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Investigation of sustainability of rain-fed agriculture through soil moisture modeling in the Pandamatenga Plains of Botswana

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Abstract

The agricultural economic sector of Botswana is limited mainly to range resources-based livestock and pockets of arable farming based on rainfall and limited irrigated agriculture at several places. In this study agricultural sustainability of rain-fed agriculture is investigated in Botswana by considering the Pandamatenga plains as a case study. Daily soil moisture regimes with respect to crop growth cycle were modelled using a water balance model based on 42 years of daily hydroclimatic inputs and corresponding simulated components of soil moisture, evaporation, surface runoff, and deep percolation. Using a sustainability criterion on crop water requirement and soil moisture availability during the cropping periods, it was found that rain-fed agriculture of maize, sunflower, and sorghum crops is sustainable. The relative sensitivity to drought of these crops was also found to conform to the Agromisa recommendations. In the pursuit to explore more IWRM opportunities, through the simulation of the corresponding direct runoff, we have also explored that more water harvesting opportunities exist in order to manage rainfall excesses effectively.

Keywords: Soil moisture modeling; Rainfed agriculture; Excess rainwater harvesting; Integrated water resources management; Botswana

1. Introduction

Rain-fed agriculture based to a large extent on smallholder, subsistence agriculture is the source of livelihood of the majority of the population in sub-Saharan Africa (e.g., Malawi, 90%; Botswana, 76%; Kenya, 85%; and Zimbabwe, 70–80%, of the population) (Rockström, 2000). An estimated 38% of the population in sub-Saharan Africa (roughly 260 million people) live in drought-prone drylands (UNDP/UNSO, 1997). Only four of the SADC member states are self-sufficient in food production with the rest engaging in substantial food imports to meet domestic food deficits (SADC, 1995). Food production in the region is characterized by annual fluctuations due to rainfall variability.

Sustainability of rain-fed agriculture is a challenge most agriculturally-supportive areas strive for generation of food for their communities. The Pandamatenga Plains, located in Northern Botswana is one of such areas where rain fed agriculture is practiced. Studying the sustainability of rain-fed agriculture is an important research area for irrigation engineers and hydrologists especially in Africa, the outcome of which is useful for agricultural planners and decision makers. This study is devoted to developing a simple Soil Moisture Accounting Crop-Specific (SMACS) model and studying the sustainability of growing maize, sunflower, and sorghum in northern Botswana by employing a sustainability criteria based on crop water requirement and soil moisture availability during the cropping periods. The Pandamatenga plains, is a prominent agricultural area for the above crops.

The model used in this study, the Soil Moisture Accounting Crop-Specific (SMACS) model is a typical case of soil–vegetation–atmospheric transfer (SVAT) models. The hydrological concept and development of SVAT

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models is a wide area of immense research. The main issue is to identify the different formulations for runoff production, soil moisture and evaporation. Boone and Wetzel (1996) stated that one of the most important components of the SVAT scheme is the soil hydrology scheme, which is used to determine the partitioning of rainfall into infiltration, runoff, drainage, and storage within the soil. Large scale soil moisture data are available from soil–water retention parameters, hydrological model and remote sensing data at the SADC scale (e.g. Alemaw and Chaoka, 2003) as well as from remote sensing (ERS scatterometer) and soil data at a global scale (e.g. Wagner et al., 1999). The spatial and temporal scale of these data limits their applicability to study soil–plant relations at localized scale such as the Pandamatenga plains considered in this study.

Researches on plant response to sub-optimal levels of soil moisture have already been conducted for several decades. In his comprehensive work Hsiao (1973) examined and ranked plant physiological responses to water stress and the underlying mechanisms. Specific studies were conducted to assess, on a more practical level, the response of single crops to various water stress levels, for example soyabean (Sionit and Kramer, 1977), and sorghum (Gardner et al., 1981). The United Nations FAO has compiled the experience, practices, and guidelines on crop water requirement and crop evapotranspiration (Doorenbos and Pruitt, 1977; FAO, 1998; FAO, 1992).

In agricultural water management, a common straightforward definition of water harvesting is the one provided by Siegert (1994) as the collection of runoff for productive use. Runoff can be collected from roofs or ground surfaces (rainwater harvesting) as well as from seasonal streams (flood water harvesting) (Agromisa, 1997).

The most important decision criteria will be to determine the level of soil moisture and its reliability to sustain crop growth without excessively depleting the available soil moisture storage. The objective of the study covered in this paper is: (i) to simulate daily soil moisture on areas cropped with maize, sunflower, and sorghum in the Pandamatenga plains; (ii) to determine the proportion of available moisture content required to sustain crop growth during the entire crop cycle; and (iii) to investigate the potential of harvesting excess runoff formed on cropped areas.

2. The study area

The study area is the Pandamatenga Plains, located in Northern Botswana where rainfed agriculture is practiced (Fig. 1). The total area considered in this study consists of approximately 25,000 ha of land of which 15,840 ha is allocated for commercial farming. The annual average rainfall is 510 mm/yr with standard deviation of about 225 mm/yr. The soil type is predominately vertisols, where there are very low drainage slopes ranging between 0.05% and 0.4%. The land cover is originally acacia/baobab deciduous savanna. Farming in the area started prior to the 1950s.

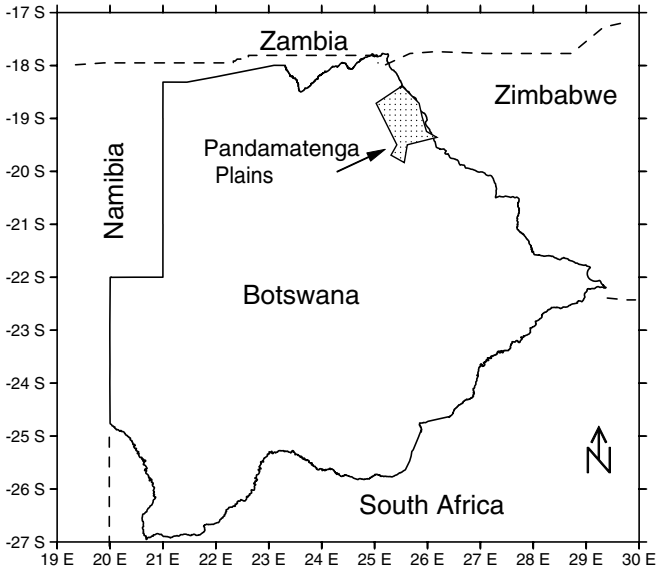

Fig. 1. The location map of the study area – Pandamatenga farm plains.

This investigation of the degree of sustainability of rain-fed agriculture in the Pandamatenga plains is an important as the outcome will be of great assistance to agricultural planners and decision makers. The Pandamatenga plains is one of the vast agricultural potential areas which is considered as a commercial farming magnet by the Government as well as private investors. Maize, sunflower, and sorghum which are predominant crops in the area have been considered to assess their agricultural sustainability.

3. Materials and methodology

The methodology employs a soil moisture accounting rainfall-runoff modeling approach and decision criteria that are based on results on: (1) simulated daily soil moisture, (2) the proportion of available moisture content that is required to sustain crop growth during the entire crop cycle, and (3) evaluated surface runoff available for potential excess water harvesting. An account of the approach followed in this study is presented below.

3.1. Simulation of soil moisture regime

In order to determine the variation of soil moisture and assess the availability of soil moisture to plants, daily soil moisture simulations were undertaken using a spreadsheet program called Soil Moisture Accounting Crop-Specific (SMACS) model developed for this study.

The SMACS model is based on a simple accounting of the daily moisture with the major terrestrial and atmospheric inputs of rainfall and potential evapotranspiration, along with the soil water retention properties and crop development factors. The approach followed is similar