IMPACTS OF CLIMATE CHANGES ON THE SUSTAINABILITY OF WATER RESOURCES OF THE RIO VERDE GRANDE BASIN, MINAS GERAIS, BRAZIL

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ABSTRACT: The Rio Verde Grande basin is located mostly in the north part of the state of Minas Gerais, which is a region with semi-arid climate, showing long and intense periods of drought. This climatic characteristic directly affects the availability of water resources and consequently the development of the main activities of the region that are livestock and irrigated agriculture. There are no studies that evaluate the effect of climate change on the availability water and the sustainability of activities with high water demand in Rio Verde Grande basin. The objective of this study was to analyse the likely changes in the water availability in the Rio Verde Grande basin and the sustainability of water resources for the water users activities, using synthetic series generated through climatic and hydrological modelling programs. This study performed the climate projections using the *Global Climate Models (GCMs)* of the *Coupled Model Intercomparison Project Phase 5 (CMIP5)*, whereas the hydrological modelling was performed through WEAP. Based on the calculations of sustainability indexes, and comparing the current and future scenarios, it was observed that even with all the interventions proposed by the Water Resources Plan of the Rio Verde Grande basin (WRPVG) implemented, there was a reduction in sustainability of water resources in some sub-basins due to climate change.

KEYWORDS: CMIP5; WEAP model; vulnerability

IMPACTOS DAS MUDANÇAS CLIMÁTICAS NA SUSTENTABILIDADES DOS REURSOS HÍDRICOS DA BACIA DO RIO VERDE GRANDE, MINAS GERAIS BRASIL

RESUMO: A bacia de Rio Verde Grande está localizada principalmente na parte norte do estado de Minas Gerais, que é uma região com clima semiárido, apresentando longos e intensos períodos de seca. Esta característica climática afeta diretamente a disponibilidade de recursos

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hídricos e, consequentemente, o desenvolvimento das principais atividades da região que são pecuária e agricultura irrigada. Não há estudos que avaliem o efeito das mudanças climáticas na disponibilidade de água e na sustentabilidade de atividades com alta demanda de água na bacia de Rio Verde Grande. O objetivo deste estudo foi analisar as mudanças prováveis na disponibilidade de água na bacia de Rio Verde Grande e a sustentabilidade dos recursos hídricos para as atividades usuárias de água, utilizando séries sintéticas geradas através de programas de modelagem climática e hidrológica. Este estudo realizou as projeções climáticas utilizando os *Global Climate Models (GCMs)* do *Coupled Model Intercomparison Project Phase 5 (CMIP5)*, enquanto que a modelagem hidrológica foi realizada através do modelo hidrológico WEAP. Com base nos cálculos dos índices de sustentabilidade e na comparação dos cenários atuais e futuros, observou-se que, mesmo com todas as intervenções propostas pelo Plano de Recursos Hídricos da Bacia Rio Verde Grande (PRHVG) implementadas, houve uma redução na sustentabilidade da água Recursos em algumas sub-bacias devido à mudança climática.
Palavras-chave: CMIP5; modelo WEAP; vulnerabilidade.

INTRODUCTION

Climate change is considered a world concern since the decade of 80. The Intergovernmental Panel on Climate Change (IPCC) created in 1988, had as its aim to gathering and evaluates researches made in this field, what enable a bigger knowledge of climate changes impacts on water resources. According to IPCC (2007), some projections made indicate that the average of temperature in global surface will increase by up till 5.8 degrees Celsius in the next hundred years, directly affecting the patterns of precipitation. The reflection of these changes will be the occurrence of extreme events, such as, the increase in the probability of drought and flood occurring, compromising water availability.

In Brazil, the climate changes may make the water access even more difficult. The lack of rain or low rainfall combined with high temperatures and high evaporation rates, as well as the competition for water resources, could lead to a potentially catastrophic crisis, being the more vulnerable those who are part of agricultural sector, especially in the region of Brazilian semi-arid (MARENGO, 2008a).

The Rio Verde Grande basin is located in a semi-arid region. The distribution of rainfall in the basin throughout the year is characterized by the clear existence of drought and humid seasons. According Marengo (2008b) the water resources management in semi-arid regions heavily depends on the climate variability. One of the results of climate change in the Rio Verde

Grande basin is the increase in climatic variability, which has as consequence the compromising of water availability. The main activity developed in the region is irrigation; therefore, in order to have water availability for this activity it is extremely important to guarantee the sustainability of water recourses in the basin.

Considering that the previous knowledge of impacts caused by climate changes on water recourses it is insufficient, it becomes necessary a study to deepen such knowledge, aiming in a better evaluation and qualification of these impacts, thus ensuring the sustainability on the use of water resources.

The objective of this study was to analyse the likely changes in water availability in the Rio Verde Grande basin and the sustainability of the water resources for the water users activities. This was done through synthetic series obtained by climate and hydrological modelling programs.

MATERIALS AND METHODS

Basin characterization

The Rio Verde Grande basin has an area of 31,410 km² of which 87% (27,219 km²) corresponds to the portion of the basin located in the State of Minas Gerais and 13% (4,191 km²) is in the State of Bahia. The total of 35 municipalities are covered by the basin, 8 of them belong to Bahia and 27 to Minas Gerais. (ANA, 2011). The basin was subdivided into eight sub-basins to assist in the planning of the Water Resources Plan of the Rio Verde Grande basin (WRPVG). The sub-basins are as follows, Alto Verde Grande (AVG); Médio Verde Grande-Trecho Alto (MVG-TA); Médio Verde Grande-Trecho Baixo (MVG-TB); Alto Gorutuba (AG); Médio Baixo Gorutuba (MBG); Alto Verde Pequeno (AVP); Baixo Verde Pequeno (BVP) e Baixo Verde Grande (BVG). The Médio Baixo Gorutuba (MBG) subbasin represents the largest area, accounting for 25% (7,715 km²) of the total basin, and the Baixo Verde Grande (BVG) sub-basin is the smallest with only 6% of the area (1,934 km²) (ANA, 2011). The Water Resources Plan of the Rio Verde Grande basin (WRPVG) proposes studies that anticipate the long periods of drought. These studies will, through a climatological system, predict and alert an exposition of extreme events, such as droughts and floods. In addition, the climate systems proposed by the Plan will analyse the effect of climate change on the hydrological regime (ANA, 2011).

Climate Modelling

The Intergovernmental Panel on Climate Change (IPCC) is a scientific body whose purpose is to assess global climate change, in order for this to be possible, researches from all over the world come together to expose the advances related to climate change and, to reach a consensus on the trends of these changes. This consensus is made official by this scientific community through reports that have up-to-date information on all researches in the sciences related to climate change (MARENGO; SOARES, 2003). The CMIP5 has more than 50 climate models working with climate change simulations both past and future (ZHAO; CHEN; MA, 2014). The MarkSim climate modelling program has 17 of the general circulation models used by CMIP5, but only four of these models were used in this work. The choice of the models used in this work was based on the models available by MarkSim that have the smallest scales, since by using the downscaling technique to regionalize these models would guarantee more satisfactory results. In addition to choosing the models MarkSim also works with scenarios elaborated by the fifth IPCC report, which are called Representative Concentration Pathways (RCP). The RCPs present four scenarios that consider changes in radiative forcing in the year 2100, these scenarios are called RPC2.6; RPC4.5; RPC6.0 and RPC8.5. From these scenarios, climate projections analyse different conditions as a reflection of different radiative forcing, such as greenhouse gas concentrations, emission of aerosols and chemical gases, and land use and occupation. These analyses allow projections on climate change to also consider human actions, which makes the scenarios more realistic (TAYLOR; STOUFFER; MEEHL, 2012). For this work the RCP6.0 scenario was adopted, which represents a radiative forcing of $6w.m^{-2}$, and considers its stabilization after the year 2100. This scenario also stabilizes the CO2 emission; in addition, it foresees a greater control regarding the emission of Greenhouse gases and air pollution gases. Assuming the chosen parameters (the models and the scenario) MarkSim was able to generate the future synthetic series, where each municipality produced monthly averages of precipitation, minimum temperature and maximum temperature, for each year studied until the year 2050.

Hydrological Modelling

This study carried out its hydrological modelling in the Rio Verde Grande basin using the WEAP (Water Evaluation and Planning) model. The calibration and verification of the model were based on historical data from basin meteorological stations. The WRPVG in elaborating the scenarios considered some changes in the basin by the year 2030, predicting a reduction in the demand of water due to a smaller loss in the water systems. Besides that, it was considered a greater control in the losses due to urban supply, and also the implantation of measures in order to improve the availability of water of the basin such as the implantation of new dams, import water and delivered water (ANA, 2011). The scenarios presented by the plan are three, Baseline, Normative 1 and Normative 2, being that the Baseline scenario considers the increase of water supply by interventions previously proposed or in progress (ANA, 2011). The calibration to validation of WEAP model was done using the interventions provided for in the WRPVG, also determined types of demands for the use of water resources, being them irrigation, livestock, urban population and rural population. Once the WEAP was calibrated and validated, this work used the future synthetic series obtained in the MarkSim climate modelling program as input data from the hydrological model.Thus, the performance criteria and the sustainability index could be calculated, generating future scenarios that represent the changes in the behaviour of the basin and, consequently, in the sustainability of the available water resources. According to Sandoval-Solis, McKinney and Loucks (2011) the performance criteria are used to evaluate water management policies and allow comparison with alternative measures. These performance criteria are based on a water supplied deficit (D_t^i) (Eq. 1), which is the difference between water demand ($X_{Target,t}^i$) and water supplied ($X_{Supplied,t}^i$) for each time period t for a determined ith water user, defined in this work as irrigated area, livestock, urban population and rural population:

$$D_t^i = \begin{cases} X_{Target,t}^i - X_{Supplied,t}^i , & If\ X_{Target,t}^i > X_{Supplied,t}^i \\ 0 , & If\ X_{Target,t}^i = X_{Supplied,t}^i \end{cases} \quad (1)$$

The reliability can be described as (eq. 2),

$$Reliability = \frac{No.\ of\ times\ D_t^i = 0}{n} \quad (2)$$

The resilience is given by equation (3),

$$Resilience = \frac{No.\ times\ D_t^i = 0\ follows\ D_t^i > 0}{No.\ times\ D_t^i > 0\ ocorred} \quad (3)$$

and vulnerability is calculated by equation 4,

$$Vulnerability = \frac{\left(\frac{\sum_{t=0}^{t=n} D_t^i}{No.\ of\ times\ D_t^i > 0\ ocorred}\right)}{X_{Target}^i} \quad (4)$$

The maximum deficit is given by the equation, where D_{annual}^i the annual demand of water (eq.5),

$$Max.\ Deficit = \frac{\max\left(D_{annual}^i\right)}{Water\ demand^i} \quad (5)$$

The performance criteria above enable the sustainability index (S.I.) to be determined by the following equation 6,

$$S.I. = \left[Reliability^{i} * \ Resilience^{i} * \ \left(1 - Vulnerability^{i}\ \right) * (1 - Max.\ Deficit)\right]^{1/4} \quad (6)$$

The calculation of the sustainability index in the water resources of the Rio Verde Grande basin allowed a comparison of the behavior of the basin between the Baseline scenario and the Normativo 2 scenario, making it possible to analyze from the climatic changes projections and the changes occurred in the basin once the interventions that improve water availability were considered implanted.

RESULTS AND DISCUSSION

In order to process the data in the WEAP model was used a time interval of 2000 to 2050, considering historical data (2000 - 2014) and future synthetic series generated in MarkSim (2015-2050). Thus, the Baseline and Normative 2 scenarios established by the WRPVG were compared by evaluating the changes in the sustainability index of the basin's water resources. In order to better understand the results generated, it is necessary to observe the behaviour of the basin through the performance criteria, given that these criteria are calculated by comparing the eight sub-basins and the different water user activities.

Reliability is described through time and volume. The reliability based on volume demonstrated by Graph 1, indicates the probability of the water available in the sub-basins meet the demand considering the simulated time interval. The urban population of the AVG sub-basin has the highest water demand in relation to the other sub-basins, but it has a very low reliability. This fact occurs because half the population of the entire Rio Verde Grande basin, mainly due to the presence of the city of Montes Claros, is in this sub-basin.

Graph 1- Reliability (Volume) of water resources in the Rio Verde Grande basin

It can be stated that all types of use (irrigation, livestock, urban population and rural population) of the BVG sub-basin present a high level of reliability. This occurs because this sub-basin represents the highest surface water availability of the basin, having a high cumulative mean flow. Among the water users activities, the irrigation presented a very variable reliability which can be explained by the different demands in the 8 sub-basins of the Rio Verde Grande basin. In some sub-basins water consumption for irrigation exceeds 90% of total demand.

The resilience demonstrated through Graph 2, represents the ability of the system to adapt to changes imposed on it, considering its recovery from a phase of failure. In this respect, the MVG-TA sub-basin does not have a recovery capacity for the rural population. This is due to the fact that this sub-basin has a large rural population in a region of low drainage density. Contrasting with the MVG-TA sub-basin, the MBG sub-basin, despite having the largest rural population, compared to other sub-basins, presents high resilience in this water user activity. This fact stems from its location, since most of the water bodies present in the basin are part of this sub-basin, as the dam of Bico da Pedra, thus increasing its drainage density and, consequently, its resilience. The irrigation activity presented low levels of resilience in all the sub-basins, not reaching 30%.

Graph 2- Resilience of water resources in the Rio Verde Grande basin

The vulnerability presented in Graph 3 describes the behavior of the sub-basins considering the maximum deficits in the system in a period of continuous failure and the probability of this deficit exceeds a previously established limit. Through this graph it is possible to note that irrigation is highly vulnerable in all sub-basins. This is a consequence of the high water availability demand used for this activity. Therefore, only considering the surface water availability and climate changes effects, the irrigation presents itself as the highest risks activity in the entire basin.

Graph 3- Vulnerability of water resources in the Rio Verde Grande basin

The AVP and BVP sub-basins present considerable values of vulnerability when it comes to the activities that use water for livestock. The land use and the vegetation cover for livestock in these sub-basins is high; however, the surface water availability in both sub-basins is low, which consequently causes a considerable vulnerability in these sub-basins.

The high vulnerability presented by the urban population in the AVG sub-basin emphasizes that this region is the one with the highest population concentration, given that, Montes Claros the main municipality of this sub-basin. The WRPVG foresees a growth of 1.95% per year for the AVG sub-basin, which in 2050 may lead this sub-basin to high vulnerability.

Graph 4 shows the maximum deficits that describe the worst annual deficit reported considering that water availability did not meet the required demands. It can be noticed that in all the sub-basins the maximum deficit was high when related to irrigation, which shows that during the simulated time the actions foreseen in WRPVG, once implemented, did not meet the growth of the water demands required by the water users activities.

Graph 4- Maximum Deficit of water resources in the Rio Verde Grande basin

The sustainability index considers the performance of alternative policies in order to guarantee a lower vulnerability to the system. Therefore, this index demonstrates the adaptability of the system. Through Graph 5, it is possible to analyze the sustainability index, relating the WRPVG's Baseline and Normative 2 scenarios.

It can be observed that, even after the implementation of all the interventions proposed in the basin plan in some sub-basins, there was an increase in the sustainability index, while in others the reduction of this index. This is due to the fact that the influence of climate change on the basin reflected directly in its behaviour reducing its sustainability in some cases.

Graph 5- Sustainability Index comparing Baseline x Normative 2

The AVG sub-basin presents a considerable increase in sustainability index due the import water from Congonhas River and implementation of dams, in order to guarantee the water supply to Urban population of Montes Claros city.

The MVG-TA and MVG-TB sub-basins also show an improvement in sustainability levels. This occurs as a consequence to the fact that both sub-basins are located near the AVG sub-basin, and make use of the main channel of the Rio Verde Grande, being also benefited by the interventions made in the AVG sub-basin.

However, the MBG, BVG, AVP and BVP sub-basins were not benefited by the water inputs implanted in the AVG sub-basin. However, even if other measures have been implemented in these sub-basins, it is possible to note that some have had an increase in sustainability index and some have not. The explanation for this behaviour is due to the fact that the interventions proposed by the water plan was heavily affected by climate change and hasn't been sufficient to improve the sustainability index performance in the sub-basins BVG, AVP and BVP, significantly. While the AG and MBG sub-basin even with the interventions carried out had its sustainability reduced, what evidences the strong influence of the climatic changes in the behaviour of the basin.

CONCLUSION

The observed results show that even considering the interventions proposed by the WRPVG, the climatic changes directly influenced the behaviour of the basin. The results observed demonstrate that:

- among the water users activities, irrigation presented the worst indexes of the performance criteria analysed, making the activity highly vulnerable in the scenario of climate change predicted in this work;
- even considering the interventions proposed by the WRPVG to increase the water supply, the climate changes directly influenced in the basin's water availability behaviour, reducing the sustainability index for some sub-basins;
- for the sustainability index of water resources to be guaranteed in the basin, more efficient adaptive measures that consider these climate changes must be included in the interventions proposed by the WRPVG.

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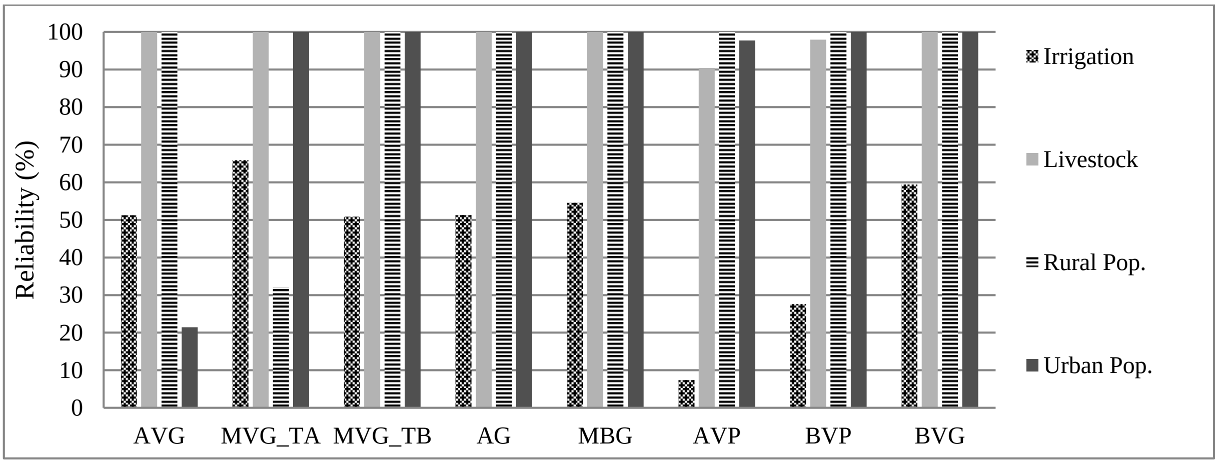
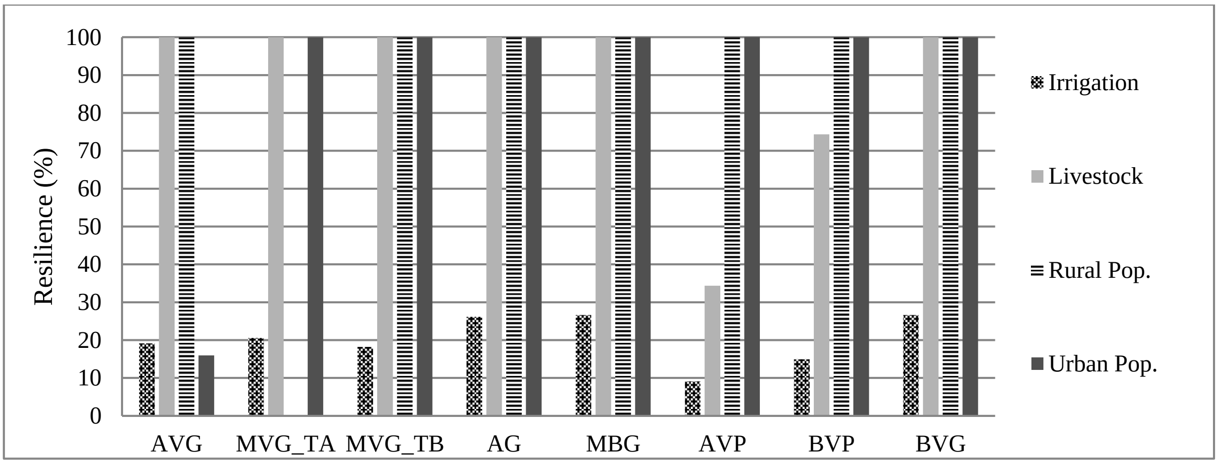
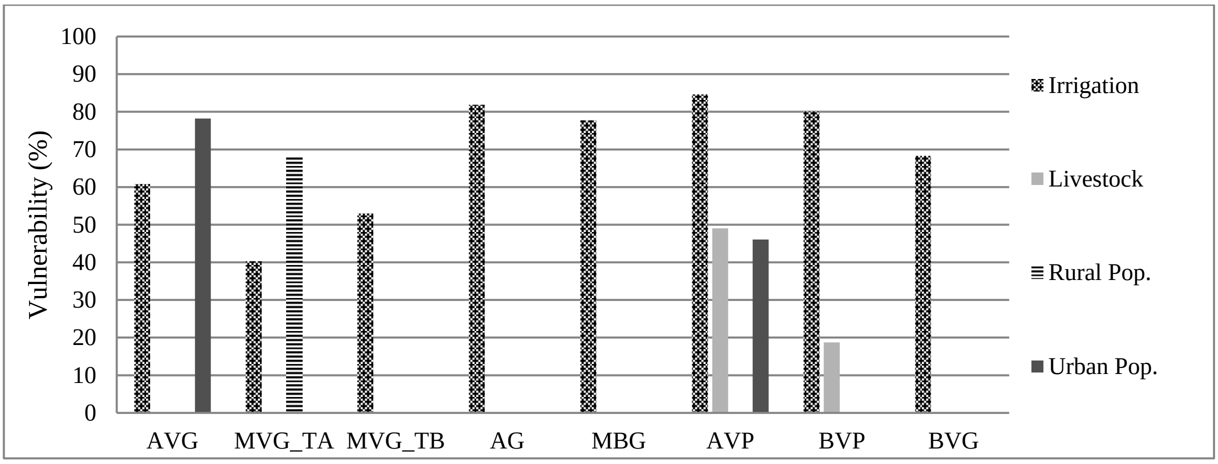
Annexes



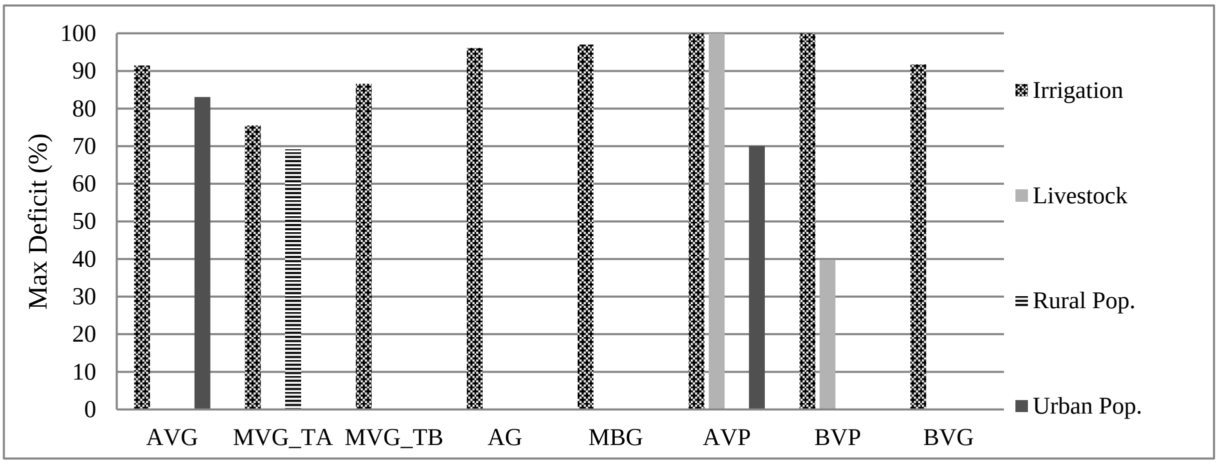
Graph 1. Reliability (Volume) of water resources in the Rio Verde Grande basin



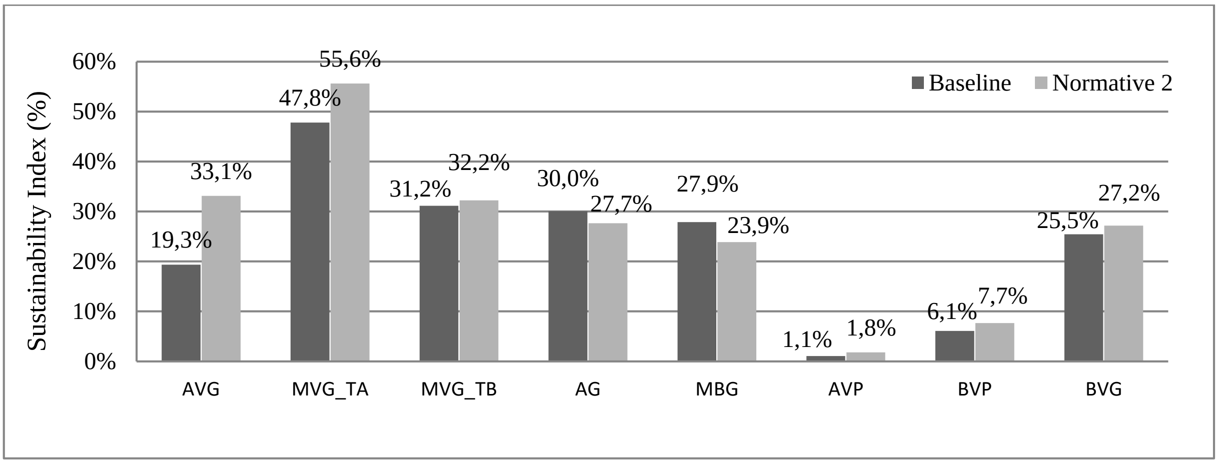
Graph 2. Resilience of water resources in the Rio Verde Grande basin



Graph 3. Vulnerability of water resources in the Rio Verde Grande basin



Graph 4. Maximum Deficit of water resources in the Rio Verde Grande basin



Graph 5. Sustainability Index comparing Baseline x Normative 2