Modern Environmental Science and Engineering (ISSN 2333-2581)
April 2018, Volume 4, No. 4, pp. 374-379
Doi: 10.15341/mese(2333-2581)/04.04.2018/010
Academic Star Publishing Company, 2018
www.academicstar.us

Water Balance of the Mbói Caé Watershed Associated to "El Niño-Southern Oscillation" through the Hydro-BID System

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Abstract: The management and planning of water resources are essential processes of the populations to resolve conflicts of the actual water crisis. To can plan and manage, it is necessary to have information about of water in watershed and principally with respect to climate. Hydro-BID is an integrated and quantitative system to simulate hydrology and water resources management under change scenarios. So this system was used to simulate the water balance of the Mbói Caé watershed in a period influenced by the climatic phenomenon El Niño-Southern Oscillation with the objective of generating useful information for the adequate Integrated Water Resources Management in southern Paraguay using hydrometeorological data of temperature, precipitation and flows in the period 2013 to 2016. The influence of the phenomenon was higher in its pre-initial phase in the year 2014 with inflow in the watershed of 6261.4 million m^3 and with a total precipitation of 2.32 million m^3 and on the other hand, in 2013 (year that El Niño does not appear) had 2553.3 million m^3 of inflow with 1.36 million m^3 of precipitation. In 2015 (year of evolution of the phenomenon) and 2016 (year of the end of the phenomenon), the values oscillated 4625.1 and 3978.4 million m^3 respectively of inflow with 1.72 and 1.41 million m^3 of precipitation. It is important to mention that this phenomenon is not the only cause of abundant rainfall in that region.

Key words: ENSO, water, water balance, watershed

1. Introduction

The water crisis is a global problem and it is important to understand that it is not only focused on its availability as is commonly believed, this often confuses and makes the problem not very relevant, mainly in Latin America and the Caribbean, a region with a high amount of water.

This crisis has three general factors: distribution, accessibility and quality.

The distribution because there are very wet and other very dry regions. The accessibility because there are populations that do not have the resources, infrastructure and monitoring to access drinking water and the quality because the water can be affected for a poor sanitation system or contamination by activities developed in the watershed, and that can limit the use of water.

All this added to the consequences of climate change and the fast population growth has a negative impact on the environment and society, so it is that the planning of water resources is one of the main tools to get over this crisis.

These consequences related to climate change vary for each region but generally have to do with: a greater frequency and intensity of floods and droughts, a greater scarcity of water, an aggravation of erosion and sedimentation, a reduction in glacier coverage and snow cover, rising sea levels and degradation of water quality, ecosystems and human health [1].

The knowledge of the water balance structure of lakes, shallow and underground basins, is fundamental for a more rational use of water resources in space and

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time, as well as to improve their control and redistribution [2].

With the use of hydrological models such as the Hydro-BID system, tool developed by the Inter-American Development Bank for Latin America and the Caribbean, it is possible to do a simulation to know the approximate behavior of the watershed, and this is possible with data of precipitation, temperature and flows; in addition to the knowledge of the modeler.

The Mbói Caé watershed is south of Paraguay, including the districts of Encarnación, Cambyretá, Capitán Miranda and Nueva Alborada. This watershed spills water in the Paraná River and Yacyretá Dam, and it has an approximate population of 160.000 people. This area is the wettest in the country and had a history of floods and droughts, for this reason it is important to know the basin to mitigate climate risks.

Knowing the percentage of reduction or increase in precipitation and the flow of the watershed when the extreme phases of ENSO gives better knowledge about the water supply of the basin [3].

With the information obtained by hydrological simulations, it is possible decide what best actions to take to manage risks when there are new cases in the same region or another with similar characteristics, knowing that extreme weather events are inevitable.

That a model is a simplification of the real world and not an exact representation of the system studied. In addition, when you are used computer models for investigations, the input data constitute a key point to develop the process, but they have limitations that affect the development of research, mainly the existence of data that is not usually spatially or temporally continuous.

This study includes a behavior of the water balance in the presence of an extreme climatic phenomenon. With respect to the study watershed, there was the disadvantage of not having a long series of flows. It is important that institutions measure this data because they constitute essential data when planning water resources for a better use of them.

2. Material and Methods

The programs were used: Excel as a spreadsheet, QGIS 2.10 Pisa as a geographic information system and HydroBID as software for hydrological modelling.

The area of the Mboi Caé watershed is south of Paraguay in the department of Itapúa, comprising four districts: Encarnación, Capitán Miranda, Cambyretá and Nueva Alborada.

This watershed is part of the Paraná watershed and lead to into the Paraná River, covering 291 km^2 of territory. The central coordinates in the UTM system correspond to 619224.11 m E and 6981753.27 m S.

The temperature and precipitation data were from the Directorate of Meteorology and Hydrology of Paraguay at the Encarnación and Capitán Miranda stations with the coordinates 55°53'46.8"W, 27° 18'14.7"S, and 55°47'22.71"W, 27°12'0.79"S, respectively during the period from 1970 to 2016.

Also from the Eastern University of Anglia (UEA) in its Climate Research Unit: average temperature (° C) and precipitation (mm) available in a series of grids in KML format displayed in Google Earth with monthly frequency in the 1970 period to 2015, called CRU TS 4.00 grid-box data. The region that includes the study watershed is located at coordinates 27.25S and 55.75W. This is to study the climate in the region of the study basin in the last four decades.

The flows (m^3/s) were from the information generated by a project of the Mixed Paraguayan-Argentine Commission of the Paraná River and the Water Observatory in the period from 09/09/2015 to 09/09/2016 (daily frequency) at a point located in a stream of the Mboi Caé watershed.

The Analytical Hydrology Dataset (AHD) were from Inter-American Development Bank (Fig. 1). It is a spatially explicit database (based on a geographical information system) of surface water. It contains the following files: Catchment.shp has the location and form of all the watershed of the AHD; AHDFLOWLINE.shp: has the rivers in each of the

watershed of the AHD; and AHDFLOW.dbf: is a table used to process the flow direction.

The identification of Mbói Caé watershed in AHD was using the QGIS program, obtaining the characteristics and the COMID of each sub-watershed and the interpolation of climatic data in the HydroBID system was through the tool "Climate Data Interpolating Tool".

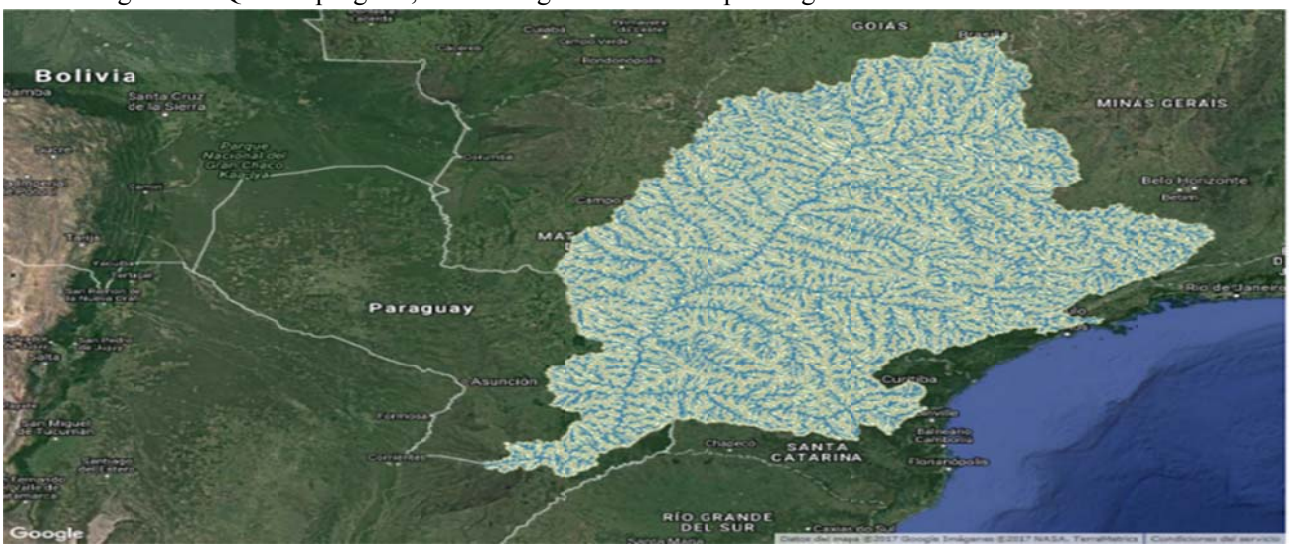

Fig. 1 Analytical hydrology dataset for the Mbói Caé watershed.

The water balance simulation of the Mboi Caé watershed was using HydroBID. The components of this system are:

- Analytical Hydrological Dataset: has an approximate number of 330,000 sub-basins represented in a file called Shapefiles and was developed through SRTM satellite images of NASA considering a resolution of 90 m by 90 m.
- SQLITE database: organizes and formulates database, has information on climate, soil characteristics and types of soils. Sqlite connects with the sub-basins of the AHD with a unique identifier (COMID); that is, a specific number for each of the 330,000 sub-basins of the AHD.
- Rain-runoff hydrological model: based on the Watertshed Loading Function algorithm to generate daily flows in each of the sub-basins. The System applies the standard model Generalized Track Load Factor — (GWLF) in conjunction with a new methodology for delay-routing time (lag-routing) developed by the RTI agency [4].

The calibration parameters of HydroBID are: stream velocity, latitude, start and end of growing season, curve number, available water content, recession coefficient, seepage, grow and dormant season ET factor and impervious cover percent [5].

3. Results and Discussion

In the analysis of the temperature, the warmest months were from December to February with an average temperature between 25°C and 26°C and the maximum-recorded peas is 42°C.

The coldest months are June and July with an average temperature of 15.5°C and 16°C. The minimums are less than 0°C, and the maximum-recorded peak is -4.5°C.

In general, the last decades are warmer with respect to the maximum and minimum temperatures. There is a 60% maximum values registered between 40 and 42°C from 2000, in the decades of 70', 80' and 90' it is recorded 40%. On the contrary, the minimum

temperatures are mostly in the 70', 80' and 90' in 74% and from the year 2000 only recorded in 26%.

The average precipitation is 1750 mm yearly, with a maximum value of 2700 mm and with a minimum value of 1100 mm.

The Mbói Caé watershed has a total area of 291.22 km^2, involves 5 sub-basins, 5 segments of currents, the total length of the stream is 33 km and the COMID of the AHD located downstream is 315185100.

The Fig. 2 represents the flow duration curve obtained from the calibration of the system. In the Y-axis (vertical) are the values of the flows and in the X-axis (horizontal) are the percentages of time in which this flow will equal or exceed. The blue line represents the modelled flows and the red line represents the observed flows.

The calibration was at a point in the Kuri'y stream. This stream is the most extensive in the Mbói Caé watershed and covers the largest sub-watershed identified with COMID 315182600 with 153,855 km^2 of area. It is difficult to obtain precise statistical values due to the short series of available flows, but the HydroBID system can perform the calibration observing the adjustment of the flow duration curve.

Table 1 shows the water balance values of the Hydro-BID simulation for the Mbói Caé watershed in the 2013/16 period.

Taking into account the average rainfall from 1970 to 2016 in the meteorological stations of Capitán Miranda and Encarnación of 1785 mm, in 2013 there was a decrease of 5%, and in the years 2014, 2015 and 2016 increase of 60%, 20% and 4% respectively.

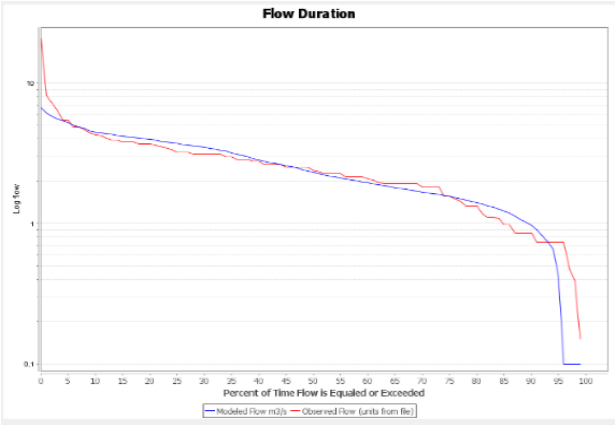

Fig. 2 Variance and percentage distribution of the electric power demand in the piglet's production.

Table 1 Water balance of Mbói Caé watershed in 2013/2016.

Year/Factor	2013	2014	2015	2016
Precipitation	1.35637E0	2.32271E0	1.71546E0	1.41128E0
Evapotranspiration	6.07263E-1	6.92997E-1	6.71198E-1	6.62995E-1
Runoff	1.79345E-4	2.26653E-3	8.54099E-4	2.02316E-5
Shallow GW	2.55149E-1	6.23874E-1	4.6166E-1	3.9782E-1
Total Flow	2.55328E3	6.2614E3	4.62514E3	3.9784E3
Δ Unsaturated Storage	3.07368E1	3.532E1	3.47041E1	3.51046E1
Δ Saturated Storage	5.00863E1	1.33381E2	1.22795E2	1.10213E2
Recharge	2.62475E-1	6.86302E-1	5.99514E-1	5.35312E-1
Volume balance error	2.31268E-1	3.17267E-1	-1.7763E-2	-1.84865E-1

The evapotranspiration was similar for all years and the average temperature in the four years of study was 21°C, with the years 2014 and 2015 being warmer than this.

In the Shallow GW, the most notable impact occurred in 2014 with 36% of the total, then the year 2015 with 26%, the year 2016 similar with 23%, and finally the year 2013 with 15%.

The variation in storage volume in the unsaturated zone was similar for the years analyzed. In the saturated zone, the variation was more different, being the year 2013 the lowest value and the other years exceeding between two and three times that value.

In the rainiest year 2014, the recharge of water to the deep saturated zone exceeds 170% more per year less rainy (2013). Runoff was highest in 2014 and 2015.

The accumulated runoff was elevated in the sub-basins identified with the COMID 315164300 of Capitán Miranda in the Itanguá stream that has the land with high slopes and COMID 31585100 of Encarnación, this land is the end of the watershed and has greater urban development.

4. Conclusion

The climate is warmer in recent years in relation to temperature and in terms of precipitation, not all the rainiest years in the region are influenced by the El Niño-Southern Oscillation phenomenon; but all Niño year categorized for intensity as "very strong" are like rainy years, even categorized as "moderate". This is for the period from 1970 to 2016. Besides the impact in terms of precipitation is more noticeable when it rains more than when it rains less, the rainiest years are 64% higher than the annual average in the region; On the other hand, the less rainy ones represent 37% less.

The variations in precipitation in the region emphasize the importance of planning water resources in the face of extremes, and principally for rainfall.

The qualitative influence of the ENSO phenomenon on the water balance of the Mbói Caé watershed was greater at the beginning of its development, mitigating its completion. The year 2014 had a neutral phase and an indication of the beginning of the phenomenon and was more relevant in changes in the water balance related to the increase in water availability; also, this year was one of the rainiest since 1970.

With the results of the water balance there is an important volume of water that flows to the ground and surface water (Paraná River) in periods of rain with values within the annual average and in periods with higher values, so it is extremely important to control and monitor water quality by three general factors:

(1) the Mbói Caé watershed is in the Guarani Aquifer region,

(2) part of the watershed is for agricultural use and there may be risks due to erosion, pollution or other, and

(3) urban development in cities gives risks of pollution due to poor sanitation

The runoff from the hydrological simulation in two regions justifies the problems that have already occurred due to rainfall.

With regard to the HydroBID system, it is an effective tool for assessing the situation of watersheds and obtaining useful information for the planning of water resources, especially in the face of extreme phenomena such as floods and droughts.

HydroBID can even serve without much availability of input data to approach the reality of each situation, facilitating research both academic grade and for government solutions. It is advisable to encourage institutions to measure more hydrological and meteorological data in order to make longer simulations.

The results obtained can help other models to deepen problems of water resource management. In addition, with the Hydro-BID climate scenarios module, an analysis of the future influence of precipitation and temperature in the watershed can be made, taking into account the variations given by climate change through global circulation models.

Hydro-BID can be applied at the national level as a tool for planning water resources and overcoming water conflicts. It also has reservoir management modules and general water allocation capabilities, simulation of groundwater, forecast change in water quality attributable to changes in surface water (transport of sediments) and economic analysis.

Acknowledgements

Thanks to Dr. Mauro Nalesso, Water and Sanitation Lead Specialist, and de technical team of Hydro-BID system of the Inter-American Development Bank.

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