Physics and Chemistry of the Earth 61–62 (2013) 1–11

Contents lists available at SciVerse ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

# Evaluating watershed service availability under future management and climate change scenarios in the Pangani Basin

Benedikt Notter [a,*], Hans Hurni [a], Urs Wiesmann [a], James O. Ngana [b]

[a] Department of Integrative Geography, University of Bern, Hallerstrasse 10, 3012 Bern, Switzerland
[b] Institute of Resource Assessment, University of Dar es Salaam, P.O. Box 35097, Mlimani, Dar es Salaam, Tanzania

ARTICLE INFO

*Article history:*
Available online 3 September 2012

*Keywords:*
Watershed services
East Africa
Modeling
Soil and Water Assessment Tool
Scenarios

ABSTRACT

Watershed services are the benefits people obtain from the flow of water through a watershed. While demand for such services is increasing in most parts of the world, supply is getting more insecure due to human impacts on ecosystems such as climate or land use change. Population and water management authorities therefore require information on the potential availability of watershed services in the future and the trade-offs involved.

In this study, the Soil and Water Assessment Tool (SWAT) is used to model watershed service availability for future management and climate change scenarios in the East African Pangani Basin. In order to quantify actual "benefits", SWAT2005 was slightly modified, calibrated and configured at the required spatial and temporal resolution so that simulated water resources and processes could be characterized based on their valuation by stakeholders and their accessibility. The calibrated model was then used to evaluate three management and three climate scenarios.

The results show that by the year 2025, not primarily the physical availability of water, but access to water resources and efficiency of use represent the greatest challenges. Water to cover basic human needs is available at least 95% of time but must be made accessible to the population through investments in distribution infrastructure. Concerning the trade-off between agricultural use and hydropower production, there is virtually no potential for an increase in hydropower even if it is given priority. Agriculture will necessarily expand spatially as a result of population growth, and can even benefit from higher irrigation water availability per area unit, given improved irrigation efficiency and enforced regulation to ensure equitable distribution of available water. The decline in services from natural terrestrial ecosystems (e.g. charcoal, food), due to the expansion of agriculture, increases the vulnerability of residents who depend on such services mostly in times of drought. The expected impacts of climate change may contribute to an increase or decrease in watershed service availability, but are only marginal and much lower than management impacts up to the year 2025.



## 1. Introduction

Watersheds offer a range of ecosystem services to people living within and outside their boundaries. The most obvious are the provision of water for basic human requirements such as drinking, domestic purposes or subsistence farming, but also commercial interests such as large-scale agriculture. Water sustains vegetation used for fuelwood or for producing building materials and other goods. In many watersheds, electric power sustaining national economies is produced from river flow. Water bodies often play an important role in cultural identity, and landscapes formed by water offer places for recreation (Landell-Mills and Porras, 2002; Millennium Ecosystem Assessment, 2003, 2005; Porras et al., 2008).

"Ecosystem services" are defined as "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005); services associated with the flow of water through a river basin are often summarized as "watershed services" (Landell-Mills and Porras, 2002; Porras et al., 2008). To represent an ecosystem service according to the above definition, water and the processes affecting it must be valued by humans as a benefit for a certain purpose, and the service provided must be accessible by the humans valuing it (Notter et al., 2011). For example, excess flow during the rainy season, or water flowing in a stream too far to reach may not be valuable for domestic purposes or farming, but

* Corresponding author. Address: Hallerstrasse 10, 3012 Bern, Switzerland.
*E-mail addresses:* bnotter@gmx.ch (B. Notter), hans.hurni@cde.unibe.ch (H. Hurni), urs.wiesmann@cde.unibe.ch (U. Wiesmann), jngana@ira.udsm.ac.tz (J.O. Ngana).

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http://dx.doi.org/10.1016/j.pce.2012.08.017

it can be valued for its role in sustaining ecosystem functions and species; on the other hand, the water amount in a stream during the dry season, within the reach of stakeholders, is valued for domestic and farming purposes as well as for sustaining ecosystems (Notter, 2010). Assessing "benefits" or "services" therefore requires spatially and temporally explicit information on the location and timing of processes, as well as information on their valuation by stakeholders.

The rapid global changes in the last decades, such as population and economic growth and increased per capita consumption, have raised the demand for watershed services in most parts of the world (World Water Assessment Programme, 2009). At the same time, the rate at which humans influence ecosystems providing the services has also increased, so that the supply side becomes more and more complex to predict and therefore insecure. Climate change with its uncertain impacts on water resources contributes to this tendency (IPCC, 2007a,b). Arid and semi-arid regions, including most of the African continent, are expected to be among the most affected (Hulme et al., 2001).

Against this background, people and water management authorities need to be able to plan ahead and set the right priorities in order to avoid or minimize scarcity of watershed services. Numerous hydrological assessments have used scenarios to quantitatively predict potential future availability of water under given conditions (e.g. Notter et al., 2007; Abbaspour et al., 2009; Wei et al., 2009; Yang et al., 2009; Mahmoud et al., 2011; Pfister et al., 2011) and thus inform the public about possible outcomes of management decisions. However, few studies have explicitly included the influence of the timing and the location of water availability and associated processes on their valuation by stakeholders, in order to make quantitative predictions on the availability of actual benefits people may obtain from watersheds in the future.

The aim of this study is to evaluate potential future watershed service availability in the 43,000 km$^2$ Pangani Basin in East Africa using the SWAT hydrological model (Soil and Water Assessment Tool, Arnold et al., 1998; Gassman et al., 2007). SWAT has been successfully applied on the African continent in various studies (e.g. Andersson et al., 2009; Betrie et al., 2011; Easton et al., 2010; Ndomba et al., 2008; Schuol et al., 2008), however mostly either at low spatial resolution, or for small-scale assessments. In order to make quantitative predictions on watershed services for a relatively large basin, SWAT had to be slightly modified, configured and calibrated at the required spatial and temporal resolution, in order to be able to characterize water resources based on their valuation by stakeholders for different purposes as well as their accessibility. The model calibration and setup process is summarized in Section 3.2; further details, as well as results on watershed service availability around the year 2000, are given in Notter et al. (2011). Here we use the calibrated model to evaluate the impacts of three management and three climate change scenarios for the year 2025, and compare watershed service availability in the Pangani Basin under these scenarios to the conditions around the year 2000. Since observed water quality and sediment yield data were unfortunately not available to calibrate the respective SWAT parameters in the Pangani Basin (Notter et al., 2011), some watershed services like water purification and erosion control have are not covered by this study. The model and the calibration procedure would however allow to do so, once observed data for calibration of water quality parameters and sediment yield become available.

## 2. The study area

The Pangani Basin covers roughly 43,000 km$^2$ between Kilimanjaro and the Indian Ocean in East Africa (Fig. 1). The Tanzanian Regions of Arusha, Kilimanjaro, Tanga and Manyara constitute about 95% of its area, and the remaining 5% belong to the Kenyan Taita-Taveta District.

The humid mountain ranges in the Northern and Eastern part of the Basin contribute most of the discharge in perennial rivers (Ngana, 2001). The surrounding lowlands have a semi-arid climate. Crops such as coffee, bananas, maize, flowers, sugarcane, or rice, are mostly cultivated on the mountain slopes and footzones, or in irrigation schemes in the river plains. Hydropower plants along Pangani River provide a significant share of Tanzania's electricity demand; the Nyumba ya Mungu reservoir, located in the center of the basin, regulates river flow for that purpose. The Upper Basin (upstream Nyumba ya Mungu) ranges among the economically most productive areas of Tanzania, with growing large-scale agriculture and industries, partly fueled by foreign investment (IUCN, 2003). In many areas of the basin, however, subsistence agriculture is the dominating income, and large parts of the population rely on natural ecosystems for fuelwood, building materials, and as complementary income and food source in times of scarcity (Turpie et al., 2005).

Already at present, water resources are perceived as scarce in the basin. The growing water demand increasingly leads to conflicts between water users (Mujwahuzi, 2001). The authority responsible for water management in the basin, the Pangani Basin Water Office (PBWO) lacks information and resources to effectively enforce regulations and resolve conflicts (IUCN, 2003). Apart from the conflicts between water users at the local scale, conflicts between development goals at the national level also become apparent. The Tanzania government's declared goals of securing domestic water supply for the entire population, fighting poverty by intensifying agriculture, fostering foreign investments in the agricultural sector, and increasing power production to help the national economy grow, all imply an increased water demand (IUCN and PBWO, 2008; United Republic of Tanzania, 2002a,b). Therefore, trade-offs will be inevitable.

## 3. Materials and methods

### 3.1. Input data

For setup and calibration of the SWAT model, spatial and hydrometeorological data of the Pangani River Basin were required. Spatial data used for model setup included the digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM) data (Farr et al., 2007), a drainage network (constructed from a spatial layer obtained from the University of Dar es Salaam and the SRTM DEM, see Notter et al., 2011), the FAO Africover land cover dataset from 1997, and a combination of the FAO soil maps for North-Eastern (Kenya) and Southern (Tanzania) Africa (Dijkshoorn, 2003; FAO, 1997). These spatial inputs were spatially corrected and aligned to each other based on the GeoCover2000 satellite image, (Earth Satellite Corporation, 2004) which was also used to identify irrigated areas. Rainfall, daily minimum/maximum temperatures, as well as river and spring flow data were obtained from the University of Dar es Salaam and the Ministry of Water.

Information about stakeholders of watershed services, their preferences, number, and their spatial distribution, were collated from census data obtained in raw format for the year 2002, as well as at District resolution for the year 1992, for the Tanzanian part of the basin, and at Sublocation resolution for the year 1999 for the Kenyan part of the basin; from the Household Budget Survey and the Agricultural Sample Census data from the year 2002 for Tanzania; from GIS layers of settlements, roads, obtained from the University of Dar es Salaam and the Tanzanian and Kenyan national statistics bureaus; from the PBWO water rights database; and various reports on socio-economy and water use in the basin