1 GENERAL INTRODUCTION

1.1 Introduction

According to de Sherbinin (2002), land-use is the term that describes human uses of the land, or immediate actions modifying or converting land cover. It includes human settlements, protected areas and agriculture. In this study, the term land-use refers to agricultural activities (extension of cropland), transhumance (livestock extension), wood extraction and the subsequent attributes (clearing of the vegetation, overgrazing and bush fire). Land-use intensity is used for comparison purposes, and it is the degree of exploitation that characterizes a particular site in the same agro-ecosystem.

Land-use is the major cause of the widespread decline of the vegetation cover in West Africa, especially in the Volta Basin, resulting from the slash-and-burn practice or shifting cultivation (Duadze, 2004). It is also the main factor affecting the hydrological cycle in the Volta Basin (Andreini et al., 2000). In West Africa, especially in Burkina Faso, economic motivations and government policies stimulate people to cultivate the land in order to increase agricultural production. This has been achieved by an expansion of the cultivated area as well as by higher productivity per hectare. The need for new agricultural land was a strong argument for the extensive clearing of natural vegetation (Ungaro et al., 2004). The situation in the White Volta River (sub-basin of Black Volta) illustrates this widespread environmental problem. According to Mahe et al. (2005), the natural vegetation in the White Volta basin declined from 43 % to 13 % of the total basin area between 1965 and 1995, the cultivated areas being increased from 53 % to 76 %, and the area of bare soil nearly tripled from 4 % to 11 %.

However, it has been widely recognized that the vegetation plays an important role in the modulation of the earth's climate and hydrological system (Dale, 1997). The changes in the vegetation cover have potential effects on the local and global environment with regard to the increase in the concentration of atmospheric carbon dioxide, changes in temperature and precipitation, loss of biodiversity, increased runoff and flooding, soil erosion, watershed process and to the biogeochemical cycles (Helmer et al., 2000). Similarly, the morphology of the vegetation influences the amount of absorbed incoming shortwave radiation as well as the aerodynamic resistance affecting the turbulence exchanges of momentum, heat, and moisture. Also, changes in the vegetative cover are associated with changes in the vegetation physiology, which could alter the surface fluxes in the absence of other forcing factors and consequently the climate both at regional and global scales (Dale, 1997; Bounoua et al., 2002). To prevent an exhaustive utilization of natural resources and agricultural land in the Volta basin, a project was initiated entitled: *Impact of changing land cover on the production and ecological functions of vegetation in inland valleys in West Africa (VinVal).* The overall objective of this project was to develop a tool for integrated land-use planning at a watershed scale to improve the sustainable agricultural production systems. This tool should take into account the balance between production and protection objectives and should assist in making informed decisions on allocation of land-use activities of smallholder farmers across the watershed on both agricultural and natural land. Such decisions are based on knowledge of the productive value of these land-use activities and their impact on ecological functions. With this purpose, an accurate knowledge of the seasonal dynamics of surface fluxes introduced by agricultural activities is necessary. Therefore, the first focus of this research was*:* How does the land-cover change coupled to seasonal farming activities affect actual evaporation (E)? The relevance of this question finds its response in the fact that E is an important component of the ecosystem water balance and strongly related to the gross ecosystem production in terrestrial vegetation (Law et al., 2001). According to Oguntunde (2004), E is responsible for 70 % of the lateral global energy transport and plays an important role in the redistribution of water on the earth's surface (Mauser and Schädlich, 1998). Consequently, its quantification is critical for water resources management, and its accurate estimation is a basic tool for computing the water balance (Pereira et al., 1999). E is also needed in the evaluation of energy partitioning, which is an important part in the understanding of the link between the surface energy balance and climate in a given environment. However, despite the importance of E, understanding of its process in tropical zones is less advanced than in temperate regions. In general, the models available for the estimation of E are calibrated for the temperate regions, where the feedback mechanisms in the boundary layer are related to the soil wetness. For the tropical zones, especially for the savanna regions, these feedbacks are more related to the way the vegetation releases water into the atmosphere (Schüttemeyer, 2005). Similarly, the effect of land-use on E is obvious, but there is no real assessment available on that issue in West Africa, where competition for water resources is very high.

Understanding the process of the actual evaporation is also an integral part of the objective of the GLOWA-Volta project, which aims to *analyze the physical and socio-economic determinants of the hydrological cycle and to develop a scientifically sound decision support for the assessment, sustainable use and development of water resources in the Volta Basin* (van de Giesen et al., 2002). This objective involves the understanding of the biosphere-atmosphere interactions considering the effect of the climate on the ecosystem functions and the potential feedbacks of the land surface to the physical climate (Oguntunde, 2004). The eco-hydrological models, which require a spatial and a temporal quantification of the surface fluxes, are relevant for this purpose.

Land-use impacts also surface runoff and its process. Removal of the vegetation from the watershed can result in a significant increase in the surface runoff because of the decrease in the interception of rainfall by the tree canopy as well as greater surface sealing. The phenomenon is obvious in West Africa where, in spite of the decline in the annual rainfall, increasing surface runoff is observed at the outlet of the major gauged basin (Mahe et al., 2005). However, as in all research fields, hydrological research in West Africa is less advanced than the other regions of the world, and the studies on the surface runoff are limited to the empirical formulas that relate the watershed characteristics to one characteristic of the flow at the watershed outlet (e.g. van de Giesen et al., 2000). The most important of these studies are those on the average yearly outflow or the 10-year peak flow (Rodier and Auvray, 1965; Rodier, 1976; Puech and Chabi-Goni, 1984). The empirical formulas are more oriented on the engineering purposes and are not relevant for water resources management. Recently, some physically based approaches have been applied in Côte d'Ivoire, Burkina Faso, Ghana (van de Giesen et al., 2000; Ajayi, 2004) related to the scale effect on surface runoff and more oriented towards water resources management at field level. These studies showed that not all the water that can be observed on the surface during a rainstorm reaches the bottom of the slope. This scale effect is found to be related to the spatial variability of soil physical properties (Julien and Moglen, 1990) and the temporal dynamic of rainfall intensity (van de Giesen et al., 2000). Actually, there is an increasing interest of researchers to understand this effect, because the water redistribution across the watershed is particularly important for agricultural water management. If the scale effect is pronounced, only some part of the watersheds needs to be protected, i.e, mainly the lower part. In contrast, if the scale effect is negligible, all parts of the watershed contribute to the surface runoff and the whole watershed needs to be managed (van de Giesen et al., 2004). The handling of the scale effect on surface runoff in land-use planning can contribute substantially to both reducing the cost of watershed management and to maintaining the soil quality. Therefore, the second focus of this research contributes to the study of the scale effect. The findings can be regarded as a contribution to a better understanding of the role of the vegetation cover in pronouncing the scale effect. It could also be a good argument for decision-makers for preventing an extensive clearing of vegetation.

In this research, we use the measurement of surface fluxes and automatic weather data (from May 2003 to November 2004), a field based measurement of the surface runoff at the plot and on the watershed scale, and other complementary measurements to achieve the objectives. When compared to Sahelian Energy Balance EXperiment (SEBEX) (Sellers et al., 1996) and Hydrological and Atmospheric Pilot Experiment-Sahel (HAPEX-Sahel) (Goutorbe et al. 1997), this study is the first long-term eddy covariance measurement ever reported in the savanna zones of West Africa The study will help to understand the energy partitioning in the savanna, and the results can be easily extrapolated to other areas of the region, since they all share similar agro-ecosystem.

The specific objectives are:

1. To investigate the energy balance closure over *Vitellaria paradoxa* (sheanut tree), over the *Sorghum vulgare* (sorghum) and maize;
2. To investigate the surface fluxes and to develop new alternative models for the estimation of the actual evaporation on a monthly time step;
3. To quantify the roughness length for momentum and the effect on the land surface models on a seasonal basis and on a daily basis;
4. To measure *in situ* and model surface albedo for sheanut trees and sorghum;
5. To investigate the scale effect on surface runoff in the savanna zone under a monomodal rainfall pattern and to show the influence of vegetation cover on this process.

1.2 Research justification

This research finds its justification in the scarcity of micrometeorological and hydrological studies in the savanna zones of West Africa as compared to the temperate regions. With respect to the micrometeorological studies, the only available documentations and serious research are the SEBEX project and the HAPEX-Sahel project. These studies are limited in time and space and give a partial insight into the dynamics of the surface fluxes in the savanna vegetation. According to Oguntunde (2004), recent research on improving the representation of the land-surface-atmosphere interactions within General Circulation Models (GCMs) led to the investigation of a wide variety of the different Soil-Vegetation-Atmosphere Transfer (SVAT) schemes. Forty-four different SVAT models were identified with the majority of them are calibrated to temperate zones. Similarly, most of the SVAT models failed to simulate the dynamics of the surface fluxes in the savanna zone, because the feedback mechanisms in the boundary layer in temperate zones to which the models were run are completely different to those in savanna zones (Schüttemeyer, 2005). Therefore, pertinent to the objective of the VinVal and GLOWA-Volta projects, there was a need for a long-term investigation of the savanna surface fluxes to improve the limited knowledge of the effect of land-use on surface fluxes, especially on actual evaporation. Beyond local application, the research will also improve our understanding of the role of savanna vegetation in the regional and the global climate circulation.

Similar to micrometeorological studies, hydrological studies, especially of surface runoff, are less advanced in tropical zones than in temperate zones (van de Giesen et al., 2000). In the particular case of West Africa, rough empirical formulas based on the research of ORSTOM and CIEH (Valentin, 1981; Albergel, 1987) are appear in the literature with respect to surface runoff. These empirical formulations were designed for large-scale estimation of the surface runoff in time and space and for engineering purposes. These empirical formulations do not have explicit representation of scale effect on surface runoff or are not an integrant part of the process of the surface runoff. Therefore, there was a need to show the relevance of scale effect on surface runoff in the savanna zone. This will be useful for an accurate representation of the scale on surface runoff effect in model of the savanna zone of West Africa.

1.3 Thesis outline

This report is divided into eight chapters. Chapter 2 focuses on the general descriptions of the study area, energy fluxes and actual evaporation as well as surface runoff. The first specific objective is investigated in Chapters 3 to 6, while the second objective is investigated in Chapter 7. Chapter 3 shows the quality and the representativeness of the data by the energy balance closure and the footprint analysis. Chapter 4 describes the inter-annual energy partitioning and the implication on the estimation of the actual evaporation and surface conductance. Chapter 5 is an extension of Chapter 4 and discusses the effect of the seasonal dynamics of vegetation cover on land surface models, while Chapter 6 focuses on surface albedo measurements and modeling for sheanut nut trees and sorghum canopies. Chapter 7 focuses on the study of the scale effect on surface runoff under different land-use conditions. The Final conclusion summarizes and discusses the main results of the study. Chapters 3 to 7 are each presented as articles and include the respective methodology and results.

2 GENERAL DESCRIPTION OF METHODS AND MATERIALS

2.1 Description of the study area

According to the selection criteria required to meet the overall objective of the VinVal project, three small watersheds were selected in the province of Kompienga (10°55&11°55 N-01°25&01°23 E). These watersheds were in the same agro-ecosystem and showed a gradient of agricultural land-use intensity from high (Tanyele), medium (Bounou) to no agricultural land-use with natural vegetation (Sambouali). All watersheds covered an area of about 10 km^2 (Kabore et al., 2003). Figure 2.1 shows the location of the watersheds.

These two major land-use types were practiced in these watersheds: Agriculture activities were carried out by the local communities (Gourmantche and Mossi) during the rainy season, especially in Tanyele and Bounou, and in all watersheds transhumance was practiced by shepherds (Fulani). The crops were rain-fed crops such as sorghum, millet, maize, sesame and cotton. The population living in the watersheds was about 765, 706 and 330 in Tanyele, Bounou and Sambouali, respectively (Diallo et al., 2002).

2.1.1 Climate and vegetation

According to the phytogeographical classification of White (1983), the south-east region of Burkina Faso belongs to the Sudan climate zone. For the study area, the annual precipitation lies between 900 and 1000 mm (Kabore et al., 2003). A rainfall peak was observed between May and October with another pronounced peak in August or September. Temperatures are very high with a peak of about 40 °C in March-April. Lower temperatures were observed in August and between December and January (22 °C on average). The region is characterized by the *Vitellaria paradoxa* tree, which dominates the vegetation cover. Other important trees are *Parkiia biglobosa*, *Andansonia digitata*, and *Anea microcarpa*. The fallow land are dominated is *Combretum micrantum* and the herbaceous stratum by *Androogon gayanus*, and *Penninsetum pedicelatum.*

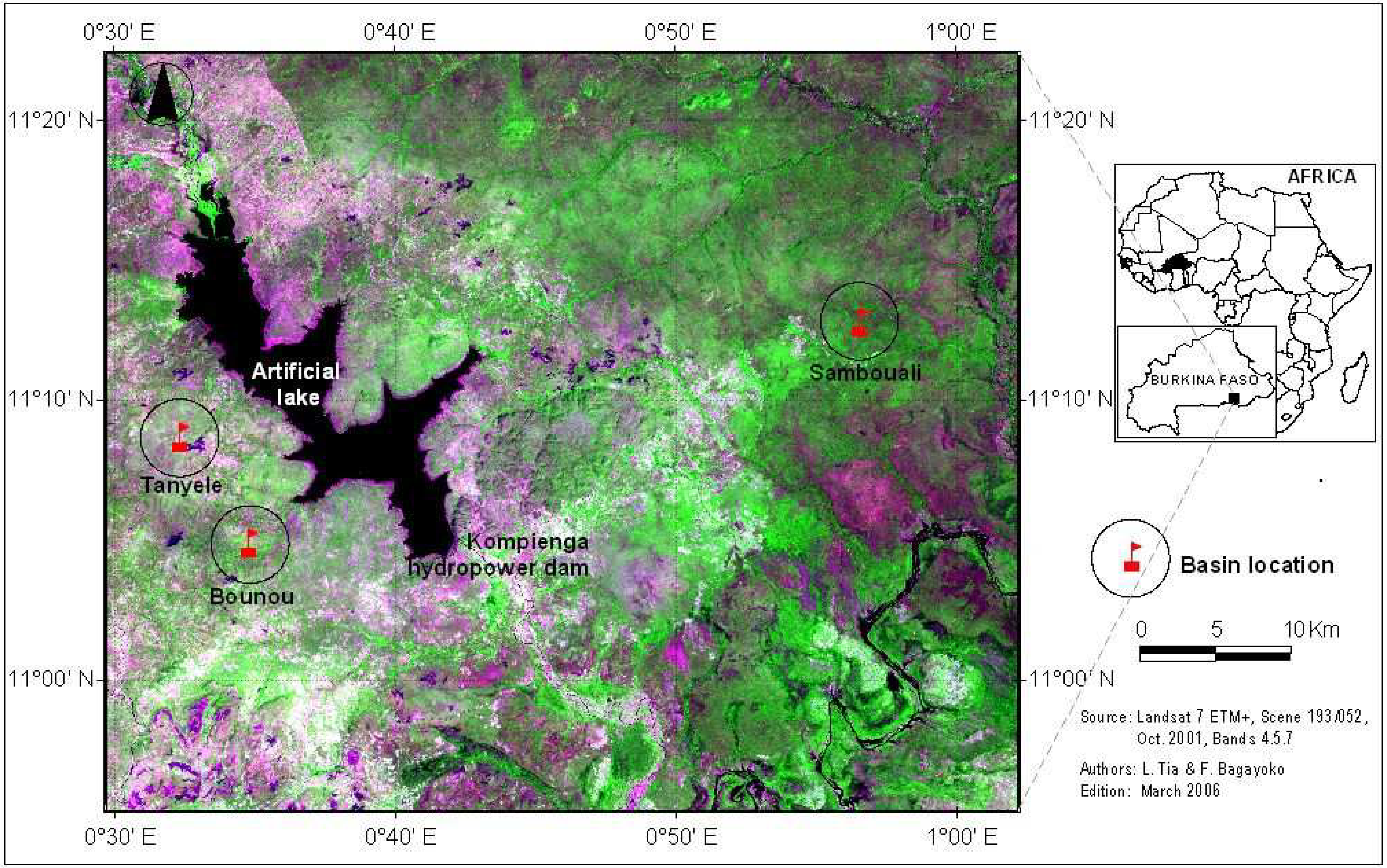

Figure 2.1: Location of the experimental sites: Tanyele (high land-use intensity); Bounou (medium land-use intensity); Sambouali (without agricultural land-use and covered with natural vegetation)

2.1.2 Geology, soil and land cover

In all the watersheds, the up-land and the low-land are characterized by breastplate mounds and some emergent granite rock formations, which mark their crests. The terrains are flat (slope ≤ 3 ‰) and the main type of soil is Lexisoil (> 60 %) as is true in most of West Africa (Braimoh, 2004). With respect to the soil texture, in Tanyele, the soil consists of sandy loam (71 % sand, 24 % silt and 5 % clay), in Bounou of loam (34 % sand, 48 % silt and 16 % clay) and in Sambouali of clay loam (25 % sand, 47 % silt and 28 % clay). Tables 2.1 and 2.2 show the major types of soil and land cover in each watershed.

Table 2.1: Soil types and the relative percentage in each watershed

Soil type	Tanyele (%)	Bounou (%)	Sambouali (%)
Lexisoil	63	46	63
Gleysoil	31	0	6
Cambisoil	0	45	23
Marginal soil	6	9	6

Source: Kabore et al. (2003)

Table 2.2: Land cover types and their relative percentage in each watershed

Landcover type	Tanyele (%)	Bounou (%)	Sambouali (%)
Farm land	20	18	0
Shrub land and old fallow	76	72	41.5
Woody savanna	3.5	9.8	58
Herbaceous savanna	0.5	0.2	0.5

Source: Kabore et al. (2003)

2.2 Energy fluxes and actual evaporation

The main energy fluxes used in hydrological modeling are shortwave and longwave radiation, sensible heat, latent heat and ground heat flux. Solar radiation is the main source of shortwave radiation, while longwave radiations are from the reflection process at earth's surface, cloud and fine particles in the atmospheres. Sensible heat (H) and ground heat flux (G) are related to the heat transfer resulting from the temperature gradient between two surfaces (Clark et al., 1989). Sensible heat transfer occurs between an evaporating surface (free water surface, soil surface and vegetation) and the atmospheric overhead, while the ground heat flux is the result of a difference in temperature between two regions in the soil. If the evaporating surface is warmer than