Journal of Hydrology: Regional Studies 19 (2018) 97–109

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

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

Water resources sustainability index for a water-stressed basin in Brazil

Edson de O. Vieira[a,*], Samuel Sandoval-Solis[b]

[a] Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais, UFMG, Montes Claros, Minas Gerais, Brazil
[b] Dept. of Land, Air and Water Resources, Univ. of California, Davis, CA, USA

ARTICLE INFO

Keywords:
Hydrologic model
Integrated water resources management
Rio Verde Grande
Water management
WEAP model

ABSTRACT

Study region: Rio Verde Grande Basin, Brazil.
Study Focus: Extensive regional development, mainly expansion of irrigated areas and urban population, has resulted in low water availability and caused water conflicts since the 1980s. Therefore, it was necessary to enact the Water Resources Plan of the Rio Verde Grande in 2011. The plan provided actions to improve water availability and meet increased water demand but there have been no studies on the sustainability of these policies. It was evaluated the future of the water management and calculate the sustainability index for water resources in the Rio Verde Grande Basin (RVGB), Brazil.
New hydrological insights for the region: The water demand and available water have been compared and evaluated for activities in the Water Resources Plan (WRP) based on three different improvement of available water scenarios. These scenarios include water imports and the construction of channels and reservoirs. A sustainability index was used to evaluate and compare alternative plans for future water availability and water supply in these scenarios, considering measures of reliability, resilience, vulnerability and maximum deficit. The SI has identified the best scenario foreseen in the WRP for the RVGB that will improve the availability of water through 2030 having positive impact to water users of the basin. The results also indicate that the increase in available water will not result in significant improvements of sustainability of water resources by the implementation of the policies proposed in the WRP for the RVGB.

1. Introduction

The Rio Verde Grande Basin (RVGB) provides significant agricultural production for important cities, such as Montes Claros (400,000 inhabitants), primary through irrigation. Extensive regional development and urban expansion have caused low water availability in regional rivers, causing water conflicts that have been recorded since the 1980s. RVGB presents several problems of water resources as a high variability in time and space of water resources (Many years of the drought), activities that demand a lot of water (as irrigation with 90% of water consuption) and there is almost no infrastructure for water resources. To solve these problems, in 2011, the "Water Resources Plan for the Verde Grande River Basin (WRP)" was approved, which aimed to articulate the instruments of the National Water Resources Policy and propose a series of actions to improve available water in the basin (ANA, 2016a,b). In the Water Resources Plan of the Rio Verde Grande, three scenarios were envisaged for implementing action. Interventions that were already underway, to increase water supply were considered in the Trend Scenario. Based on the Trend Scenario, two other

* Corresponding author.
E-mail addresses: eovieira@ica.ufmg.br (E. de O. Vieira), samsandoval@ucdavis.edu (S. Sandoval-Solis).

https://doi.org/10.1016/j.ejrh.2018.08.003
Received 12 January 2018; Received in revised form 11 July 2018; Accepted 27 August 2018

scenarios were developed, Normative 1 and 2, in which water management leads to successive efficiencies that both increase available water and efficiency of use. However, there have been no studies in the RVGB that evaluate and compare the sustainability of different actions or methods for water management in these scenarios proposed on WRP.

Recently, other countries have placed great emphasis on the adaptability of water resources using measures that reduce the vulnerability of these systems in proposed future scenarios (Cerón et al., 2011; Sandoval-Solis et al., 2011; Cerón et al., 2012; Cortés et al., 2012; Koop and van Leeuwen, 2015; Loucks and Van Beek, 2005). The vulnerability is the magnitude of an adverse impact on a system. The objective is to seek ways to reduce the negative impacts of actual and expected events, and meet the water requirements for various human activities and the environment, considering various future scenarios. To achieve this target, performance measures or indices are required that can be used to evaluate and compare water resources, subject to varying actions and policies under different scenarios (Sandoval-Solis et al., 2011). The sustainability index (SI) identifies policies that preserve or improve the desired water management characteristics of the basin in the future. Thus, SI of water resources is an index that provides a mechanism for evaluating and comparing different methods of management and water uses with regard to sustainability. If proposed policy or action of the water plan make the system more sustainable, the SI will show that the system will have a larger adaptive capacity. Thus, given the increasing conflicts between water users in the RVGB, the can SI be applied to assess the various actions proposed in the WRP with regard to the various sectoral demands and future scenarios proposed in the WRP? Could SI to be used to evaluate and compare policies proposed in water plan of others basin in the region? SI used in this study was developed by Loucks (1997), adapted by Sandoval-Solis et al (2011) and recently extended by Srdjevic and Srdjevic (2017).

The objective of this work is to calculate the SI of water resources in the Rio Verde Grande Basin, Brazil, evaluating and comparing water demand and available water for activities foreseen in the WRP for three water availability future scenarios.

2. Methodology

2.1. Study area and model geography

The Rio Verde Grande is a major tributary to the east side of São Francisco River, and forms the boundary between the states of Bahia and Minas Gerais along part of its course. The Rio Verde Grande Basin has an area of 31,410 km^2 covering eight municipalities in Bahia (13% of the total area) and 27 municipalities in Minas Gerais (87% of the total area). The population was 768,000 inhabitants as of 2011, which corresponds to about 5% of the total population of the São Francisco River Basin (ANA, 2016a,b). The headwaters of the Rio Verde Grande are at an elevation of 1256 m in Minas Gerais, and travels 577 km to join the São Francisco River, at an elevation of 431 m. The segmentation of the Rio Verde Grande Basin (RVGB) into smaller subcatchments was proposed in the WRP for the basin; the intention was to obtain a spatial structure of the basin to analyze information, from diagnosis to future scenarios phase. The eight RVGB subcatchments are defined as follows:

Alto Verde Grande (AVG) – This region contains the highest elevations of the RVGB, and has a watershed area of 3098 Km^2. The AVG sub basin contains about 48% of the population and most of the industries in the RVGB.

Medio Verde Grande-Trecho Alto (MVG_TA) – This region is located downstream of the AVG and has a watershed area of 7102 km^2. It contains most of the cattle operations in the RVGB.

Médio Verde Grande – Trecho Baixo (MVG_TB) – This region contains the Verde Grande River from the end of the MVG_TA and goes to mouth of Verde Pequeno River. The area is 3161 km^2.

Alto Gorutuba – (AG) – The largest reservoir in the RVGB is in AG sub basin. The area is 2133 km^2.

Médio Baixo Gorutuba – (MBG) – This region is the largest subcatchment of the RVGB at 7715 km^2. It has the second largest population of the entire basin.

Alto Verde Pequeno – (AVP) – The area is 2899 km^2.

Baixo Verde Pequeno – (BVP) –The area is 3368 km^2

Baixo Verde Grande – (BVG) – This region is the smallest sub basin of the RVGB at 1934 km^2. It has the smallest population of the entire basin, but has the largest irrigated area; more than 21,000 ha is irrigated. That sub basin stretches from the confluence of Verde Pequeno and Verde Grande Rivers to the confluence with the São Francisco River.

In the upper RVGB, the prevailing climate is semi-humid and warm with mean annual rainfall around 1100 mm, occurring mostly between November and February (Summer); the mean annual rainfall in the lower basin is around 700 mm. The mean annual potential evapotranspiration is around 2000 mm considering whole basin (ANA, 2016a,b).

2.2. Model description

A model for the RVGB was built using the Water Evaluation and Planning System (WEAP), an Integrated Water Resource Management (IWRM) model developed by the Stockholm Environment Institute (Yates et al., 2005a). The soil moisture method in WEAP was used to model the hydrologic response of the basin. This method is based on empirical functions that describe the behavior of surface runoff, interflow, baseflow evapotranspiration, and deep percolation for a basin (Yates et al., 2005a, b). As in the WRP for the RVGB (ANA, 2016a,b), the Rio Verde Grande Basin was subdivided into eight sub catchments with the same water users and connected to a network of rivers (see Fig. 1). The water user withdraws this resource from various water sources (e.g. rivers, groundwater and reservoirs) and for its demands. The water users were divided into the four largest groups: irrigation, livestock, urban population, and rural population. The RVGB map (Fig. 1) includes the upper and lower catchment and schematic diagram that shows six control points (CP) and all catchments contributing to the Rio Verde Grande.