Catena 115 (2014) 104–114

Contents lists available at ScienceDirect

Catena

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

Assessment of water resources availability and demand in the Mara River Basin

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ARTICLE INFO

Article history:
Received 21 March 2013
Received in revised form 4 October 2013
Accepted 27 November 2013

Keywords:
Water demand
Mara River
Water availability
SWAT
Irrigation

ABSTRACT

A simple model was developed to assess space–time relationships of water resource availability and demand in data limited watersheds. The model used a defined index method to evaluate water resource status with respect to anticipated demands. Input data requirements and data processing steps and strategies were discussed. The model takes outputs from a hydrologic system model and demand estimates and compares supply–demand relationships on the basis of expected percentage of demand satisfaction for the basin of interest. Space–time matrices were used to display results of the model for ease of understanding and decision making. The model was customized and applied for the Mara River Basin (MRB) to assess water resource availability and demand. Assessment of water resources in blocks of water use using indicators of the growing water demand among competing sectors threatening the sustainability of communities and ecosystems in the basin. The spatial and temporal distribution of water resources and the corresponding demand were quantified. Twelve distinct sub-basins were defined in the basin and their water availability was assessed based on long term rainfall-runoff simulation using the Soil and Water Assessment Tool (SWAT). Water demands from six consumptive sectors were divided into three classes and compared with a corresponding three classes of monthly water availability. Results have shown significant variability of water availability and demand in the MRB. Further study on possible quantitative indicators to redistribute water among stakeholders may assist in improving water management.

1. Introduction

Fresh water resources are finite in space and time. In the face of growing water demand (Vorosmarty et al., 2000), natural river flow is being challenged by land ownership (Pearce, 2004), economic growth (Chong and Sunding, 2006), advances in technology (Bittermann, 2008), legislations (Ansink and Weikard, 2009), political will and social barriers (Lueck, 1995; Mostert et al., 2007). Watershed scale hydrological processes are also being affected by climate and land use change/variability (Xu, 1999). These challenges are felt at varying levels by different watersheds. For example, Paavola and Adger (2006) and Collier et al. (2008) argued that the implications of climate change for Africa are far more severe because of vulnerability of the economy and livelihood to climate variation and limited capacity. Legal, moral, political and other prevailing soft decision inputs compete with economic return of water use making water resource problems not only a demand–supply centered but also complex social and environmental challenges. Syme et al. (1999) reported that the public exercises complex decision procedures in water resource utilization that transcend the sphere of 'traditional social psychological definitions of equity and procedural justice.' Water management is anthropocentric in its nature that ecological demands are treated equally with other demands to their humanly derived benefit (Griffen, 2006). Fair and efficient distribution thrives to use robust techniques to estimate the water availability and demand, setup evaluation tools and feedback mechanism.

The Mara River basin (MRB) has been maintaining the livelihoods of people and renowned biodiversity from the Mau Escarpment in Kenya through Mara–Serengeti protected areas to the flood plains in Tanzania (Fig. 1). MRB presents a delicate balance of water utilization by human settlement and wildlife. Loss of native forest cover (Gereta et al., 2002), climate change (Dessu and Melesse, 2013), agricultural expansion and intensification (Lamprey and Reid, 2004), increasing settlement and human population (Hoffman et al., 2011), growing tourist facilities (Karanja, 2003), and water pollution and abstractions by industries (Majule, 2010) are among the prominent challenges altering the river's hydrologic regime. Mara River has been reported to experience decreasing low flows during the dry season and increasing peak flow in the wet season (Mati et al., 2008), while the quantity of water demanded to sustain livelihoods is increasing (Hoffman et al., 2011).

Dessu and Melesse (2013) applied the Soil Water Assessment Tool (SWAT) (Arnold et al., 1998) to model the hydrology of the MRB using daily observed rainfall and temperature. Investigation of past hydrological regimes of the MRB reported changes in the rainfall-runoff process

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http://dx.doi.org/10.1016/j.catena.2013.11.017

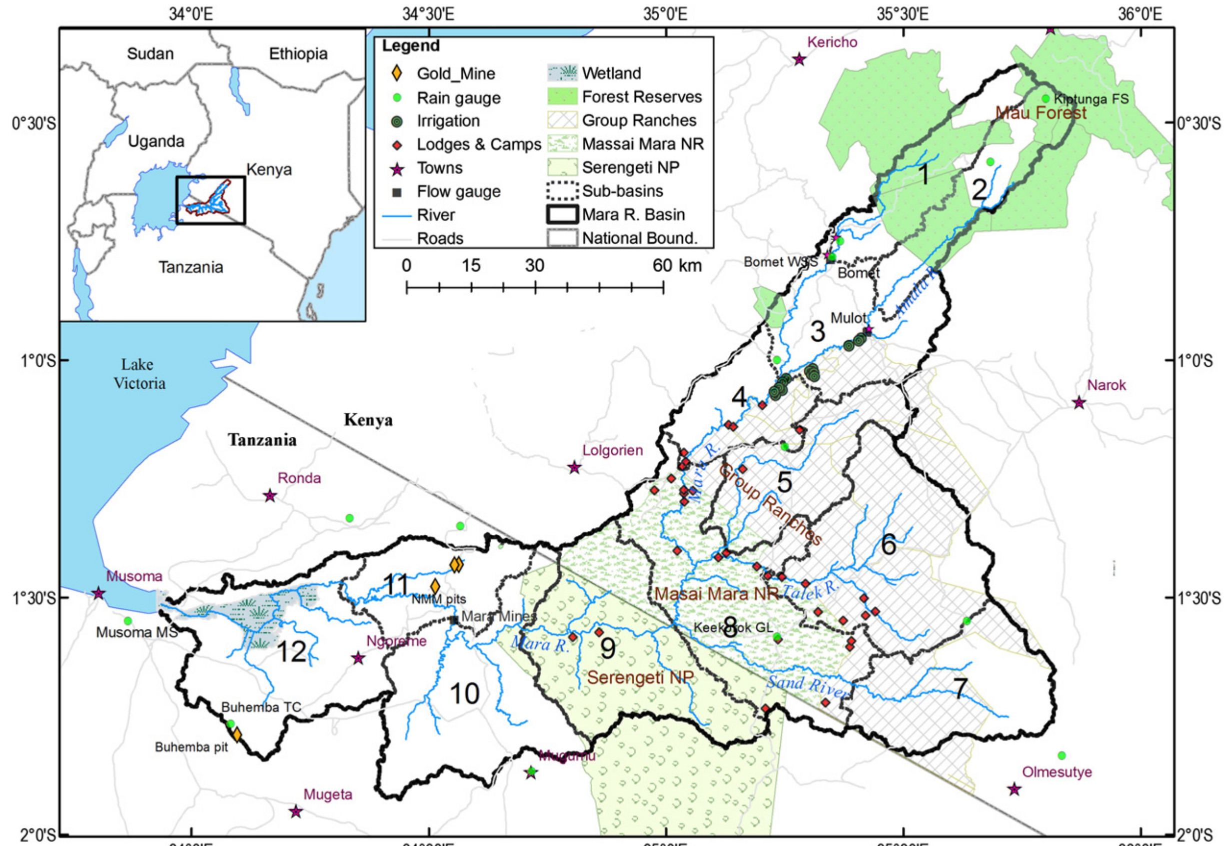

Fig. 1. The Mara River Basin location map with major land use types and distribution of monitoring stations.

and water balance of MRB (Dessu and Melesse, 2012; Mango et al., 2011; Mati et al., 2008). Dessu and Melesse (2013) looked at the hydrologic impact of climate change in the MRB using outputs from diverse Global climate models (GCMs) and showed that the basin is considerably vulnerable and sensitive. Gereta et al. (2002) assessed the impact of a proposed Amala Weir to divert the headwaters of Mara River on the Serengeti ecosystem. Most of the previous findings were either comparisons of basin-wide water availability and demand comparisons (Hoffman et al., 2011) or sector specific water shortage impact studies (Gereta et al., 2002).

A growing demand of the limited water resource over a given hydrological year signals scarcity and higher value. As long as the total demand is less than the available water resource, proper estimation and management of quantity demanded may ensure minimal waste of resource. As the demand starts to exceed the available water, quantitative understanding of the demand–supply relationship may assist to equitably allocate the limited resource among users.

The general objective of this study is to assess the relationship between temporal and spatial distribution of water availability and its corresponding demand in the MRB. Specific objectives of the study are to 1) assess the spatial variability of water resource availability in the MRB, 2) estimate the spatial variability of water demand in the MRB, and 3) identify areas and seasons of surplus/scarcity in meeting the demand. Findings of this study will assist in basin-wide allocation and distribution of the limited water resource among competing demand sectors of the MRB to promote sustainable development. Results may also assist in planning of future water resources development and reducing ecological hazards and social crisis that may prevail in MRB due to water scarcity. The study will also help identify specific sites that may be vulnerable to extreme climate events such as drought in the MRB.

2. Description of the study area

The Mara River drains 13,750 km^2 combined area of south western Kenya and north western Tanzania over a stretch of 395 km length before entering to Lake Victoria (Fig. 1). Livelihood in the MRB relies heavily on the quantity and quality of flow in the Mara River and its tributaries. The major economic activities include farming, livestock husbandry, mining and tourism. Livestock husbandry is the major economic activity of the Massai Tribe (Lamprey and Reid, 2004) living in the group ranches. In Kenya, the Massai Mara accounted for an average of 13% of visitors to Game parks and reserves from 2004 to 2007 with a regional 8% of all tourist bednights in Kenya (KNBS-ES, 2009) and a gross revenue of $20 million (Norton-Griffiths, 1996). The tea plantations, large scale rainfed wheat farms and the commercial irrigation farms at the middle reach of the basin contribute significantly to gross domestic product and food security of Kenya. The exiting forests in the basin contribute to the economy through logging and charcoal burning. The MRB is also known for high grade gold mining at the North Mara Mine (NMM) and Buhemba Mine.

The basin has a bi-modal rainfall distribution driven by the migration of Inter-Tropical convergence Zone. The first and major rain occurs between mid-March and June while the second and relatively intermittent rain is between September and December (Fig. 2). Annual rainfall varies from 1000 to 1750 mm at upstream, 900 to 1000 mm in the middle and 300 to 850 mm at the lower reaches of the river. Surface water occurrence changes from perennial rivers of the upper section (Nyangores and Amala rivers) to occasional in the ephemeral rivers of the west (Talek and Sand Rivers) and the flood plains. The spatial variation in annual rainfall in the basin indicates an orographic effect at the higher altitudes with significant variability across the basin. Amala, Nyangores and Mara Mines flow gauge stations have the longest records. The average annual flows