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RESEARCH ARTICLE

HYDROLOGIC MODELING IN DIASS RIVER BASIN USING RAINFALL-RUNOFF MODEL SWMM

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ABSTRACT

Conceptual distributed rainfall runoff models are very useful tools for water resources assessment in river system. In this study, we have used one of them SWMM, to simulate the hydrological behavior of Diass river basin. The aim is to evaluate the availability of water in this river basin for application to irrigation and market gardening. With hydroclimatic data and physical data of river basin, this software has calculated the flow and losses. We have first analyzed the spatio-temporal evolution of the losses. Secondly, we have compared graphically simulated and measured catchment runoff to appropriate model evaluation. The results show strong losses during the rainy season and a good fitness between calculated and observed flows. These results show the performance of SWMM to accurately represent the natural system. This study provides an opportunity for decision maker to take account many important elements before investment plans for irrigation in this area.

INTRODUCTION

The efficient assessment of water resources is a fundamental step for the rational management of water resources especially in arid or semi-arid areas where the pressure is increasing. This requires first understanding the different processes involved in the functioning of the water cycle (Singh, 1997). The environment of these water resources, today faces numerous challenges and issues such as the reduction of water reserves, irregularities rain, drought, climate change impacts and anthropogenic developments, etc. (Abdel *et al*.,2012). The use of numerical models has become essential to better understand the various risks faced by the water cycle (Dupont *et al*., 1998). A model is a description of a real system, natural, in a graphical or mathematical expression; and it is also the simulation of relations "cause and effect" of natural processes of nature by managing physical reproduction on a smaller scale (Matlas, 1967; Singh and Woolhiser, 2002). Modeling allows understanding the natural system, characterizing the variability of its components in order to study its behavior and to design

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the same in conditions or scenarios out of its normal environment (Chaponnière *et al*., 2007). Many disciplines use models to study issues relating to the basins of the environment, which constitute complex systems which are not currently possible to understand in all their detail (Morias *et al*., 2007). The modeling of hydrological systems is the application of mathematical expressions that define quantitative relationships between the characteristics of the output variables and the factors influencing these variables (Beven, 2000). As the rain and flow are the two dominant variables in the path of water in the continental area, it is called hydrological modeling of rainfall-runoff relationship (Madson, 2000).

The terminology has changed, now including more complex hydrological models, which use new variables, such potential evapotranspiration. Some prefer to call these tools, models of watersheds, or just, hydrological models (Anctil *et al*., 2003). However, there are as many models as hydrologists as each model corresponds to a given problem (Refsgaard 1996; Ambrose, 1999). Hydrological modeling poses first the problem of choosing the type of model and system performance, and secondly the choice of equations to represent the process, third representation of equations in the form of computer code and fourth parameterization, calibration model and its validation (Fleming, and Neary, 2004; Haberlandt, 2010). The transition from one stage to the next is possible only under certain approximations (Beven, 2000). Most Hydrologists try to find better model simulation of stream flow by using rainfall-runoff modeling. One of the most outstanding achievements of the last three decades is the development of rainfall-runoff model that hydrologists are possible to use rainfall data comprehensively to predict the discharge of river (Singh, *et al*., 2006). Rainfall-runoff modeling is often used because the discharge data of river is limited (Dhemi, *et al*., 2010). From available rainfall data, there are many modeling developed to predict inflow data for irrigation design or flood analysis. Several forms or approaches can be used to classify mathematical hydrologic models. In terms of how processes are represented, the time and space scale that are used and what methods of solution to equations are used, rainfall-runoff models are empirical, conceptual and physically based (Todini, 2007). The empirical model is based on a simple mathematical link between input and output variables or if it includes the description, even if in a simplified way, of the basic processes involved in the runoff formation and development.

They contain parameters that may have little direct physical significance and can be estimated only by using concurrent measurements of input and output (Melone *et al*., 2005). Physically-based models have a logical structure that tries to closely simulate the real-world system, based on the incorporation of the known physical laws governing the hydrologic phenomena (Beven, *et al*., 1979). This type of models includes some such as watershed runoff models based on St. Venant equations. Finally, when the model structure considers only highly simplified physical laws, models are said to be conceptual, and they constitute an intermediate between physically-based and empirical models (Ye, *et al*., 1997; Melone, *et al*., 2005). From the spatial point of view, rainfall-runoff models are classified as lumped, semi-distributed, and distributed (Traore *et al*., 2014). Lumped models ignore spatial variations in parameters within a system. They treat the complete basin as a homogeneous whole, and impose many assumptions, especially in large watersheds, as variables and parameters are representative average values (Madson, 2002). These models are generally designed to simulate the stream flow just at the watershed outlet. However, one may want to estimate the flow at some interior locations in a river basin for engineering design, for real time operational flood forecasting and also for studying the effects of land use or climate change. Distributed models, in turn, account for behavior variations from point to point throughout the system (Moradkhani, *et al*., 2009). The basin is divided into elementary unit areas and flows are passed from one to another as water drains through the basin (Refsgaard, 1997). Such models give the closest representation of the real system; they incorporate as many components of actual physical processes as possible (Shakti *et al*., 2010). These models present the advantage of simulating the values of different hydrologic variables at many points of the basin (Xu, and al., 2002).

Semi-distributed models attempt to calculate flow contributions from separate areas that are treated as homogeneous within themselves (Ambroise, *et al*, 1995; Schuurmans, 2008). They are a compromise between distributed process models and lumped models (Jeannaud, 2007; Vahid *et al*., 2011). The choice of one of these approaches is influenced by the modeler himself (Lenhart, *et al* 2002). In this paper, we aim at evaluating water resource of Diass river basin on the west of Senegal. This requires a better understanding of the hydrologic phenomena and of how changes in the catchment may affect these phenomena. According to the scale of Diass river catchment, available data, required accuracy and our main objective, conceptual distributed models are more suitable for us. These models are able to simply accurately represent a complex system, describing its basic and most important components. An example of such models is the SWMM (Storm Water Management Model), developed by the agency of the environmental protection in the United States (U.S. EPA).

MATERIALS AND METHODS

Study Area

The Diass watershed covers an area of 681.41 km2 (Fig1.). It is located west of Senegal (between latitude 14.64 ° N and longitude: -17.09 ° W .It is characterized by a Sahelian climate. There are two seasons, rainy from July to October and a dry season from November to June. The rainfall varies from 500mm to 800mm. The temperature reaches its maximum value (32.4°C) in October and the minimum value (17.7 ° C) in January and February. The average temperature is 25.3 ° C. Wind velocity varies according to the seasons. During the dry season, wind velocity ranging from 4.4 to 5.3 m / s and in winter, the winds have a velocity which is less than 4 m /s. In sum, the average wind velocity is of the order of 4 to 5 m / s. Sunburn has two respective peaks in May and November and two hollow in August and December. The climatic parameters (temperature, wind speed, insolation etc ...) play a vital role in the flow of this area. Diass boasts interesting soil and climatic agro potential for the development of market gardening and fruit growing. In this study, we have used the data of Penthior and Somone stations (Faye, 2009).

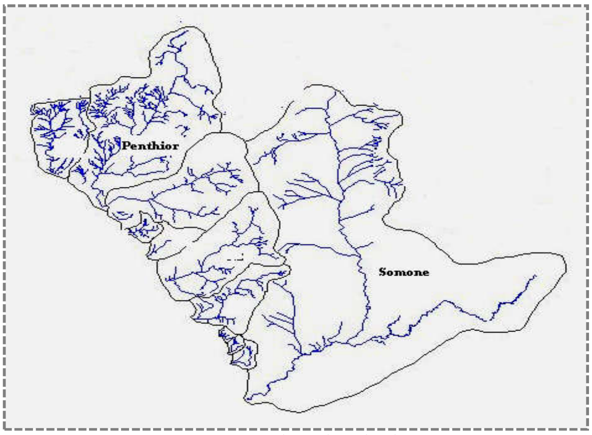


Figure 1.Diass river basin

Recall on the water cycle

The water cycle (fig.2), is a global sun-driven process whereby water is transported from the oceans to the atmosphere, to the land and back to the sea, while it's being transformed between liquid, solid and gaseous phases. It is usually described in terms of five major components: precipitation, infiltration, evapotranspiration, surface runoff and groundwater flow (Chaponnière, *et al*., 2007) .The relation between these five components is illustrated as following: When precipitation (rain, snow) reaches the land surface, it becomes of interest for hydrologists (Schuurmans, 2008). Some of the precipitated water is intercepted by the vegetation and other ground covers, from where it can evaporate back into the atmosphere. The other part reaches the soil and after that may form ponds on the surface, infiltrate or run over the ground. Ponds water can evaporate or infiltrate. Infiltrated water may too evaporate, percolate, be consumed by plants and then transpired or slowly move through the soil layers until reaching a stream (base flow). Finally stream water reaches lakes or oceans and evaporates back into the atmosphere (Todini, 2007).

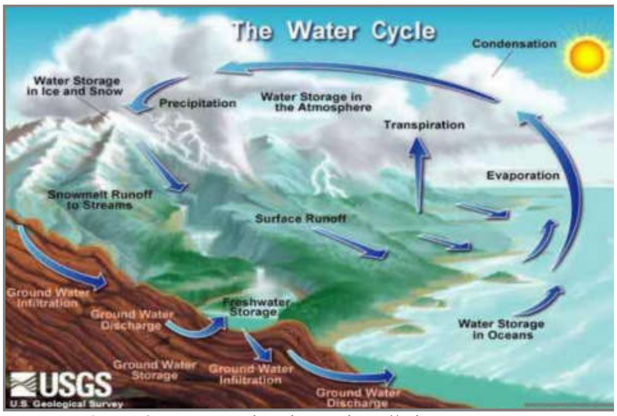


Figure 2. Water cycle scheme .http://nd.water.usgs.gov

Description of SWMM model

SWMM (Storm Water Management Model) is originally developed by the U.S. EPA (agency of the environmental protection) in 1971. It is a spatially distributed, rainfall-runoff simulation model used for single event or continuous simulation of runoff quantity and quality. SWMM has been updated many times since its first release, the most recent version being SWMM5.0.022 (Robert *et al*., 2012). SWMM5 hydrology operates on a collection of catchments that receive precipitation and generate runoff and pollutant hydrographs, accounting for evapotranspiration, infiltration and groundwater percolation (Rossman, 2008). Runoff is transported through a system of pipes, channels, storage/treatment devices, pumps, and regulators. It is particularly well suited to urban basin to calculate simple or complex sewer systems and apply either for one-off events or for continuous simulations (Julien, 2008). SWMM5 models have been used for a wide variety of watershed applications, as reported in the long series of many annual monographs resulting from the annual International Conference on Stormwater and Urban Water Systems held in Toronto every February.

SWMM5 has an advantage in that it accounts for the loss of flood plain storage, conveyance and area. On the other hand, floodway analyses in steady flow models account only for the loss of conveyance.) SWMM5 is worldly accepted for floodway/flood plain determination (James *et al*., 2011). The basic data requirements for simulation are included: rainfall, temperature, wind velocity, evaporation, basin area, perimeter, equivalent length, overall slope, the perimeter, equivalent length, overall slope, land cover rate and possibly soil type. With SWMM mathematical model, the flow is transported into predefined pipes or channels based on the equations of Saint-Venant. The SWMM model transforms the rainfall to runoff using a non-linear method of reservoirs, seepage losses (infiltration, evapotranspiration) are estimated by Horton equation.

Application

Data

In this study, we have used the hydro-climatic data of the stations of Penthior and Somone and the physical data of the watershed. The hydro climatic data come from the database of ANACIM (National Civil Aviation Agency of Meteorology) and physical data was obtained using the ArcView software. The period extending from 1980 to 2002, has been selected. It is the only period available for our study area.

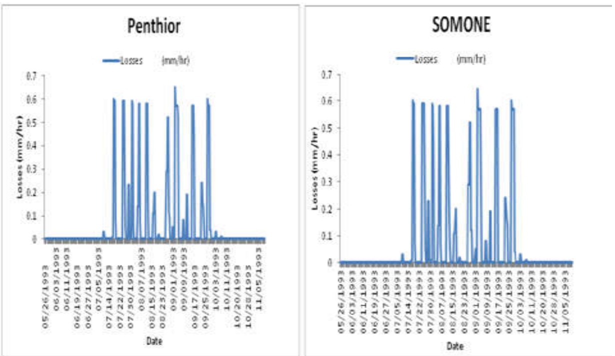
Principe of Study

Once all necessary data are provided to the software, we have launched the simulation. The software gives as output the calculated runoff (or simulated) and estimated losses which were then recovered in Excel. We have essentially adopted in this study, graphical approach based on a visual analysis. Thus, we have first traced the hydrographs of losses to analyze the degree of infiltration and evapotranspiration and finally, the comparative hydrographs between observed and simulated flows to assess the performance of the model on the watershed. 1993 being the most interesting year hydrologically according to the non-parametric statistical tests in the area, we have chosed to represent its output in the first two parts. For the third part, the fact that only 1998 provides comprehensive flow measurements, we have also chosed its outputs to the comparison of simulated and observed flows. All the results obtained are presented in the next section.

RESULTS AND DISCUSSION

Evolution of losses

We present in Fig.3a and Fig.3b the evolution of losses respectively at Penthior and Somone stations. It is been observed the strong losses from July to September corresponding to rainy season. These strong losses would be due to the strong infiltration (or percolation) because of the soil texture through its permeability, evaporation under the effect of the sun and transpiration related to the plants. This result gives an idea on the climatic and pedological conditions of the basin.

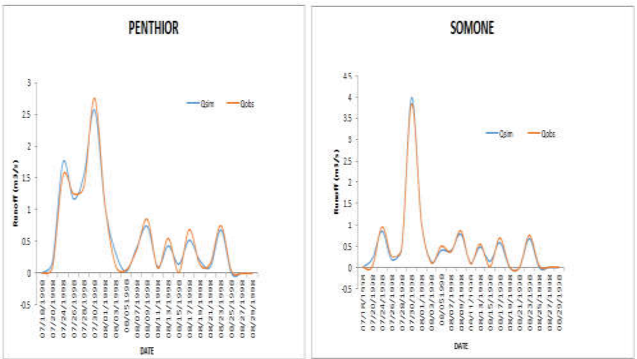


a) b)

Figure 3. Distribution of losses: a) at Penthior b) at Somone

SWMM Performances

Evaluation of the model is done to establish how well it is reproducing the measured data. In this study, we have used graphical techniques to appropriate SWMM evaluation. This approach provides a visual comparison of simulated and measured data. Thus, Fig.4a and fig.4b show the corresponding comparison between observed and simulated hydrographs respectively at Penthior and Somone stations. The results show a good agreement between the simulated and observed catchment runoff (i.e. a good water balance) for each of the two stations. Then, SWMM is well suitable to restore missing flows from rainfall, and particularly to assess the water resources.



a) b)

Figure 4 Observed flows Vs Simulated flows: a) at PENTHIOR b) at SOMONE

CONCLUSION

Due to the complex nature of the most of the hydrologic systems, hydrologists often use distributed rainfall-runoff models to simplify this complexity to better understand in all their detail. The distributed models have gained popularity over the other models thanks to "the possibilities of considering spatially variable inputs and outputs and analyzing the hydrological response at ungauged basins", and "their potential to provide information about the flow characteristics at points within the catchments". In this, we have used one of them named SWWM. We aim here at evaluating water resource of Diass river basin. We have adopted in this study, graphical approach based on a visual analysis. Thus, we have first traced the hydrographs of losses to analyze the degree of the losses and finally, the comparative hydrographs between observed and simulated flows to assess the performance of the model on the watershed. The results show strong losses during the rainy season (due infiltration and evapotranspiration) and a good fitness between calculated and observed flows. Then, this study shows that SWMM is well suitable to restore missing flows from rainfall, and particularly to assess the water resources. However, it's necessary to keep in mind that hydrologic model involves similarity but not identity, and simulates some, but not all the characteristics of the real system. Other research including other model and approaches under different conditions, are necessary to widen the angle of reflection for the better Knowledge of the physical system.

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