Available online at www.sciencedirect.com
ScienceDirect
Physics and Chemistry of the Earth 31 (2006) 1048–1061
PHYSICS and CHEMISTRY of the EARTH
www.elsevier.com/locate/pce

Assessment of overland flow variation and blue water production in a farmed semi-arid water harvesting catchment

I. Mekki [a,*], J. Albergel [b], N. Ben Mechlia [c], M. Voltz [d]

[a] *Institut National de Recherches en Génie Rural, Eaux et Forêts (INRGREF), B.P. 10, 2080 Ariana, Tunisia*
[b] *IRD, Laboratoire d'études des Interactions Sols-Agrosystèmes-Hydrosystèmes, UMR LISAH AgroM-INRA-IRD, 2 place Viala, 34060 Montpellier, France*
[c] *Institut National Agronomique de Tunisie (INAT), 43 Avenue Charles Nicolle, 1080 Tunis, Tunisia*
[d] *INRA, Laboratoire d'études des Interactions entre Sol-Agrosystèmes-Hydrosystèmes, UMR LISAH AgroM-INRA-IRD, 2, place Viala, 34060 Montpellier, France*

Received 10 October 2005; accepted 6 July 2006
Available online 17 October 2006

Abstract

Upgrading agriculture in semi-arid areas and ensuring its sustainability require an optimal management of rainfall partition between blue and green waters in the farmed water harvesting catchment. The main objective of this study is to analyze the influence of heterogeneous land use on the spatial and temporal variation of rainfall partitioning and blue water production within a typical farmed catchment located in north-eastern Tunisia. The catchment has an area of 2.6 km^2 and comprises at its outlet a dam, which retains the runoff water in a reservoir. Overland flow and soil water balance components were monitored during two cropping seasons (2000/2001 and 2001/2002) on a network of eleven plots of 2 m^2 each with different land use and soil characteristics. The hydrological balances of both the catchment and reservoir have been monitored since 1994.

Observed data showed a very large temporal and spatial variability of overland flow within the catchment reflecting the great importance of total rainfall as well as land use. During the 2001/2002 season the results showed a large variation of the number of observed runoff events, from 27 to 39, and of the annual overland flow depths, from 8 mm (under vineyard on calcaric cambisols) up to 43 mm (under shrubs-pasture on haplic regosols), between the plots. The annual runoff amounts were moderate; they always corresponded to less than 15% of the annual rainfall amount whatever the observation scale. It was also observed that changes in land use in years with similar rainfall could lead to significant differences in blue water flow. An attempt for predicting the overland flow by the general linear regression approach showed an r^2 of 31%, the predictors used are the class of soil infiltration capacity, the initial moisture saturation ratio of the soil surface layer and the total rainfall amounts.

These experimental results indicate that the variation in land use in a semi-arid catchment is a main factor of variation in soil surface conditions and explain the major role played by the former on hydrological behavior of the upstream area and on rainfall partition between overland flow and infiltration. Therefore, to predict the water harvesting capacities in terms of blue water production of a farmed catchment in semi-arid areas it seems essential to consider precisely its land use and its temporal evolution related to management practices.

Keywords: Overland flow; Farmed water harvesting catchment; Blue water production; Spatial and temporal variation; Semi-arid

1. Introduction

Water harvesting systems, used to overcome water scarcity and improve water productivity in rainfed agriculture in arid and semi-arid climates throughout the world, have ancient roots (El Amami, 1977; Oweis et al., 1999). They

* Corresponding author. Tel.: +216 71 719 630; fax: +216 71 717 951.
E-mail address: mekki.insaf@iresa.agrinet.tn (I. Mekki).

1474-7065/$ - see front matter
doi:10.1016/j.pce.2006.07.003

are still of interest. As an example, many hundreds of hill reservoirs have been constructed recently in northern and central Tunisia (Albergel and Rejeb, 1997). Apart from limiting erosive fluxes downstream, their main aims are to collect surface runoff water, that is lost from the upstream cropping systems and catchments, and to store this water for either developing fully irrigated crops or providing supplemental irrigation for dry spell mitigation. Water harvesting systems produce so-called blue water, which corresponds to water in liquid form that is at atmospheric pressure and "economically usable" (Cosgrove and Rijsberman, 2000). This nomenclature was introduced by Falkenmark (1995), who in complement named as "green" water the part of precipitation that is stored initially in the unsaturated zone of the soil and lost by evapotranspiration.

Upgrading agriculture in semi-arid areas and ensuring its sustainability will require an optimal management of rainfall partitioning between blue and green water in the farmed catchment-hill reservoirs. Both kinds of waters are important for sustainable farming. On one hand, green water is the main component of the water balance in semi-arid areas (e.g. Yu et al., 2000; Flerchinger and Cooley, 2000; Gerten et al., 2005) and is a basic resource for crop evapotranspiration. It directly stems from the local infiltration of rainfall into the soil and, consequently, does almost not require any specific energy expense from the farmer. However, as estimated by Savenije (2000), its average residence time is 5 months, which is not enough to allow for mitigating the effect of long dry periods. On the other hand, blue water requires energy for its reuse as irrigation water, whether supplemental or not. But, given its much larger residence time, 2.7 years on average after Savenije (2000), it may be used to reallocate water from periods without or with small water shortage to periods with intense water scarcity, which helps to decrease the risk of complete crop failure. Depending on the climate, soils and topography, these average residence times can vary significantly at the local scale Savenije (2000). There is therefore a need to define and manage the best balance between green and blue water resources for sustainable farming systems. This is also essential because the processes generating green and blue waters are closely linked. It is rather obvious that increasing upstream green water resources by maximizing rainfall infiltration through adapted farming systems may limit the downstream production of blue water and vice versa. As stressed by Savenije (2000), not much information about the respective importance of blue and green water exists over medium sized catchments.

Land use is a major instrument through which blue and green water can be manipulated. It is known to largely influence the partition of rainfall into overland flow and infiltration (e.g. Albergel, 1987; Voltz et al., 1997; Lasanta et al., 2000; Moussa et al., 2001; Falkenmark, 2001; Fohrer et al., 2002; Niehoff et al., 2002; Dunjó et al., 2003; Kauffman and Lynden, 2004; Chahinian et al., 2005). In other words, land use may be seen as a "driver" of green and blue water production. However, apart from modelling approaches that simulated the influence of land use at catchment scales there are not many experiments that observed its influence over whole cropping seasons.

In this paper, we present and analyze in situ observations of the variation of overland flow and blue water production that arise from soil and land use patterns in a typical semi-arid farmed catchment-hill reservoir in north-eastern Tunisia. The specific objectives of this work were (i) to assess the magnitude of the influence of land use and soil characteristics on overland flow, (ii) to determine the main factors controlling the observed variations, and (iii) to analyze the relationships between overland flow patterns and blue water production at the catchment scale.

2. Study site and experimental design

2.1. Study site and climate characteristics

The studied water harvesting system was the Kamech catchment-hill reservoir (10°52′14.3E, 36°52′03.8N), in the hilly zone (elevations ranging from 100 m to 200 m) of the peninsula of Cap Bon, north east of Tunisia. It belongs to a long-term environmental research observatory called OMERE (Mediterranean observatory of water and rural environment) which aims at studying the anthropogenic impacts on catchment hydrology and water quality. The catchment exhibits an area of 2.6 km^2 and its associated reservoir has an area of 3.7 ha with a storage capacity at construction of about 145 000 m^3 which corresponds to about 60 mm of water if distributed over the upstream area. The climate is of semi-arid mediterranean type with a hot and dry summer and a mild and rainy winter season. Average annual precipitation is 450 mm (averaged over 90 years at the nearest station meteorological located about 30 km away at Kelibia). The annual precipitation at the Kamech site ranges from 400 to 600 mm in most of the years, and it reached up to 1000 mm during rainy years, e.g. 1995–1996. Rainfalls mainly occur from October to April while the main dry season lasts from May to September. Average annual potential evaporation is 1500 mm.

2.2. Soils characteristics

The soils in the catchment are developed from a succession of marl layers and associated to a very thin sandstone layers (Collinet and Zante, 2001). Four major soil types were distinguished and mapped according to the FAO classification (FAO, 1998). Three of the four soil classes, namely Luvisols, Cambisols and Vertisols, are mostly covered by annual crops, whereas the fourth class, Regosol, is more commonly associated with pasture and shrubs. Rock outcrops coincide with ridges. The major physical characteristics of the four soil classes and of their subclasses can be seen in Table 1. Soil textures are very variable ranging from clay to sandy loam according to USDA textural triangle (Soil Survey Staff, 1998) with clay contents varying