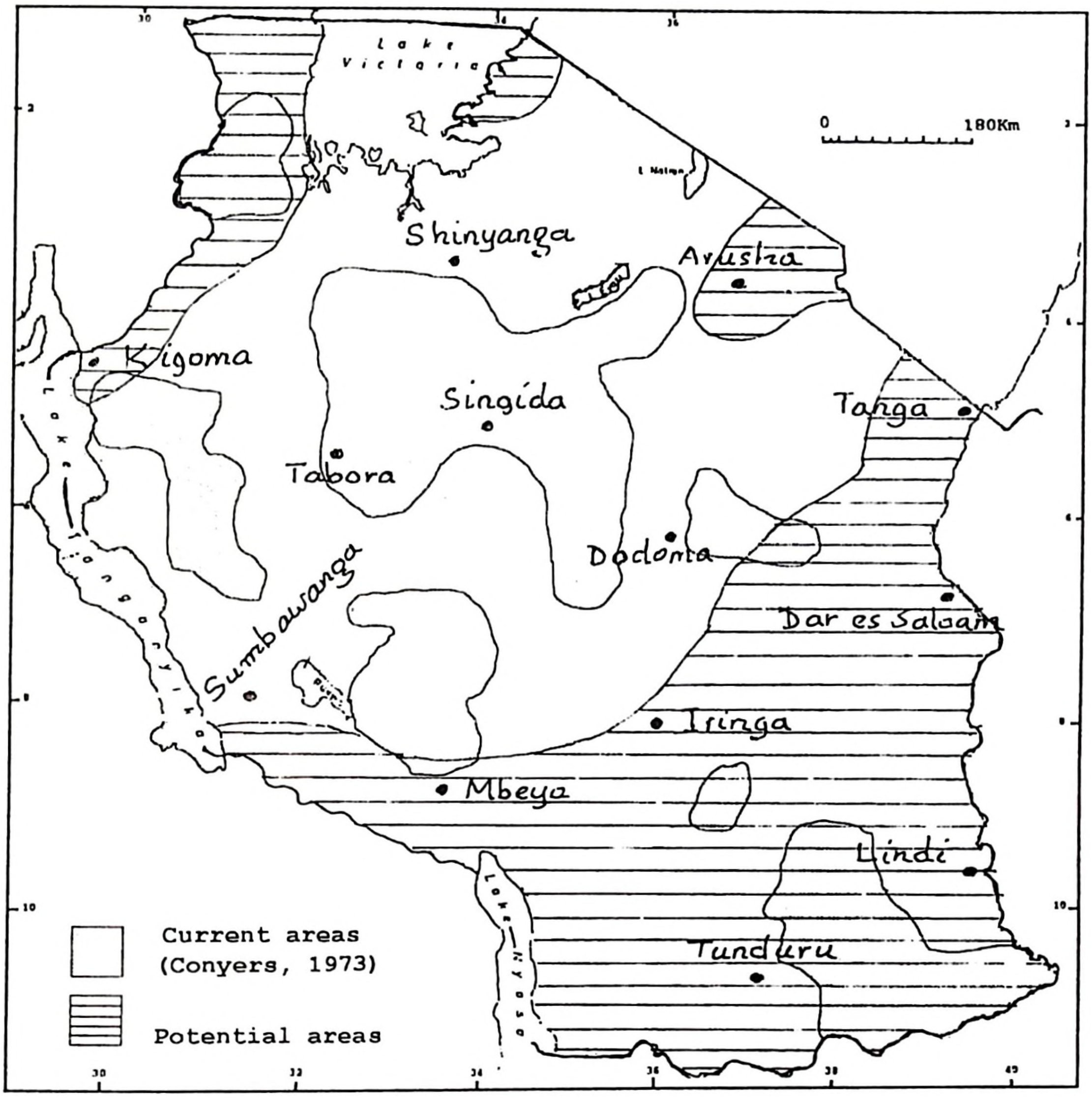

Figure 12: Current and potential areas for groundnut production

are grown in most areas below an altitude of 1500m and the unimodal rainfall pattern regions like Dodoma and Tabora favour most of the groundnuts varieties (Mwenda, 1987). The above two reasons may explain the non-prevalence of groundnuts in most high rainfall areas, such as, the northern and southern highlands, although they are mapped as potential based on crop water requirements.

4.5.4 Beans

Figure 13 shows the optimal and marginal zones for beans production. The optimal zone was formed by those areas noted above as optimal and marginal for maize, sorghum and groundnuts. The marginal zone covers the Kigoma and Shinyanga region, southern areas of Mwanza region and the northern parts of Singida and Tabora. The Mbulu and Hanang of Arusha plus small areas of Kondoa in Dodoma are also part of the marginal area.

Results obtained by Conyers (1973) identified the following areas as suitable for beans production: Kiteto, Mbulu, Hanang, Kilosa, Morogoro, Mbinga, Songea, Tanga, Handeni and Lushoto districts and the Pare

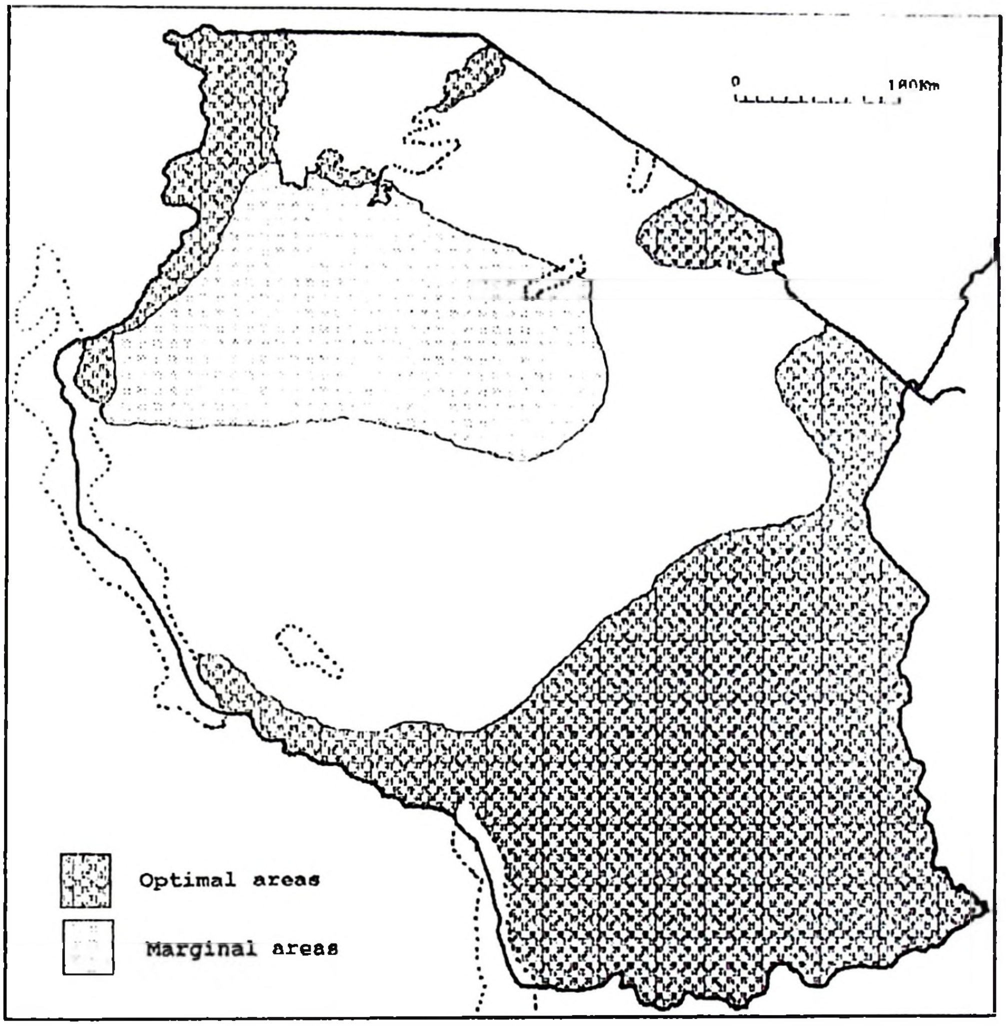

Figure 13: Current areas for beans production

mountains. There are also small patches in Kagera and Kigoma which cultivate beans (Fig. 14).

The comparison between the established areas and the current ones points out that, from the point of view of water availability, production of beans can greatly be extended. A similar observation was made by the Ministry of Agriculture (1987). Conyers (1973) identified only a small area for beans production as seen in the Figure 14. The above study considered only the unimodal rainfall regions (like Karagwe, Arusha, Kigoma) which are known to be the major suppliers of market beans (Ministry of Agriculture, 1987). Fewer areas have been noted in this study most probably due to the use of one bean variety.

4.6 Comparative Summary of Areas from Planimeter

Table 6 shows the percentages of the current and potential areas over the total area of the country excluding the major water bodies. It also shows the percentages of the potential area which fall under current area, and that of unutilized potential, over the total potential area for each crop.

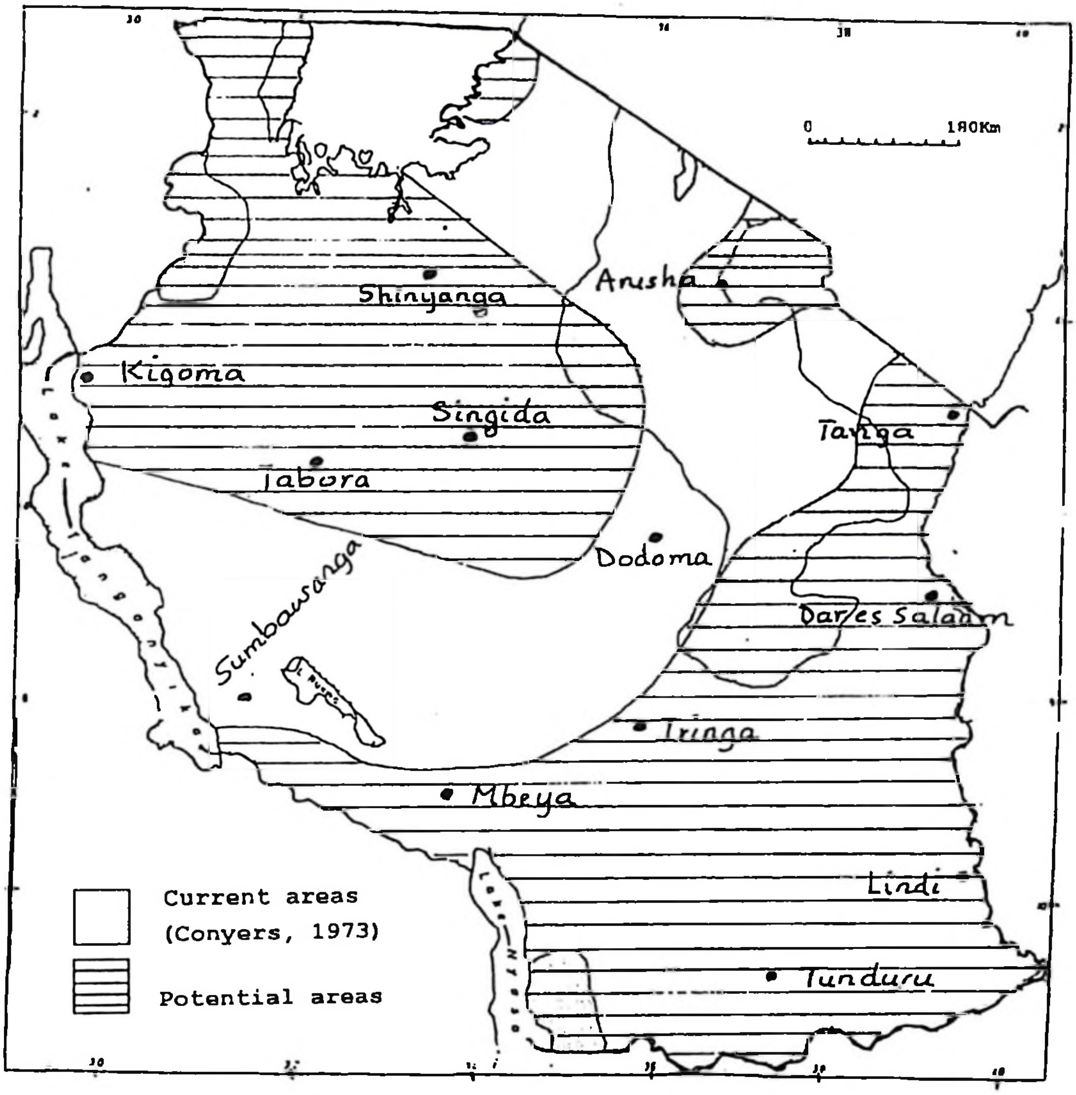

Figure 14: Current and potential areas for beans production

Table 6: Percentage of current and potential areas from Planimeter measurement

	Crop			
	Maize	Sorghum	Groundnuts	Beans
Current area over the country's total area (%)	58	42	39	20
Potential area over the country's total area (%)	45	45	45	63
Potential area coinciding with current area (%)	67	51	20	21
Percentage of unutilized potential area	33	49	80	79

The following can be noted based on data in Table 6. Beans have shown the greatest potential over the country's area while only 20% of it is utilized. In regard to the potential area coinciding with current area, it can be argued that the crop zoning method used in this study has proved fairly successful for maize and sorghum, whose potential areas coincide by 67% and 51%, respectively. The low coincidences of areas grown with groundnuts and beans may mean that the potential areas are inadequately being utilized or the study of current growing areas did not take into account other possible areas for production. A good example is for beans where the study conducted by Conyers (1973) delimited only those areas which are good suppliers of marketed beans. Groundnuts have the highest percentage of its potential area being unutilized which may also be due to the reasons mentioned earlier.

4.7 Relation Between Humidity Lines and Crop Zones

It was observed in this study that there were no defined relationships between humidity lines and the crop zones as can be observed in Figure 15. However, considering Figure 4 and Figure 9 together it can be deduced that the main production zone (southern part of the country) is limited on the north by the line of zero humid month while the north-eastern zone is limited on the south-west also by the same line. Both zones run to the respective country border sides with simultaneous increase of humidity up to three humid months. The situation is not so clear in those production zones in Kagera and Mara regions.

The limits for the marginal zones in relation to the humidity zones could not be clearly defined as can be noted from Figure 15. This was for both cases, i.e, for production of maize, sorghum and groundnuts; and beans.

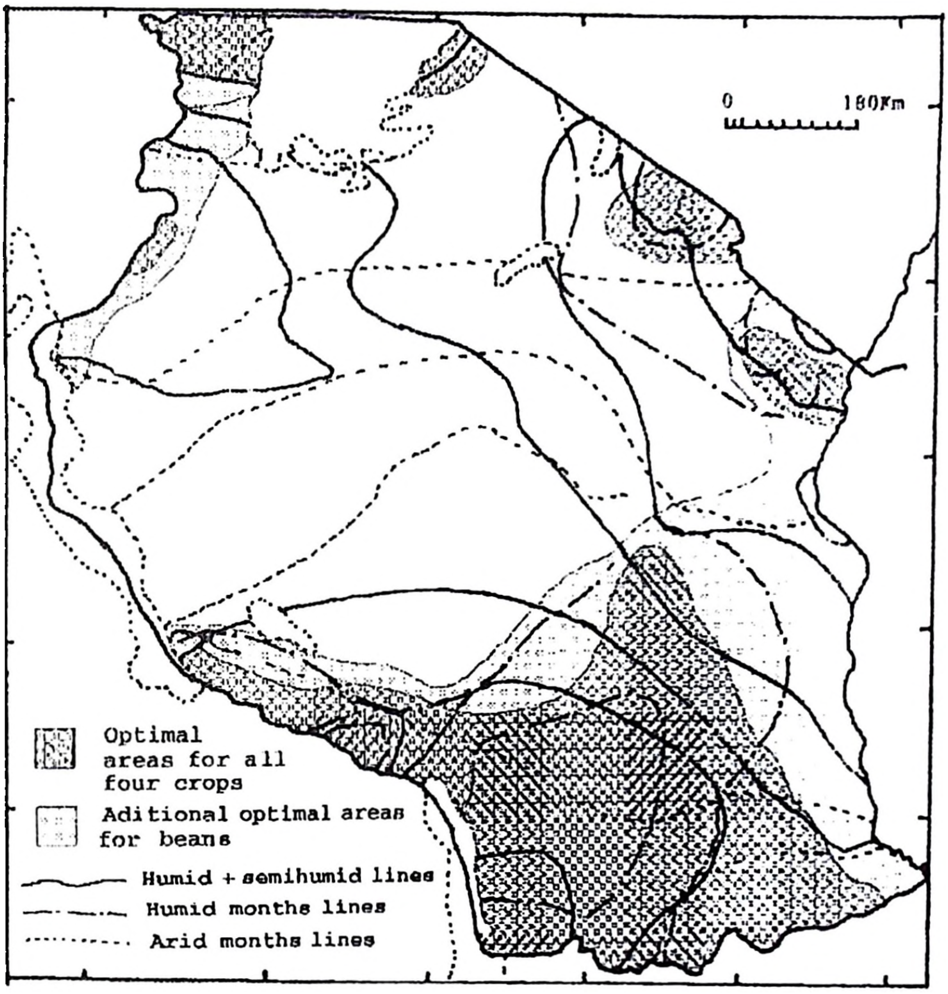

Figure 15: Relation between humidity and crop zones

5 CONCLUSION AND RECOMMENDATIONS

The study has shown more positive results on maize and sorghum as opposed to beans and groundnuts. The reason may be due to the fact that the current areas for beans and groundnuts were based on only those places where they are produced for commercial purposes. Other factors, such as soil characteristics, cultural preferences and low domestic consumption rates of the crops, may also have contributed to the discrepancy.

The approach seems to provide realistic results on crop potentials and can, therefore, be used for agricultural planning purposes. The reason behind is that most of the areas established through this method, especially for maize and sorghum, coincide fairly with the current areas for production.

Although the information provided is based only on humidity and crop water requirements, still it can serve as an indicator especially during initial agricultural planning process. Consultations for more detailed information on other factors is thus inevitable for a specific crop variety and particular areas. The reason is that the broad agro-ecological zoning may not answer all questions related to agricultural potentials and constraints.

On the basis of the data collected and results obtained the following can be recommended:

- Mapping out of crop potentials as related to production factors (e.g. soil types, temperature,) is necessary to improve the predictability of the method for agricultural planning.

- Similar studies on specific crops be carried out in smaller areas which can later on be combined to cover the whole country.

- Zonal research centres should be involved in establishing more meteorological stations so that each portion of the country is well covered. There is also a need to use more crop varieties in order to obtain better and more conclusive results.

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APPENDICES

Appendix A: Mean daily percentage (p) of annual daytime hours for different latitudes

Latitude: North / South	Jan / Jul	Feb / Aug	Mar / Sep	Apr / Oct	May / Nov	Jun / Dec	Jul / Jan	Aug / Feb	Sep / Mar	Oct / Apr	Nov / May	Dec / Jun
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	[illegible]	.17	.13
55°	.17	.21	.26	.32	.36	.39	.38	.33	.28	[illegible]	[illegible]	[illegible]
50°	.19	.23	.27	.31	.34	.36	.35	.32	[illegible]	[illegible]	[illegible]	[illegible]
45°	.20	.23	.27	.30	.34	.35	.34	.32	[illegible]	[illegible]	.21	[illegible]
40°	.22	.24	.27	.30	.32	.34	.33	.31	.28	[illegible]	.22	.21
35°	.23	.25	.27	.29	.31	.32	.32	.30	.29	[illegible]	.23	[illegible]
30°	.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	[illegible]	[illegible]
25°	.24	.26	.27	.29	.30	.31	.31	.29	.28	[illegible]	.25	[illegible]
20°	.25	.26	.27	.28	.29	.30	.30	.29	.28	[illegible]	[illegible]	.25
15°	.26	.26	.27	.28	.29	.29	.29	.28	.28	[illegible]	[illegible]	[illegible]
10°	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5°	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0°	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

Source: Critchley (1992)

Appendix B: Alphabetical index of stations

	Station	Location	Altitude (m)	Maximum WC (mm)	Method applied for pEt data
1	Alavi Sisal Estate	6° 50' S, 38° 52' E	152	300	Pan evaporation
2	Amani Malaria	5° 06' S, 38° 38' E	911	225	Penman
3	Ambangulu Sisal Est.	5° 05' S, 38° 26' E	1220	225	Blaney-Criddle
4	Arusha Agric.	3° 23' S, 36° 41' E	1372	300	Penman
5	Bagamoyo Agric.	6° 25' S, 38° 55' E	9	250	Pan evaporation
6	Balangai Coffee Est.	4° 56' S, 38° 28' E	1402	300	Blaney-Criddle
7	Berega Mission	6° 12' S, 37° 10' E	854	150	Penman
8	Biharamulo	2° 38' S, 31° 19' E	1479	300	Penman
9	Bukoba Met. Station	1° 20' S, 1° 49' E	1144	300	Penman
10	Dar es Salaam Lab.	6° 49' S, 39° 18' E	9	250	Penman
11	Dodoma Met. Station	6° 10' S, 35° 46' E	1120	225	Penman
12	Dodoma Reservoir No.1	6° 13' S, 35° 46' E	1143	225	Blaney-Criddle
13	Handeni Distr. Office	5° 26' S, 38° 02' E	677	250	Pan evaporation
14	Ifakara Mission	8° 09' S, 36° 39' E	274	250	Penman
15	Igabiro Estate	1° 48' S, 31° 33' E	1524	300	Penman
16	Iringa	7° 47' S, 35° 42' E	1640	225	Penman
17	Kagondo Mission	1° 33' S, 31° 42' E	1296	300	Pan evaporation
18	Kahama Distr. Office	3° 50' S, 32° 36' E	1220	150	Pan evaporation
19	Kala Mission	8° 09' S, 31° 00' E	793	300	Pan evaporation
20	Karimi Estate	5° 14' S, 38° 35' E	286	250	Pan evaporation
21	Kawalinda Coffee Est.	1° 34' S, 31° 43' E	1296	300	Blaney-Criddle
22	Kibondo Mission	3° 35' S, 30° 42' E	1518	225	Pan evaporation
23	Kibosho Mission	3° 15' S, 37° 19' E	1479	300	Penman
24	Kigoma Met. Station	4° 53' S, 29° 38' E	885	300	Penman
25	Kilema Mission	3° 18' S, 37° 30' E	1433	450	Pan evaporation
26	Kilosa Agric. Office	6° 50' S, 37° 00' E	491	225	Penman
27	Kilwa Kivinje	8° 45' S, 39° 25' E	9	275	Penman
28	Kipalapala Seminary	5° 06' S, 32° 48' E	1220	150	Blaney-Criddle
29	Kome Mission	2° 21' S, 32° 29' E	1134	300	Blaney-Criddle
30	Komera Coffee Estate	9° 09' S, 32° 56' E	1585	172	Penman
31	Kondoa Mission	4° 55' S, 35° 47' E	1386	225	Penman
32	Korogwe Distr. Office	5° 10' S, 38° 28' E	292	300	Pan evaporation
33	Kurio Mission	5° 13' S, 35° 23' E	1372	225	Pan evaporation
34	Lindi Met. Station	10° 00' S, 39° 42' E	40	250	Penman
35	Liuli Mission	11° 05' S, 34° 38' E	503	150	Pan evaporation
36	Lituhi Mission	10° 34' S, 34° 36' E	518	150	Pan evaporation
37	Liwale	9° 47' S, 37° 58' E	457	150	Pan evaporation
38	Lushoto Agric. Office	4° 47' S, 38° 17' E	1396	300	Pan evaporation
39	Madibira Mission	8° 14' S, 34° 49' E	1159	250	Penman
40	Magunga Estate	5° 00' S, 38° 38' E	610	250	Pan evaporation
41	Mahenge Hospital	8° 41' S, 36° 43' E	1107	225	Penman
42	Malangali School	8° 34' S, 34° 55' E	1524	225	Pan evaporation
43	Manyoni Distr. Office	5° 44' S, 34° 50' E	1243	225	Pan evaporation
44	Masasi Mission	10° 42' S, 38° 49' E	457	150	Penman
45	Mazinde Factory	4° 49' S, 38° 13' E	439	250	Penman
46	Mbeya Boma	8° 54' S, 33° 27' E	1768	175	Pan evaporation
47	Mbeya Met. Station	8° 56' S, 33° 28' E	1759	172	Penman
48	Mbulu Boma	3° 52' S, 35° 33' E	1738	150	Penman
49	Mikindani	10° 16' S, 40° 07' E	18	250	Pan evaporation
50	Milo Mission	9° 53' S, 34° 37' E	1220	150	Pan evaporation
51	Mkoe Plantation	9° 32' S, 39° 39' E	91	250	Pan evaporation
52	Morogoro Met. Station	6° 51' S, 37° 40' E	579	250	Penman
53	Moshi Met. Station	3° 21' S, 37° 20' E	813	300	Penman

54	Mpwapwa Vet. Office	6° 20' S, 36° 30' E	1128	225	Penman
55	Msimbazi Mission	6° 48' S, 39° 15' E	15	250	Penman
56	Mtotohovu	4° 43' S, 39° 09' E	46	250	Pan evaporation
57	Musekera Estate	9° 20' S, 33° 41' E	1220	172	Pan evaporation
58	Musoma Met. Station	1° 30' S, 33° 48' E	1148	300	Penman
59	Mvumi Mission	6° 23' S, 35° 55' E	1067	225	Penman
60	Mwanza Agric. Office	2° 31' S, 32° 54' E	1131	450	Penman
61	Mwita	10° 17' S, 40° 05' E	51	250	Pan evaporation
62	Narok Forest Station	3° 20' S, 36° 40' E	1829	300	Blaney-Criddle
63	Ndanda Mission	10° 30' S, 39° 02' E	305	250	Penman
64	Newala	10° 57' S, 39° 18' E	793	250	Pan evaporation
65	Ngara	2° 28' S, 30° 38' E	1799	300	Pan evaporation
66	Ngaraya Coffee Est.	5° 01' S, 38° 27' E	1067	225	Pan evaporation
67	Ngombezi Sisal Est.	5° 10' S, 38° 25' E	335	250	Penman
68	Ngudu Distr. Office	2° 57' S, 33° 21' E	1220	450	Pan evaporation
69	Ngurumahamba Estate	10° 02' S, 39° 38' E	21	250	Blaney-Criddle
70	Njombe Distr. Office	9° 20' S, 34° 46' E	1829	225	Penman
71	Nzega Distr. Office	4° 13' S, 33° 11' E	1220	225	Pan evaporation
72	Old Shinyanga	3° 33' S, 33° 24' E	1220	150	Pan evaporation
73	Olmotonyi Forest	3° 18' S, 36° 39' E	1610	300	Blaney-Criddle
74	Pangani Distr. Office	5° 26' S, 38° 59' E	9	225	Blaney-Criddle
75	Peramiho Mission	10° 34' S, 35° 28' E	1159	350	Penman
76	Rombo Mission	3° 12' S, 37° 36' E	1433	450	Blaney-Criddle
77	Rubya Mission	1° 45' S, 31° 37' E	1433	300	Blaney-Criddle
78	Ruvu Estate	6° 48' S, 38° 43' E	37	250	Pan evaporation
79	Sakarre Coffee Est.	4° 59' S, 38° 25' E	1372	275	Blaney-Criddle
80	Sakura Estate	5° 37' S, 38° 53' E	40	225	Pan evaporation
81	Selian Coffee Est.	3° 21' S, 36° 36' E	1402	300	Penman
82	Shanwa	3° 10' S, 33° 46' E	1341	150	Penman
83	Singida Distr. Office	4° 48' S, 34° 45' E	1498	225	Pan evaporation
84	Singu Estates	4° 12' S, 35° 40' E	1738	225	Pan evaporation
85	Songea Met. Station	10° 41' S, 35° 35' E	1067	350	Penman
86	Sumbawanga	7° 57' S, 31° 36' E	1723	300	Penman
87	Sumvwe Mission	2° 46' S, 33° 13' E	1220	300	Blaney-Criddle
88	Tabora Observatory	5° 02' S, 32° 49' E	1266	150	Penman
89	Tanga Town Council	5° 04' S, 39° 06' E	9	250	Penman
90	Tarime	1° 22' S, 34° 23' E	1524	300	Pan evaporation
91	Tengeru Coffee Est.	3° 22' S, 36° 48' E	1463	300	Penman
92	Tukuyu Distr. Office	9° 15' S, 33° 38' E	1616	172	Pan evaporation
93	Tunduru Distr. Office	11° 06' S, 37° 22' E	701	150	Pan evaporation
94	Tungi Sisal Estate	6° 46' S, 37° 42' E	503	150	Blaney-Criddle
95	Ujiji Mission	4° 55' S, 29° 41' E	777	300	Pan evaporation
96	Utete District Office	8° 01' S, 38° 45' E	52	275	Pan evaporation
97	Uvinza Salt Mine	5° 07' S, 30° 22' E	991	275	Penman

Source: East African Meteorological Department (1966)

Appendix C: Balancing of water budget for sample stations

C1: Stations with Penman evapotranspiration data

Musoma Met.: (1° 30' S 33° 48' E) Altitude (1148m) WC: 300mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	178	166	181	156	159	160	165	179	186	189	166	171
p	74	97	153	225	159	75	48	75	81	113	119	118
p - pET	-104	-69	-28	69	0	-85	-117	-104	-105	-76	-47	-53
St	4	3	3	72	69	49	31	20	13	10	8	7
cSt	-2	-1	-0	69	-3	-20	-18	-11	-7	-3	-2	-1
aEt	76	98	153	156	159	95	66	85	88	116	121	120
aWA/pEt	0.43	0.59	0.85	1.44	1.00	0.59	0.40	0.48	0.47	0.62	0.73	0.70

Mbulu: (3° 52' S 35° 33' E) Altitude (1738m) WC: 150mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	169	165	171	133	108	118	119	139	167	187	160	165
p	110	90	149	165	73	5	1	2	3	20	72	128
p - pET	-59	-75	-22	32	-35	-113	-118	-137	-164	-167	-88	-37
St	1	1	1	33	28	18	11	6	3	2	1	1
cSt	-0	-0	-0	32	-5	-10	-7	-5	-3	-2	-1	-0
aEt	110	90	149	133	77	15	8	7	6	22	73	128
aWA/pEt	0.65	0.55	0.87	1.00	0.72	0.13	0.07	0.05	0.04	0.12	0.45	0.78

Seliani Coffee: (3° 21' S 36° 36' E) Altitude (1402m) WC: 300mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	154	150	151	120	113	111	120	147	164	183	152	146
p	67	68	129	276	146	10	3	7	9	15	66	94
p - pET	-87	-82	-22	156	33	-101	-117	-140	-155	-168	-86	-52
St	5	4	3	159	192	128	80	46	25	13	9	7
cSt	-2	-1	-1	156	33	-64	-48	-34	-21	-12	-4	-2
aEt	69	69	130	120	113	74	51	41	30	27	70	96
aWA/pEt	0.45	0.46	0.86	2.30	1.29	0.66	0.42	0.28	0.18	0.15	0.46	0.66

Dodoma Met.: (6° 10' S 35° 46' E) Altitude (1120m) WC: 225mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	167	153	160	149	160	150	160	188	210	229	209	188
p	146	116	121	51	6	1	0	0	0	5	22	105
p - pET	-21	-37	-39	-98	-154	-149	-160	-188	-210	-224	-187	-83
St	0	0	0	41	22	12	6	3	1	1	0	0
cSt	-0	-0	-0	41	-19	-10	-6	-3	-2	-0	-0	-0
aEt	146	116	121	10	25	11	6	3	2	6	22	105
aWA/pEt	0.87	0.76	0.76	0.07	0.16	0.07	0.04	0.02	0.01	0.03	0.11	0.56

Lindi Met.: (10° 0' S 39° 42' E) Altitude (40m) WC: 250mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	181	168	184	166	166	152	161	172	187	210	210	209
p	142	140	176	170	40	11	7	5	13	14	46	146
p - pET	-39	-28	-8	4	-126	-141	-154	-167	-174	-196	-164	-63
St	1	1	1	164	99	56	30	16	8	4	2	1
cSt	-0	-0	-0	163	-65	-43	-26	-14	-8	-4	-2	-1
aEt	142	140	176	166	105	54	33	20	21	18	48	146
aWA/pEt	0.79	0.83	0.96	1.02	0.63	0.35	0.20	0.12	0.11	0.09	0.23	0.70

C2: Stations with Pan evaporation data

Ujiji Mission: (4° 55' S 29° 41' E) Altitude (777m) WC: 300mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	140	133	142	129	148	160	179	199	200	181	130	128
p	120	97	144	127	52	3	0	1	23	43	113	139
p - pET	-20	-36	2	-2	-96	-157	-179	-198	-177	-138	-17	11
St	2	2	4	120	82	44	21	10	5	3	3	3
cSt	-1	-0	2	116	-38	-38	-23	-11	-5	-2	-0	0
aEt	120	97	142	11	90	41	22	3	28	45	113	139
aWA/pEt	0.86	0.73	1.01	0.09	0.61	0.26	0.12	0.02	0.14	0.25	0.87	1.09

Singida: (4° 48' S 34° 45' E) Altitude (1498m) WC: 225mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	188	174	178	148	142	138	149	167	193	214	205	197
p	149	120	118	72	13	2	0	0	1	6	39	132
p - pET	-39	-54	-60	-76	-129	-136	-149	-167	-192	-208	-166	-65
St	1	0	115	85	51	29	16	8	4	2	1	1
cSt	-0	-1	115	-30	-34	-22	-13	-8	-4	-2	-1	-0
aEt	149	120	3	102	47	23	13	8	5	8	40	132
aWA/pEt	0.79	0.69	0.02	0.49	0.09	0.17	0.09	0.05	0.03	0.04	0.19	0.67

Bagamoyo Agric.: (6° 25' S 38° 55' E) Altitude (9m) WC: 250mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	203	187	179	137	138	137	149	157	166	183	191	199
p	75	75	103	241	214	40	26	36	23	47	76	96
p - pET	-128	-112	-76	104	76	-97	-123	-121	-143	-136	-115	-103
St	4	2	2	106	180	122	75	46	26	15	10	6
cSt	-2	-2	-0	104	74	-58	-47	-29	-20	-11	-5	-4
aEt	78	76	104	137	138	98	73	65	43	58	82	99
aWA/pEt	0.38	0.41	0.58	1.76	1.55	0.71	0.49	0.41	0.26	0.32	0.43	0.50

Mbeya Boma: (8° 54' S 33° 27' E) Altitude (1768m) WC: 175mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	125	103	123	124	125	116	125	153	184	212	178	145
p	211	167	180	94	16	2	0	1	2	14	51	169
p - pET	86	64	57	-30	-109	-114	-125	-152	-182	-198	-127	24
St	110	174	231	205	132	84	51	28	13	6	4	24
cSt	86	64	57	-26	-73	-48	-33	-23	-15	-7	-2	20
aEt	125	103	123	124	125	51	33	24	16	21	53	149
aWA/pEt	1.69	1.62	1.46	1.00	1.00	0.44	0.26	0.16	0.09	0.10	0.30	1.17

Malangali School: (8° 34' S 34° 55' E) Altitude (1524m) WC: 225mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	165	141	158	150	136	161	157	158	212	177	217	206
p	173	161	198	54	5	0	0	0	1	5	51	164
p - pET	8	20	40	-96	-131	-161	-157	-158	-211	-172	-166	-42
St	8	28	68	46	27	14	8	4	2	1	0	0
cSt	8	20	40	-22	-19	-13	-6	-4	-2	-1	-0	-0
aEt	165	141	158	76	24	13	7	4	3	6	51	164
aWA/pEt	1.05	1.14	1.25	0.51	0.17	0.08	0.04	0.02	0.02	0.03	0.24	0.80

C3: Stations with Blaney-Criddle evapotranspiration

Rubya Mission: (1° 45' S 31° 37' E) Altitude (1433m) WC: 300mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	137	133	141	126	129	115	141	143	139	138	123	127
p	111	115	169	228	158	24	11	43	75	105	138	134
p - pET	-26	-18	28	102	29	-91	-130	-100	-64	-33	15	7
St	55	52	80	182	211	146	87	58	45	40	55	62
cSt	-7	-3	28	102	29	-65	-59	-29	-13	-5	15	7
aEt	117	119	141	126	129	88	70	72	88	111	123	127
aWA/pEt	0.85	0.89	1.20	1.81	1.22	0.77	0.50	0.50	0.63	0.80	1.12	1.06

Olmotonyi Forest: (3° 18' S 36° 39' E) Altitude (1610m) WC: 300mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	136	135	136	119	102	99	104	127	140	161	122	124
p	78	78	124	264	148	11	4	6	6	25	95	130
p - pET	-58	-57	-12	145	46	-88	-100	-121	-134	-136	-27	6
St	18	14	14	159	205	176	118	73	42	25	22	23
cSt	-5	-4	-0	46	29	-74	-58	-45	-30	-18	-3	1
aEt	83	82	125	119	102	85	62	51	36	43	98	129
aWA/pEt	0.61	0.60	0.92	2.22	1.45	0.86	0.60	0.40	0.26	0.27	0.80	1.04

Rombo Mission: (3° 12' S 37° 36' E) Altitude (1433m) WC: 450mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	195	180	189	152	120	111	113	136	161	192	186	183
p	89	92	216	290	126	35	22	44	36	77	267	186
p - pET	-106	-88	27	138	6	-76	-91	-92	-125	-115	81	3
St	75	53	80	216	222	164	114	79	48	30	111	114
cSt	-39	-22	27	136	6	-58	-50	-35	-31	-18	81	3
aEt	128	114	189	152	120	93	72	79	67	95	186	183
aWA/pEt	0.66	0.63	1.14	1.91	1.05	0.84	0.64	0.58	0.42	0.49	1.44	1.02

Pangani: (5° 26' S 38° 59' E) Altitude (9m) WC: 225mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	217	211	199	167	152	133	142	154	170	173	193	209
p	43	47	118	279	291	69	57	63	62	80	98	97
p - pET	-174	-164	-81	112	139	-64	-85	-91	-108	-93	-95	-112
St	9	5	4	116	225	194	138	96	62	43	29	19
cSt	-10	-4	-1	112	109	-31	-56	-42	-34	-19	-14	-10
aEt	52	51	119	167	152	125	113	105	96	99	112	108
aWA/pEt	0.24	0.24	0.60	1.67	1.91	0.94	0.79	0.68	0.56	0.57	0.58	0.51

Tungi Sisal: (6° 46' S 37° 42' E) Altitude (503m) WC: 150mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pEt	173	159	167	126	111	106	112	126	146	179	176	179
p	146	94	136	191	76	22	14	11	14	25	43	88
p - pET	-27	-65	-31	65	-35	-84	-98	-115	-132	-154	-133	-91
St	2	2	1	66	57	41	28	17	10	6	3	2
cSt	-0	-0	-1	65	-9	-16	-13	-11	-7	-4	-3	-1
aEt	146	94	136	126	85	38	27	21	21	30	45	89
aWA/pEt	0.85	0.59	0.82	1.52	0.76	0.36	0.24	0.17	0.15	0.17	0.26	0.50

Appendix D: Ratios of actual water availability to potential evapotranspiration (aWA/pEt)

No.	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Hu.Ref.
1	Kagondo Mission	0.99	0.97	1.50	2.54	1.85	0.89	0.65	0.60	0.72	0.87	1.33	1.24	1470
2	Rubya Mission	0.85	0.89	1.20	1.81	1.22	0.77	0.50	0.50	0.63	0.80	1.12	1.06	0561
3	Bukoba Met.	1.13	1.10	1.62	2.87	2.50	0.93	0.93	0.98	0.91	0.99	1.33	1.52	2550
4	Igabiro Estate	0.71	0.79	1.09	1.56	0.94	0.41	0.29	0.26	0.48	0.65	0.85	0.95	0264
5	Kawalinda Coffee	0.96	0.98	1.31	2.33	1.79	0.90	0.68	0.64	0.67	0.89	1.24	1.25	1470
6	Musoma Met.	0.43	0.59	0.85	1.44	1.00	0.59	0.40	0.48	0.47	0.62	0.73	0.70	0264
7	Tarime	0.43	0.59	0.85	1.44	1.00	0.59	0.40	0.48	0.47	0.62	0.73	0.70	0264
8	Ngara	0.63	0.70	0.79	1.26	0.69	0.15	0.07	0.13	0.38	0.43	0.82	0.75	0165
9	Biharamulo	0.59	0.71	0.99	1.33	0.58	0.16	0.06	0.15	0.21	0.39	0.76	0.72	0165
10	Mwanza Agric.	0.59	0.61	0.86	1.04	0.56	0.12	0.06	0.10	0.20	0.29	0.67	0.79	0165
11	Kome Mission	0.40	0.59	0.81	0.96	0.45	0.12	0.10	0.25	0.42	0.64	0.71	0.65	0066
12	Sumvwe Mission	0.46	0.41	0.76	0.80	0.45	0.13	0.05	0.04	0.11	0.17	0.52	0.60	0048
13	Ngudu	0.52	0.45	0.22	0.92	0.38	0.08	0.03	0.03	0.05	0.13	0.52	0.72	0048
14	Kibondo Mission	0.96	1.06	1.20	1.46	0.67	0.25	0.12	0.09	0.14	0.34	1.06	1.25	0525
15	Kahama	0.78	0.63	0.82	0.82	0.32	0.18	0.11	0.07	0.10	0.23	0.62	0.78	0066
16	Old Shinyanga	0.72	0.65	0.77	0.80	0.05	0.15	0.07	0.04	0.04	0.17	0.38	0.79	0057
17	Shanwa	0.58	0.56	0.64	0.86	0.07	0.12	0.05	0.03	0.06	0.11	0.41	0.67	0057
18	Mbulu	0.65	0.55	0.87	1.00	0.72	0.13	0.07	0.05	0.04	0.12	0.45	0.78	0156
19	Olmotonyi Forest	0.61	0.60	0.92	2.22	1.45	0.86	0.60	0.40	0.26	0.27	0.80	1.04	1263
20	Arusha Agric.	0.58	0.64	1.21	3.13	2.08	0.91	0.68	0.52	0.36	0.32	0.83	0.98	2172
21	Selian Coffee	0.45	0.46	0.86	2.30	1.29	0.66	0.42	0.28	0.18	0.15	0.46	0.66	1137
22	Tengeru Coffee	0.50	0.58	0.97	2.80	2.56	0.93	0.75	0.60	0.45	0.38	0.72	0.78	2073
23	Narok Forest	0.66	0.78	1.22	4.10	3.73	0.97	0.83	0.67	0.51	0.47	1.00	1.16	2361
24	Moshi Met.	0.24	0.26	0.58	2.01	1.56	0.82	0.57	0.40	0.27	0.24	0.24	0.29	1137
25	Kibosho Mission	0.59	0.55	0.93	5.83	7.27	2.40	1.11	0.94	0.74	0.56	0.66	0.67	3180
26	Rombo Mission	0.66	0.63	1.14	1.91	1.05	0.84	0.64	0.58	0.42	0.49	1.44	1.02	0552
27	Kilema Mission	0.62	0.72	1.57	4.23	3.73	1.27	0.97	0.91	0.73	0.68	1.13	0.82	2370
28	Kigoma	0.88	0.86	1.15	1.13	0.46	0.15	0.08	0.04	0.10	0.30	1.00	1.16	0426
29	Ujiji Mission	0.86	0.73	1.01	0.09	0.61	0.26	0.12	0.02	0.14	0.25	0.87	1.09	0246
30	Nzega	0.75	0.69	0.77	0.78	0.39	0.17	0.08	0.04	0.03	0.08	0.37	0.84	0057
31	Singida	0.79	0.69	0.02	0.49	0.09	0.17	0.09	0.05	0.03	0.04	0.19	0.67	0039
32	Kondoa Mission	0.63	0.01	0.80	1.00	1.00	0.16	0.08	0.04	0.02	0.03	0.12	0.57	0237
33	Singu Estate	0.57	0.58	0.02	1.07	0.74	0.38	0.21	0.11	0.06	0.07	0.35	0.64	0147
34	Balangai Coffee	0.39	0.34	0.73	1.99	3.09	1.00	0.94	0.88	0.76	0.67	0.56	0.51	1182
35	Lushoto Agric.	0.54	0.47	0.96	1.96	2.32	0.95	0.81	0.65	0.50	0.49	0.72	0.70	1182
36	Sakarre	0.37	0.34	0.68	2.14	3.01	0.99	0.92	0.83	0.69	0.59	0.55	0.51	1182
37	Mazinde Factory	0.28	0.30	0.45	1.00	1.28	0.30	0.16	0.13	0.09	0.12	0.35	0.33	0219
38	Mtotohovu	0.16	0.09	0.40	0.92	1.70	0.72	0.52	0.43	0.41	0.42	0.49	0.27	0138
39	Uvinza Salt	0.81	0.88	0.88	0.88	0.25	0.03	0.01	0.02	0.07	0.15	0.73	1.11	0156
40	Tabora Observatory	0.83	0.80	0.91	0.82	0.20	0.03	0.01	0.01	0.02	0.06	0.41	1.06	0147
41	Kipalapala Seminary	0.79	0.84	1.05	0.89	0.20	0.04	0.01	0.01	0.03	0.07	0.43	1.09	0237
42	Manyoni	0.86	0.62	0.77	0.03	0.20	0.08	0.04	0.02	0.01	0.02	0.19	0.62	0048
43	Kurio Mission	0.78	0.64	0.75	0.02	0.37	0.17	0.09	0.05	0.03	0.03	0.16	0.52	0048
44	Ngaraya Coffee	0.65	0.51	1.00	3.27	4.43	1.10	1.00	0.99	0.94	0.91	0.83	0.80	2280
45	Amani Malaria	0.95	0.78	1.15	3.12	3.42	1.06	1.00	1.00	1.00	1.00	1.00	1.08	2640
46	Ambangulu Sisal Est.	0.62	0.52	1.15	4.34	5.79	1.63	1.00	1.00	0.99	0.97	0.89	0.79	2370
47	Pangani	0.24	0.24	0.60	1.67	1.91	0.94	0.79	0.68	0.56	0.57	0.58	0.51	0282
48	Handeni	0.42	0.41	0.68	0.98	0.05	0.50	0.32	0.26	0.23	0.31	0.28	0.36	0028
49	Korogwe	0.27	0.19	0.51	1.62	1.97	0.93	0.72	0.60	0.48	0.52	0.30	0.29	0255
50	Sakura Estate	0.28	0.21	0.56	1.28	1.27	0.87	0.64	0.54	0.45	0.45	0.61	0.44	0255
51	Karimi Estate	0.25	0.27	0.57	1.48	1.54	0.91	0.68	0.56	0.47	0.54	0.48	0.34	0255
52	Magunga Estate	0.40	0.39	0.78	2.94	3.49	0.98	0.92	0.88	0.86	0.89	0.74	0.56	2002
53	Ngombezi Sisal Est.	0.27	0.20	0.48	1.56	1.81	0.87	0.67	0.56	0.44	0.50	0.33	0.33	0246
54	Tanga Town	0.16	0.19	0.60	1.32	1.94	0.86	0.67	0.60	0.57	0.59	0.56	0.41	0273
55	Dodoma Met.	0.87	0.76	0.76	0.07	0.16	0.07	0.04	0.02	0.01	0.03	0.11	0.56	0048
56	Dodoma Reservoir	0.83	0.69	0.77	0.06	0.16	0.08	0.04	0.02	0.01	0.02	0.07	0.55	0048
57	Mvumi Mission	0.82	0.82	0.71	0.30	0.05	0.08	0.03	0.02	0.01	0.01	0.07	0.52	0048
58	Mpwapwa Vet.	0.81	0.81	0.81	0.05	0.40	0.16	0.09	0.05	0.03	0.03	0.15	0.59	0048
59	Morogoro Agric.	0.55	0.64	0.95	1.63	0.96	0.44	0.25	0.20	0.16	0.17	0.35	0.48	0147
60	Kilosa Agric.	0.62	0.65	0.94	1.48	0.71	0.25	0.14	0.15	0.11	0.14	0.35	0.59	0156
61	Tungi Sisal	0.85	0.59	0.82	1.52	0.76	0.36	0.24	0.17	0.15	0.17	0.26	0.50	0147
62	Berega Mission	0.89	0.75	0.83	1.00	0.02	0.35	0.19	0.11	0.06	0.07	0.14	0.50	0137
63	Bagamoyo Agric.	0.38	0.41	0.58	1.76	1.55	0.71	0.49	0.41	0.26	0.32	0.43	0.50	0228
64	Ruvu Estate	0.45	0.43	0.85	1.77	1.23	0.55	0.38	0.32	0.30	0.34	0.54	0.44	0237
65	Alavi Sisal Estate	0.29	0.37	0.88	1.90	0.95	0.51	0.28	0.20	0.16	0.27	0.50	0.49	0138
66	Dar es Salaam Lab.	0.31	0.41	0.67	1.86	1.47	0.72	0.49	0.35	0.26	0.29	0.35	0.38	0228
67	Msimbazi Mission	0.29	0.33	0.76	1.88	1.44	0.70	0.46	0.34	0.25	0.34	0.40	0.40	0228

68	Sumbawanga	1.00	0.98	1.03	0.01	0.42	0.20	0.12	0.07	0.06	0.05	0.36	0.92	0228
69	Iringa	1.15	0.96	1.14	0.70	0.14	0.04	0.02	0.01	0.01	0.04	0.20	0.71	0237
70	Kala Mission	1.50	1.70	1.31	0.96	0.65	0.38	0.22	0.12	0.08	0.13	0.59	1.00	0435
71	Mbeya Boma	1.69	1.62	1.46	1.00	1.00	0.44	0.26	0.16	0.09	0.10	0.30	1.17	0606
72	Mboya Met.	1.56	1.60	1.31	1.01	0.60	0.36	0.22	0.14	0.08	0.09	0.29	0.99	0426
73	Madibira Mission	0.81	0.75	0.82	0.05	0.31	0.14	0.07	0.04	0.02	0.02	0.16	0.49	0039
74	Malangali School	1.05	1.14	1.25	0.51	0.17	0.08	0.04	0.02	0.02	0.03	0.24	0.80	0327
75	Ifakara Mission	1.07	1.04	1.79	2.34	1.00	0.82	0.54	0.32	0.19	0.13	0.25	0.57	1344
76	Mahenge Hospital	1.90	1.52	2.51	2.69	1.00	0.83	0.57	0.38	0.31	0.24	0.42	1.28	2334
77	Utete	0.59	0.47	0.78	0.33	0.76	0.37	0.21	0.11	0.11	0.15	0.35	0.54	0048
78	Kilwa Kivinje	0.68	0.56	0.79	1.35	0.59	0.19	0.12	0.09	0.08	0.08	0.22	0.45	0147
79	Komera C Estate	2.05	2.24	2.20	1.53	0.90	0.59	0.36	0.22	0.14	0.25	0.78	1.80	3234
80	Musekera Estate	2.01	2.07	3.41	6.12	2.29	1.00	0.88	0.72	0.48	0.25	0.97	1.68	5142
81	Tukuyu	2.02	2.10	2.87	4.74	2.78	1.00	0.93	0.77	0.57	0.42	0.84	1.52	5151
82	Milo Mission	1.97	1.93	2.30	2.25	0.97	0.76	0.50	0.32	0.20	0.16	0.59	1.58	2343
83	Njombe	2.15	1.89	2.08	1.27	0.88	0.60	0.39	0.25	0.16	0.14	0.31	1.39	2325
84	Liwale	1.26	1.40	1.52	0.90	0.52	0.28	0.15	0.09	0.07	0.06	0.20	0.59	0336
85	Mkoe Plantation	0.71	0.55	0.80	0.15	0.63	0.30	0.16	0.10	0.11	0.12	0.24	0.57	0057
86	Lituhi Mission	2.02	1.82	1.83	1.21	0.87	0.59	0.38	0.23	0.13	0.08	0.19	0.92	1335
87	Peramiho Mission	1.82	1.97	2.06	0.99	0.79	0.50	0.32	0.20	0.11	0.08	0.27	1.16	1335
88	Songea Met.	2.41	2.12	2.03	1.00	0.82	0.53	0.33	0.21	0.13	0.09	0.28	1.26	3135
89	Masasi Mission	1.31	1.45	1.26	0.95	0.50	0.25	0.15	0.08	0.07	0.07	0.24	0.58	0327
90	Lindi Met.	0.79	0.83	0.96	1.02	0.63	0.35	0.20	0.12	0.11	0.09	0.23	0.70	0156
91	Newala	1.68	1.52	1.34	1.51	0.44	0.21	0.13	0.07	0.05	0.07	0.14	0.84	0416
92	Ndanda Mission	1.14	1.09	1.10	1.08	0.32	0.13	0.07	0.05	0.04	0.06	0.21	0.80	0417
93	Ngurumahamba Estate	0.89	0.93	1.03	1.09	0.17	0.22	0.11	0.10	0.09	0.10	0.22	0.60	1137
94	Mikindani	1.15	0.84	1.02	0.92	0.28	0.11	0.06	0.04	0.10	0.10	0.25	0.66	1137
95	Mwita	1.04	0.77	0.89	0.88	0.10	0.26	0.15	0.09	0.11	0.11	0.17	0.61	0147
96	Liuli Mission	1.92	2.24	2.80	1.92	1.00	0.90	0.70	0.44	0.29	0.23	0.54	1.47	2343
97	Tunduru	1.72	1.85	1.60	0.97	0.66	0.37	0.21	0.12	0.07	0.06	0.19	0.80	0336

* Hu. Ref. = Humidity reference number

* The order of the stations is from west to east and from north to south

Appendix E: Reference for drawing of isohygromene map

No.	Station	Location		Hu.Ref.	HU	SH	SA	AR	H	A
					No. of months falling under					
1	Kagondo Mission	1° 33' S	31° 42' E	1470	1	4	7	0	5	7
2	Rubya Mission	1° 45' S	31° 37' E	0561	0	5	6	1	5	7
3	Bukoba Met.	1° 20' S	31° 49' E	2550	2	5	5	0	7	5
4	Igabiro Estate	1° 48' S	31° 33' E	0264	0	2	6	4	2	10
5	Kawalinda Coffee	1° 34' S	31° 43' E	1470	1	4	7	0	5	7
6	Musoma Met.	1° 30' S	33° 48' E	0264	0	2	6	4	2	10
7	Tarime	1° 22' S	34° 23' E	0264	0	2	6	4	2	10
8	Ngara	2° 28' S	30° 38' E	0165	0	1	6	5	1	11
9	Biharamulo	2° 38' S	31° 19' E	0165	0	1	6	5	1	11
10	Mwanza Agric.	2° 31' S	32° 54' E	0165	0	1	6	5	1	11
11	Kome Mission	2° 21' S	32° 29' E	0066	0	0	6	6	0	12
12	Sumvwe Mission	2° 46' S	33° 13' E	0048	0	0	4	8	0	12
13	Ngudu	2° 57' S	33° 21' E	0048	0	0	4	8	0	12
14	Kibondo Mission	3° 35' S	30° 42' E	0525	0	5	2	5	5	7
15	Kahama	3° 50' S	32° 36' E	0066	0	0	6	6	0	12
16	Old Shinyanga	3° 33' S	33° 24' E	0057	0	0	5	7	0	12
17	Shanwa	3° 10' S	33° 46' E	0057	0	0	5	7	0	12
18	Mbulu	3° 52' S	35° 33' E	0156	0	1	5	6	1	11
19	Olmotonyi Forest	3° 18' S	36° 39' E	1263	1	2	6	3	3	9
20	Arusha Agric.	3° 23' S	36° 41' E	2172	2	1	7	2	3	9
21	Selian Coffee	3° 21' S	36° 36' E	1137	1	1	3	7	2	10
22	Tengeru Coffee	3° 22' S	36° 48' E	2073	2	0	7	3	2	10
23	Narok Forest	3° 20' S	36° 40' E	2361	2	3	6	1	5	7
24	Moshi Met.	3° 21' S	37° 20' E	1137	1	1	3	7	2	10
25	Kibosho Mission	3° 15' S	37° 19' E	3180	3	1	8	0	4	8
26	Rombo Mission	3° 12' S	37° 36' E	0552	0	5	5	2	5	7
27	Kilema Mission	3° 18' S	37° 30' E	2370	2	3	7	0	5	7
28	Kigoma	4° 53' S	29° 38' E	0426	0	4	2	6	4	8
29	Ujiji Mission	4° 55' S	29° 41' E	0246	0	2	4	6	2	10
30	Nzega	4° 13' S	33° 11' E	0057	0	0	5	7	0	12
31	Singida	4° 48' S	34° 45' E	0039	0	0	3	9	0	12
32	Kondoa Mission	4° 55' S	35° 47' E	0237	0	2	3	7	2	10
33	Singu Estate	4° 12' S	35° 40' E	0147	0	1	4	7	1	11
34	Balangai Coffee	4° 56' S	38° 28' E	1182	1	1	8	2	2	10
35	Lushoto Agric.	4° 47' S	38° 17' E	1182	1	1	8	2	2	10
36	Sakarre	4° 59' S	38° 25' E	1182	1	1	8	2	2	10
37	Mazinde Factory	4° 49' S	38° 13' E	0219	0	2	1	9	2	10
38	Mtotohovu	4° 43' S	39° 09' E	0138	0	1	3	8	1	11
39	Uvinza Salt	5° 07' S	30° 22' E	0156	0	1	5	6	1	11
40	Tabora Observatory	5° 02' S	32° 49' E	0147	0	1	4	7	1	11
41	Kipalapala Seminary	5° 06' S	32° 48' E	0237	0	2	3	7	2	10
42	Manyoni	5° 41' S	34° 50' E	0048	0	0	4	8	0	12
43	Kurio Mission	5° 13' S	35° 23' E	0048	0	0	4	8	0	12
44	Ngaraya Coffee	5° 01' S	38° 27' E	2280	2	2	8	0	4	8
45	Amani Malaria	5° 06' S	38° 38' E	2640	2	6	4	0	8	4
46	Ambangulu Sisal Estate	5° 05' S	38° 26' E	2370	2	3	7	0	5	7
47	Pangani	5° 26' S	38° 59' E	0282	0	2	8	2	2	10
48	Handeni	5° 26' S	38° 02' E	0028	0	0	2	8	0	10
49	Korogwe	5° 10' S	38° 28' E	0255	0	2	5	5	2	10
50	Sakura Estate	5° 37' S	38° 53' E	0255	0	2	5	5	2	10
51	Karimi Estate	5° 14' S	38° 35' E	0255	0	2	5	5	2	10
52	Magunga Estate	5° 00' S	38° 38' E	2002	2	0	8	2	2	10
53	Ngombezi Sisal Estate	5° 10' S	38° 25' E	0246	0	2	4	6	2	10
54	Tanga Town	5° 04' S	39° 06' E	0273	0	2	7	3	2	10
55	Dodoma Met.	6° 10' S	35° 46' E	0048	0	0	4	8	0	12
56	Dodoma Reservoir	6° 13' S	35° 46' E	0048	0	0	4	8	0	12
57	Mvumi Mission	6° 23' S	35° 55' E	0048	0	0	4	8	0	12
58	Mpwapwa Vet.	6° 20' S	36° 30' E	0048	0	0	4	8	0	12
59	Morogoro Agric.	6° 51' S	37° 40' E	0147	0	1	4	7	1	11
60	Kilosa Agric.	6° 50' S	37° 00' E	0156	0	1	5	6	1	11
61	Tungi Sisal	6° 46' S	37° 42' E	0147	0	1	4	7	1	11
62	Berega Mission	6° 12' S	37° 10' E	0137	0	1	3	7	1	10
63	Bagamoyo Agric.	6° 25' S	38° 55' E	0228	0	2	2	8	2	10
64	Ruvu Estate	6° 48' S	38° 43' E	0237	0	2	3	7	2	10

65 Alavi Sisal Estate	6° 50' S	38° 52' E	0138	0	1	3	8	1	11
66 Dar es Salaam Lab.	6° 49' S	39° 18' E	0228	0	2	2	8	2	10
67 Msimbazi Mission	6° 48' S	39° 15' E	0228	0	2	2	8	2	10
68 Sumbawanga	7° 57' S	31° 36' E	0228	0	2	2	8	2	10
69 Iringa	7° 47' S	35° 42' E	0237	0	2	3	7	2	10
70 Kala Mission	8° 09' S	31° 00' E	0435	0	4	3	5	4	8
71 Mbeya Boma	8° 54' S	33° 27' E	0606	0	6	0	6	6	6
72 Mbeya Met.	8° 56' S	33° 28' E	0426	0	4	2	6	4	8
73 Madibira Mission	8° 14' S	34° 49' E	0039	0	0	3	9	0	12
74 Malangali School	8° 34' S	34° 55' E	0327	0	3	2	7	3	9
75 Ifakara Mission	8° 09' S	36° 39' E	1344	1	3	4	4	4	8
76 Mahenge Hospital	8° 41' S	36° 43' E	2334	2	3	3	4	5	7
77 Utete	8° 01' S	38° 45' E	0048	0	0	4	8	0	12
78 Kilwa Kivinje	8° 45' S	39° 25' E	0147	0	1	4	7	1	11
79 Komera C Estate	9° 09' S	32° 56' E	3234	3	2	3	4	5	7
80 Musekera Estate	9° 20' S	33° 41' E	5142	5	1	4	2	6	6
81 Tukuyu	9° 15' S	33° 38' E	5151	5	1	5	1	6	6
82 Milo Mission	9° 53' S	34° 37' E	2343	2	3	4	3	5	7
83 Njombe	9° 20' S	34° 46' E	2325	2	3	2	5	5	7
84 Liwale	9° 47' S	37° 58' E	0336	0	3	3	6	3	9
85 Mkoe Plantation	9° 32' S	39° 39' E	0057	0	0	5	7	0	12
86 Lituhi Mission	10° 34' S	34° 36' E	1335	1	3	3	5	4	8
87 Peramiho Mission	10° 34' S	35° 28' E	1335	1	3	3	5	4	8
88 Songea Met.	10° 41' S	35° 35' E	3135	3	1	3	5	4	8
89 Masasi Mission	10° 42' S	38° 49' E	0327	0	3	2	7	3	9
90 Lindi Met.	10° 00' S	39° 42' E	0156	0	1	5	6	1	11
91 Newala	10° 57' S	39° 18' E	0416	0	4	1	6	4	7
92 Ndanda Mission	10° 30' S	39° 02' E	0417	0	4	1	7	4	8
93 Ngurumahamba Estate	10° 02' S	39° 38' E	0237	0	2	3	7	2	10
94 Mikindani	10° 16' S	40° 07' E	0237	0	2	3	7	2	10
95 Mwita	10° 17' S	40° 05' E	0147	0	1	4	7	1	11
96 Liuli Mission	11° 05' S	34° 38' E	2343	2	3	4	3	5	7
97 Tunduru	11° 06' S	37° 22' E	0336	0	3	3	6	3	9

Key:

Hu. Ref. = Humidity reference number
HU = Humid months
SH = Sub-humid months
SA = Semi-arid months
AR = Arid months
H = Humid + sub-humid
A = Arid + semi-arid

Appendix F: Stations and their aWA/pEt values in the crop potential areas

Table F1: Maize, sorghum and groundnut optimal areas

Station	Humidity Reference No.	aEt/pEt or p/pEt values in months I	II	III	IV	V	VI
Kagondo Mission	1470	0.97	1.50	2.54	1.85	0.89	0.65
Rubya Mission	0561	0.89	1.20	1.81	1.22	0.77	0.50
Bukoba Met.	2550	1.10	1.62	2.87	2.50	0.93	0.93
Igabiro Estate	0264	0.71	0.79	1.09	1.56	0.94	0.41
Kawalinda Coffee	1470	0.98	1.31	2.33	1.79	0.90	0.68
Musoma Met.	0264	0.43	0.59	0.85	1.44	1.00	0.59
Tarime	0264	0.43	0.59	0.85	1.44	1.00	0.59
Kibondo Mission	0525	0.96	1.06	1.20	1.46	0.67	0.25
Olmotonyi Forest	1263	0.60	0.92	2.22	1.45	0.86	0.60
Arusha Agric.	2172	0.64	1.21	3.13	2.08	0.91	0.68
Selian Coffee	1137	0.46	0.86	2.30	1.29	0.66	0.42
Tengeru Coffee	2073	0.58	0.97	2.80	2.56	0.93	0.75
Narok Forest	2361	0.78	1.22	4.10	3.73	0.97	0.83
Kibosho Mission	3180	0.93	5.83	7.27	2.40	1.11	0.94
Rombo Mission	0552	0.63	1.14	1.91	1.05	0.84	0.64
Kilema Mission	2370	0.72	1.57	4.23	3.73	1.27	0.97
Balangai Coffee	1182	0.73	1.99	3.09	1.00	0.94	0.88
Lushoto Agric.	1182	0.47	0.96	1.96	2.32	0.95	0.81
Sakarre	1182	0.68	2.14	3.01	0.99	0.92	0.83
Ngaraya Coffee	2280	0.51	1.00	3.27	4.43	1.10	1.00
Amani Malaria	2640	0.78	1.15	3.12	3.42	1.06	1.00
Ambangulu Sisal Est.	2370	0.52	1.15	4.34	5.79	1.63	1.00
Pangani	0282	0.60	1.67	1.91	0.94	0.79	0.68
Korogwe	0255	0.51	1.62	1.97	0.93	0.72	0.60
Sakura Estate	0255	0.56	1.28	1.27	0.87	0.64	0.54
Karimi Estate	0255	0.57	1.48	1.54	0.91	0.68	0.56
Magunga Estate	2002	0.78	2.94	3.49	0.98	0.92	0.88
Ngombezi Sisal Est.	0246	0.48	1.56	1.81	0.87	0.67	0.56
Tanga Town	0273	0.60	1.32	1.94	0.86	0.67	0.60
Morogoro Agric.	0147	0.55	0.64	0.95	1.63	0.96	0.44
Kilosa Agric.	0156	0.62	0.65	0.94	1.48	0.71	0.25
Kala Mission	0435	1.00	1.50	1.70	1.31	0.96	0.65
Mbeya Boma	0606	1.17	1.69	1.62	1.46	1.00	1.00
Mbeya Met.	0426	0.99	1.56	1.60	1.31	1.01	0.60
Ifakara Mission	1344	0.57	1.07	1.04	1.79	2.34	1.00
Mahenge Hospital	2334	1.28	1.90	1.52	2.51	2.69	1.00
Komera C Estate	3234	0.78	1.80	2.05	2.24	2.20	1.53
Musekera Estate	5142	0.97	1.68	2.01	2.07	3.41	6.12
Tukuyu	5151	1.52	2.02	2.10	2.87	4.74	2.78
Milo Mission	2343	1.58	1.97	1.93	2.30	2.25	0.97
Njombe	2325	1.39	2.15	1.89	2.08	1.27	0.88
Liwale	0336	0.59	1.26	1.40	1.52	0.90	0.52
Lituhi Mission	1335	0.92	2.02	1.82	1.83	1.21	0.87
Peramiho Mission	1335	1.16	1.82	1.97	2.06	0.99	0.79
Songea Met.	3135	1.26	2.41	2.12	2.03	1.00	0.82
Masasi Mission	0327	0.58	1.31	1.45	1.26	0.95	0.50
Newala	0416	0.84	1.68	1.52	1.34	1.51	0.44
Ndanda Mission	0417	0.80	1.14	1.09	1.10	1.08	0.32
Liuli Mission	2343	0.54	1.47	1.92	2.24	2.80	1.92
Tunduru	0336	0.80	1.72	1.85	1.60	0.97	0.66

Table F2: Additional optimal areas for bean production

Station	Humidity Reference No.	aEt/pEt or p/pEt values in months I	II	III	IV	V
Ngara	0165	0.63	0.70	0.79	1.26	0.69
Biharamulo	0165	0.59	0.71	0.99	1.33	0.59
Mwanza Agric.	0165	0.59	0.61	0.86	1.04	0.56
Moshi Met.	1137	0.58	2.01	1.56	0.82	0.57
Kigoma	0426	0.88	0.86	1.15	1.13	0.46
Mtotohovu	0138	0.40	0.92	1.70	0.72	0.52
Tungi Sisal	0147	0.59	0.82	1.52	0.76	0.36
Bagamoyo Agric.	0228	0.58	1.76	1.55	0.71	0.49
Ruvu Estate	0237	0.43	0.85	1.77	1.23	0.55
Alavi Sisal Estate	0138	0.37	0.88	1.90	0.95	0.51
Dar es Salaam Lab.	0228	0.67	1.86	1.47	0.72	0.49
Msimbazi Mission	0228	0.76	1.88	1.44	0.70	0.46
Iringa	0237	0.71	1.15	0.96	1.14	0.70
Malangali School	0327	0.80	1.05	1.14	1.25	0.51
Kilwa Kivinje	0147	0.56	0.79	1.35	0.59	0.19
Mikindani	0237	0.66	1.15	0.84	1.02	0.92

Table F3: Marginal areas of bean production

Station	Humidity Reference No.	aEt/pEt or p/pEt values in months I	II	III	IV	V
Kome Mission	0066	0.40	0.59	0.81	0.96	0.45
Sumvwe Mission	0048	0.46	0.41	0.76	0.80	0.45
Ngudu	0048	0.52	0.45	0.22	0.52	0.72
Kahama	0066	0.78	0.63	0.82	0.82	0.32
Old Shinyanga	0057	0.72	0.65	0.77	0.80	0.79
Mbulu	0156	0.65	0.55	0.87	1.00	0.72
Ujiji Mission	0246	0.86	0.73	1.01	0.09	0.61
Nzega	0057	0.75	0.69	0.77	0.78	0.39
Singida	0039	0.79	0.69	0.02	0.49	0.67
Kondoa Mission	0237	0.63	0.01	0.80	1.00	1.00
Singu Estate	0147	0.57	0.58	0.02	1.07	0.74
Mazinde Factory	0219	0.30	0.45	1.00	1.28	0.30
Uvinza Salt	0156	0.81	0.88	0.88	0.88	0.25
Tabora Observatory	0147	0.83	0.80	0.91	0.82	0.20
Kipalapala Seminary	0237	0.79	0.84	1.05	0.89	0.20
Manyoni	0048	0.86	0.62	0.77	0.03	0.62
Kurio Mission	0048	0.78	0.64	0.75	0.02	0.52
Dodoma Met.	0048	0.87	0.76	0.76	0.07	0.56
Dodoma Reservoir	0048	0.83	0.69	0.77	0.06	0.55
Mvumi Mission	0048	0.82	0.82	0.71	0.30	0.52
Mpwapwa Vet.	0048	0.81	0.81	0.81	0.05	0.59