1 GENERAL INTRODUCTION

1.1 Introduction

Sustainable food production and industrial development will depend to a large extent on the judicious use of water resources, as fresh water for human consumption and agriculture is becoming increasingly scarce. An increasing number of countries with limited water and land resources are faced with greater challenges. The dependency on water for future development has become a critical constraint especially in arid and semi-arid regions, where water scarcity is expected by the year 2025 (Smith, 2000). The situation is aggravated by the declining quality of soil and water resources caused, to a large extent, by human activities. There is an urgent need to arrest this human-induced degradation of water and soil resources and reclaim those that have already been degraded in order to meet the present and future needs of mankind. Hence, needs for sustainable use of water resources with respect to different land use patterns and climatic forcing. A good understanding and description of the dynamics of a local/regional/global hydrologic cycle as affected by natural and human activities is the starting point for effective management of water resources of a given basin or region.

Evapotranspiration (ET) is an important component of the water cycle. It is the term used to describe the transfer of water from a variety of surfaces into the atmosphere. Actual evapotranspiration is, through latent heat, responsible for 70% of the lateral global energy transport. ET plays an important role in the redistribution of water on the Earth's surface (Mauser and Schädlich, 1998). Accurate measurement and estimation of evapotranspiration is a basic tool to compute water balances and to estimate water availability and requirements (Pereira et al., 1999). Recently, increased emphasis has been placed on understanding the interaction between regional climate and the hydrological cycle in arid and semi-arid regions (Chehbouni et al., 1997). The water balance of these regions is important for many reasons, including water resource assessment, dry land agriculture, and the possible link between the surface energy balance and climate (Wallace and Holwill, 1997). Advances in hydrological research in the past two decades have been enormous especially in the temperate region while the hydrological knowledge of the tropical zones has advanced much less (van de Giesen et al., 2000). Varied environmental factors exist between the two climatic zones such that models and approaches developed in one should be locally tested before they are transferred to another zone.

The Volta River Basin in West Africa is a typical example of a semi-arid region in which studies to obtain a better insight into the interactions between soil, vegetation, climate, water and human activities are very important for the overall development of the region. The area is largely characterized by poverty, high population growth and widely varied precipitation, while the main source of livelihood in the sub-region is rain-fed agriculture. The continued pressure on the natural resources in a region like West Africa necessitates a good understanding of catchment hydrology for sustainable water use (Wallace and Batchelor, 1997; van de Giesen et al., 2000). Therefore, effective watershed management is a key to improving agricultural production with significant implications for meeting other water needs.

Several factors such as regional land use/land cover change (LUC) as well as components of the basin water balance should be carefully studied and understood. The development of an effective water management strategy depends on a precise estimate of these components/factors, their interactions and existing feedback mechanisms. Evapotranspiration is one of the most important phenomena in the Volta River Basin; a preliminary study of the annual water balance based on historical data showed that up to 90% of total catchment rainfall is accounted for by ET (Andreini et al., 2000).

The Volta Basin, with a recently observed declining water level in the lake, has undergone numerous environmental changes since the formation of the Akosombo dam about 30 years ago. Studies related to sustainable water use in general, and agricultural water management in particular, is of priority importance in order to increase production without degrading the basin’s resources. Changes in land use lead to changes in water use, as evaporation from each component of the land surface is controlled by different factors. These different factors influence both evaporation from the soil and plant transpiration whereby the former is a purely physical process and the latter is also affected by physiological responses (Allen and Grime, 1995).

Any change in actual ET, either through a change in vegetation or climate, directly affects the available water resources and runoff. Changes in vegetal cover through human influence are taking place, both on the field scale through the introduction of new or modified species in agriculture and forestry, and on the regional scale through deforestation, irrigation and man-induced erosion hazards (Mauser and Schädlich, 1998).

The GLOWA-Volta project (van de Giesen et al., 2002), a research project designed to study "sustainable water use under changing land use, rainfall reliability, and water demands in the Volta Basin" (West Africa), is expected to produce a decision support system (DSS) for sustainable water management in the Volta Basin. Such a DSS package should be based on sound scientific knowledge of regional water cycles amongst other factors. Furthermore, pertinent to our understanding of regional to global change in hydrological cycles is the study of biosphere-atmosphere interactions that consider the effects of climate on ecosystem functions and the potential feedbacks of the land surface to the physical climate system. Studying these interactions require a nested experimental design whereby measurements of fluxes are taken using a variety of methods at different time and space scales (Margolis and Ryan, 1997).

This research (sub-project) seeks to provide field level data needed to validate and/or test land-surface sub-models in the regional circulation models as well as to compute independent estimates of regional evapotranspiration that by-pass the need for soil and vegetation parameters and the complex feedback within the land-atmosphere continuum. The specific objectives are:

1. To measure *in situ* and model surface albedo;
2. To measure tree water use and its dynamic interaction with the ambient environment; and
3. To model the spatial distribution of actual regional evapotranspiration using the complementary relationship hypothesis.

1.2 Research justification

In problems of regional hydrology and global climatology, a knowledge of the large-scale behavior of processes defining fluxes of sensible and latent heat is of paramount importance in understanding the climate, weather, biochemical cycles and ecosystem dynamics. Recent research on improving the representation of land surface-atmosphere interactions within general circulation models (GCMs) has led to the investigation of a wide variety of different soil-vegetation-atmosphere transfer (SVAT) schemes. The project for the Intercomparison of Land Surface Parameterisation Schemes (PILPS) and the Gediz Basin project are good examples of this effort. Forty-four different SVAT models were identified and investigated by Moehrlen et al. (1998). No clearly defined patterns have emerged from these analyses and no particular model could be adjudged most accurate (Pitman and Henderson-Sellers, 1998; Kite and Droogers, 2000). Accounting for the feedback mechanism in land-surface interactions seems to be the bottleneck of these schemes. Pertinent to our understanding of regional and global change in the hydrological cycle is the knowledge of biosphere-atmosphere interactions that include the effects of climate on ecosystem functions and the potential feedbacks of the land surface to the physical climate system. Studying these interactions requires a nested experimental design whereby measurements of fluxes are taken using a variety of methods, at different time and space scales (Margolis and Ryan 1997). Furthermore, land use effects that may be captured by its surface albedo property and individual components of ET (soil evaporation and transpiration) should be properly understood. To avoid the above complexities, there is therefore a need for models of regional evapotranspiration that incorporate complex feedback mechanisms existing in the soil-plant-atmosphere system. Models based on Bouchet's complementary hypothesis (Bouchet 1963) are examples of such models. The main advantage of these kind of models is that they do not require data on surface resistance, soil moisture content, or other land surface measures of aridity (Brutsaert and Stricker, 1979).

1.3 Thesis outline

This report is divided into six chapters. Chapter 2 reviews the recent developments in evapotranspiration research: basic definitions and concepts, the available paradigms in ET studies, the measurement techniques, and the estimation models. Chapter 3 gives the description of the study area for the whole Volta Basin at large and the Ejura sub-basin where the actual field level measurements took place. Chapter 4 deals with the research methods and analytical procedures. Experimental procedures, modeling techniques, and a complementarity relationship model based on the Advection-Aridity approach are presented. In Chapter 5 and 6, research results and pertinent discussions are presented, while Chapter 7 is the summary and conclusion of the major research findings.

2 RECENT DEVELOPMENTS

2.1 Introduction

Evapotranspiration (ET) is used to describe two processes of water loss from surfaces- evaporation and transpiration. Globally, ET returns about 60% of precipitation to the atmosphere (Brutsaert, 1982), and close to 90% of the water flowing through a river basin may be used in evapotranspiration processes in the tropics (Jensen, 1990). Although ET is one of the most important components of the hydrological cycle, it probably remains, the most poorly understood. The basic definitions and brief description of the ET processes and the influencing factors presented here are based largely on FAO 56 (Allen et al., 1998)

2.1.1 Basic definitions

Evaporation

Evaporation is the process whereby liquid water is converted to water vapor and removed from the evaporating surface. Where the evaporating surface is the soil surface, the degree of shading of the plant canopy and the amount of water available at the evaporating surface are other factors that affect the evaporation process.

Transpiration

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere. Plants predominately lose their water through stomata. These are small openings on the plant leaf through which gases and water vapor pass.

Evapotranspiration

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. When the plant is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. The following definition relevant to this study can be given as:

Potential *Evapotranspiration:* The evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and never short of water (Penman, 1948)