Feasibility of rain-fed agriculture in the Pangani River basin Tanzania

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Abstract

Distributed soil moisture model was used to estimate daily soil moisture balance for different crops in the Pangani River basin in Tanzania. The model calculates the soil moisture balance using rainfall and reference crop evapotranspiration at grid resolution of 1 km. The reference crop evapotranspiration was estimated using growth stage dependent crop coefficients making the model able to make crop-type sensitive spatially distributed soil moisture balance estimates. The simulated soil moisture balance at each grid was compared to readily available soil moisture (RAM) for a specific crop and a failure of crop was established if the simulated soil moisture was less than RAM for a critical period over which that specific crop starts wilting. Probability of crop failure for each crop were estimated grid wise and mapped to show areas where rain-fed agriculture for specific crop is feasible in the basin. The results shows that beans have probability of failure less than 20% for most parts of the basin. This crop may be considered as drought resistant and suitable for rain-fed agriculture in the basin. The probability of failure of the Maize crop was found to be less than 20% in Maasai steppe, part of the Usambara and areas around mount Kilimanjaro. Rain-fed agriculture is considered feasible only in these areas while areas around North and south pare mountains would not be feasible for rain-fed maize cultivation. The probability of failure for the rice crop was found to be higher than 80% for most parts of the basin and this crop is considered infeasible for rain-fed agriculture in the basin.

Keywords: Pangani basin, maize, beans, rice, soil water balance model, crop failure

Introduction

Rain-fed agriculture is a major source of food and fiber. About 60% of the world staple food production relies on rain-fed agriculture. Rainfall is also responsible for meat production through grazing and wood from forest. In Tanzania and other Sub-Saharan African countries where irrigation is very limited almost the entire food production and production of industrial crops such as cotton, tobacco and wood depends on rainfall Rockström, 2000). The relative importance of rain-fed agriculture in these countries is very high and its proper management is essential for socio-economic development. One important technique of improving productivity of rain-fed farming is to choose the best possible crops and crop varieties for given local soil and climatic conditions. The knowledge of which crops can be grown when and where within the watershed or country helps to increase overall area productivity by avoiding losses which would otherwise occur due to failure of crops located where local climate and soil is unsuitable.

Since soil, rainfall and climatic variables vary spatially within a given area it is unlikely that a single crop will be suitable over the whole area. It is therefore necessary to delineate areas suitable for different crops according to these conditions to increase the overall productivity from the area. The stochastic nature of rainfall and other climatic variables means also that there will be a risk associated with production of crops in the delineated zones. The decision to adopt a certain cropping pattern therefore depends on the level of risk involved.

In this paper a methodology for mapping crop failure probability is presented. The crop failure probability maps can be used to judge which areas are suitable for rain-fed agriculture for a given crop. The method is applied in Pangani river basin, Tanzania and the results are presented.

The study area and rain-fed agriculture

Pangani river basin is located on the North Eastern part of Tanzania. The river system is formed by streams flowing from Mount Kilimanjaro the highest mountain in Africa, mount Meru, and Pare and Usambara mountain ranges. Basin area is estimated as 42000 km^2 with 6% of the area extending across the border into Kenya. (Luhumbika and Kamugisha, 1996). Elevation in the basin varies from sea level at Pangani the basin outlet to 5895 masl on top of Mount Kilimanjaro.

There is high spatial variability of rainfall in the basin mainly characterized by the topography. While mountainous parts of Kilimanjaro, Meru, Pare and Usambara receive much rainfall (typically between 800 and 1200mm per annum) a vast majority of low laying areas receive less 500 mm per year. The mountains are located on the eastern part of the basin which also overlooks the Indian Ocean and receives much rainfall. The western part of the basin including low lands in Same and Mwanga districts are very dry and consist of savannah bush lands. Mount Kilimanjaro and Meru are located on the northern part of the basin and rainfall in this area is one of the highest in the country with an annual average up to 2000 mm. (Ministry of water, 1980)

Since colonial times fertile uplands fertile especially in Kilimanjaro and Meru and to some extent Pare and Usambara have been committed to growing of cash crops especially coffee and tea. The production of food crops is very limited in these areas due to presence of large coffee and tea estates covering the whole area leaving little room for other crops. As a result of this upland people rely on food supplies from low laying areas which depend on rain-fed agriculture. Unlike in the high lands rainfall is more unreliable in the low laying areas and its timing and spatial distribution often affects food production.

Maize is the main food crop grown in Tanzania and in the basin. There are very limited irrigated maize farms in the basin including NAFCO farms in Kahe lower Moshi area. The rest of farms run by individuals farmers depend on rainfall. Incidences of crop failures in the basin and Tanzania occur quite frequently due to erratic rainfall. Recent crop failures due to droughts occurred in 1983 and 1993 (Amaglo, 1997). Rain-fed maize crop is often plagued by dry spells in Tanzania. For example is estimated that, in semi-arid locations in Kenya and Tanzania, there is a minimum probability of 0.2 – 0.3 for a dry spell to last more than 10 days at any time of the growing season of the crop, and a probability of 0.7 for such a dry spell to occur during the sensitive flowering stage (Rockström 2000). Other studies on effects of droughts on agricultural outputs and economy in general in the region are documented by Mhita, (1990), and Ogallo, (1994).

It may be noted that low laying areas of Pangani river basin are drought prone and different methods for improving food productivity from rain-fed agriculture must be adopted. For planning purposes it is essential to asses the viability of rain-fed agriculture with a view of advising farmers on the most suitable crops to be grown in different areas to maximize the output of rain-fed agriculture.

Objectives of the study

The objective of this study is to assess the viability for rain-fed agriculture in the basin by mapping the probability of failure of different food crops to indicate risk of growing a particular crop at different locations in the basin. Specifically the study concentrated on mapping the probability of failure of rain-fed maize, beans and rice crop in the study basin. The probability maps can be used to decide which crops to be grown at different locations in the basin with minimum risk of failure.

Data and Methods

The aim of the study is to come up with failure probability map of different rain-fed crops in the study basin. A grid based approach is used and the probability of failure of a given crop is established at grid level. The spatial distribution of the failure probability is then presented. Steps for establishing the probability of failure at grid level are discussed briefly below.

Crop failure probability

In this study the probability of crop failure is calculated as the number of times (annual counts) a crop failure have occurred divided by the length of annual record used in the analysis. For any grid in the basin, crop failure occur when readily available soil moisture (RAM) is less than soil moisture in that grid for a critical duration I .

- i) Calculate the RAM
- ii) Calculate I
- iii) Calculate soil moisture
- iv) If soil moisture is less than RAM for consecutive number of days equal to I crop failure have occurred.

The readily available soil moisture RAM is a function of both crop and soil type. It may be estimated as;

$$RAM = p * (S_{FC} - S_{WP}) \tag{1}$$

where p is the fraction of total available soil water which can be taken by the plant without affecting transpiration and /or growth. S_{FC} is the moisture content at field capacity and S_{WP} moisture content at wilting point. The value of soil parameters S_{FC} and S_{WP} were determined based on soil type. The soil map of Tanzania derived from FAO database (FAO, 1998) was used for determining the soil type for each grid

The critical duration I (days) over which if soil moisture is throughout below RAM a crop experiences failure is calculated according to the irrigation frequency formula (FAO, 1988) as;

$$I = \frac{RAM * D}{ET_{CROP}} \tag{2}$$

Once RAM and I are known for a given crop what remains is estimate of soil moisture to complete the procedure for establishing crop failure. The estimation of soil moisture is explained in the following section.

Estimation of soil moisture

Grid based estimation of soil moisture is the main methodology in this analysis. Daily soil moisture S_W is estimated using a simple soil moisture balance model (equation 3).

$$SW_t = SW_{t-1} + R_t - Q_t - AET_t - P_t \tag{3}$$

where S_W is soil moisture, R is rainfall, Q is runoff, P is deep percolation and AET is the actual evapotranspiration. The model runs on daily time step and at 1km by 1km grid resolution matching the grids of the global digital elevation model (DEM) by the United States Geological Survey (USGS). In the above equation only rainfall is measured and the rest of components including surface runoff Q, percolation beyond root zone *P* and actual evapotranspiration have to be estimated using available data and techniques.

Surface runoff *Q* for each grid is estimated using a modification of soil conservation service (SCS) curve number (CN) technique. Runoff calculation takes into account the effect of slope, soil type and antecedent moisture conditions.

Evapotranspiration *AET* is calculated using the FAO 1998 Penman-Monteith formula (equation 5).

$$ET = \frac{0.408\Delta\left[R_n - G\right]}{\Delta + \gamma(1 + 0.34u_2)} + \frac{\gamma}{\Delta + \gamma(1 + 0.34u_2)}\frac{900u_2(e_s - e_a)}{(T + 273)} \tag{5}$$

where R_n is the net radiation, *G* is the soil heat flux, (e_s-e_a) is vapor pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat capacity of the air Δ is the slope of the saturation vapor pressure temperature relationship, γ is the psychometric constant, r_s and r_a are the bulk surface aerodynamic resistances. Symbol *T* is air temperature in Celsius degrees and u_2 is wind speed at 2 m above ground.

The actual evapotranspiration *AET* is then calculated by multiplying *ET* with crop coefficient K_c crop type and the stage of growth.

$$AET = ET * Kc \tag{6}$$

To complete the soil water balance accounting it is assumed that when soil is saturated any excess water is percolating to the ground water store.

<u>Data used</u>

The methodology described above needs a lot of data to implement. The primary data required includes DEM, soil type, vegetation type and time series data of rainfall and climatic variables. The primary data is used to generate secondary data required to implement the model including soil parameters (S_{FC}, S_{WP}), slope and biophysical parameters such as K_c.

The DEM data at 1kmx1km for study area was obtained from global DEM data of USGS. Soil map at the same resolution was obtained from the FAO database (FAO, 1998).

Time series data for rainfall and climatic variables was obtained from the meteorological agency database and the ministry of water and livestock. The distribution of mean annual rainfall in the Pangani river basin is shown in figure 1 below.

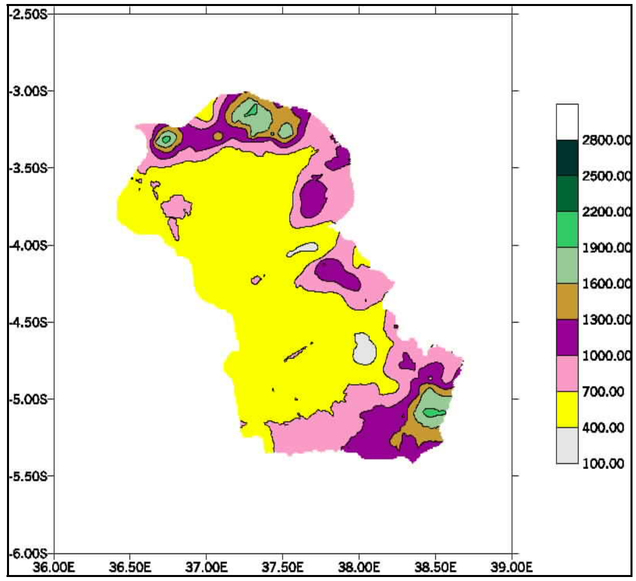

Figure 1. The Distribution of mean annual rainfall in Pangani River basin.

Application and results

To determine the probability of failure of a given crop at a given grid the soil moisture balance model must be run for the whole period of available record. The annual counts when a crop fails at any grid are noted, and the probability of crop failure at such grid is taken as the number of crop failure annual counts over the number of years in the record. The procedure is applied for each crop in turn. The model was applied to check the viability of maize, beans and paddy for rain-fed agriculture in the study basin. The results of application are shown in figure 1 below.

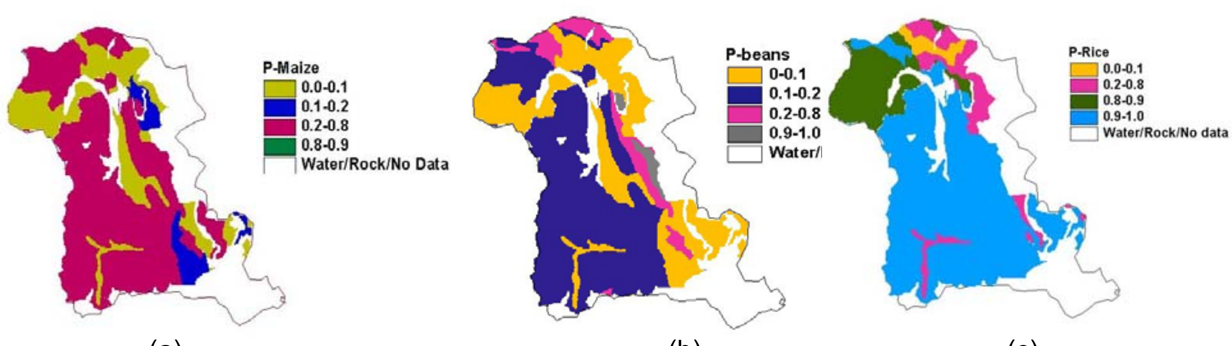

Figure 2. Distribution of probability of failure of selected food crops in Pangani river basin.

Discussion of results

For purposes of discussion of the results it is assumed that rain-fed agriculture for a given crop is possible if the probability of failure is less than 0.2. If the probability of failure (P_f) is between 0.2 and 0.8 rain-fed agriculture must be supplemented with irrigation to avoid crop failure. It is totally impossible to have rain-fed agriculture if P_f is more than 0.8.

Figure 1(a) shows the spatial distribution of probability of failure of the rain-fed maize crop. According to the results, rain-fed maize crop can only be practiced with supplementary irrigation for a large part of the basin. This follows clearly the same pattern of rainfall distribution in the basin.

The practice of rain-fed maize crop is possible in some parts of the basin where P_f less than 0.2. These areas are located on the western side of North Pare Mountains, west of Usambara Mountains and a small part on the eastern side of Usambara Mountains. There is also possibility of practicing rain-fed maize farming in elevated areas around Mount Kilimanjaro and Meru where rainfall is pretty high and P_f is between 0.1 and 0.2.

It is worth noting however that maize may not be grown in some areas indicated as suitable for rain-fed maize farming e.g. highlands in Kilimanjaro and Meru due to commitment of land to production of coffee. In general the blue polygons ($0.1< P_f <0.2$) on the western side of north pare and around Usambara mountains are suitable for rain-fed maize farming. Based on the knowledge of the area rain-fed maize cultivation is being practiced in the area indicated by the blue polygon western part of north pare mountains with high reliability as indicated by this analysis. Although a portion of basin on western part of Usambara Mountains is suitable for rain-fed maize farming this area have large sisal plantations and only limited land may be available for maize farming.

Figure 2(b) shows the distribution of probability of failure of rain-fed beans crop in the basin. Comparatively results indicate that beans have more potential for rain-fed agriculture than maize and of course rice. The results indicate that even in the western part of the basin where rainfall is very little beans can survive without irrigation.

Figure 2(c) shows the distribution of probability of failure of rain-fed rice crop in the basin. Due to high water requirement rain-fed rice farming is not possible for most part of the basin as shown in the figure. Rain-fed paddy crop seem to be possible only on the foot of Mount Kilimanjaro where such activity may not be possible due to commitment of land for growing other crops.

Conclusions

A simple method for investigating the viability of rain-fed agriculture in Pangani basin was presented. The method evaluates the probability of failure crop based on climatic data and soil and digital elevation model. Preliminary results presented highlight the potential of this method for assessing the possibility of practicing rain-fed agriculture for different crops at any location in the basin. The method may be used a rough guide to farmers to help them choose the type of crop to be grown at any location with less risk of failure. For basin wide management, the method may be used to determine the best combination of crop types to achieve maximum output from the land.

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