THE USE OF GIS TECHNOLOGY IN WATERSHED MANAGEMENT

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Abstract

Planning and assessment in land and water resource management are evolving from simple, local-scale problems toward complex, watershed-wide regional ones. Such problems have to be addressed with numerical models that can compute runoff in large (basin scale) complex watersheds with varying soils, land use and management conditions. GIS provides the framework within which spatially-distributed data are collected and used to prepare model input files and evaluate model results. GIS-based tools, such as the Automated Geospatial Watershed Assessment - Soil and Water Assessment Tool (AGWA - SWAT), can be used to illustrate the effects of land use practices on runoff, and to support watershed-wide land use management decisions. This paper illustrates how the AGWA tool represents a powerful and flexible tool for managing resources and understanding and predicting complex and changing systems. By integrating spatial data and distributed modeling in natural resources management, AGWA allows stakeholders and decision makers to assess the relative impacts of several alternative sets of options and thus provides an important tool to help make better informed choices for an improved future. AGWA automates the process of converting commonly available GIS data to input parameter files for the SWAT hydrologic model. Input parameters for this model were obtained using AGWA in conjunction with available topographic, soil and land cover data. In this work briefly a simple case of application in Vrana River - Bulgaria is presented.

Keywords: *GIS technology, hydrological modeling, AGWA-SWAT, watershed management.*

1 INTRODUCTION

Effective watershed management requires the integration of knowledge, data, simulation models, and expert judgment to solve practical problems and provide a scientific basis for decision-making at the watershed scale. The GIS technologies nowadays occupy a prominent place among the modern computer tools and constitute an invaluable support in the decision making of problems with a spatial dimension. The Automated Geospatial Watershed Assessment (AGWA) tool was developed jointly by the USDA Agricultural Research Service, the U.S. Environmental Protection Agency, the University of Arizona, and the Univ. of Wyoming to conduct hydrologic modeling and watershed assessments at multiple time and space scales (Miller et al., 2002; Goodrich et al., 2006). AGWA is a standalone, desktop application that uses widely available standardized spatial data sets. The required data sets include topography (DEM data), soils, and land-cover data. These data are used to develop input parameter files for watershed runoff models: the Kinematic Runoff and Erosion Model (KINEROS2) (Smith et al., 1995) and the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1994). GIS-based tools, such as the Automated Geospatial Watershed Assessment - Soil and Water Assessment Tool (AGWA - SWAT), can be used to illustrate the effects of land use practices on runoff, and to support watershed-wide land use management decisions. This paper illustrates how the AGWA tool represents a powerful and flexible tool for managing resources and understanding and predicting complex and changing systems. AGWA automates the process of converting commonly available GIS data to input parameter files for the SWAT hydrologic model. SWAT, developed at the USDA-ARS (Arnold et al., 1998), is a physically based, distributed parameter continuous simulation model that runs on daily time step. Input parameters for this model were obtained using AGWA in conjunction with available topographic, soil and land cover data. The purpose of this work is to investigate the potential possibilities of the AGWA-SWAT model and its adaptation to Vrana River – Bulgaria.

2 STUDY AREA

A small tributary of Kamchia River (5358 sq. km) that ends at Black Sea, namely Vrana River situated in the North-Eastern part of Bulgaria, with an area of 937.6 sq. km has been selected for showcasing the creation of a hydrological framework for watershed management (Figure 1). The Vrana River springs in the Lisa Mountain, eastern part of the Stara Planina Mountain. It drains trough forested lands (broad leaved forest) and agricultural areas (non-irrigated land) to mouth in to the Kamchia River near to Han Krum Village. The length of the main river is 67,6 km. On its way

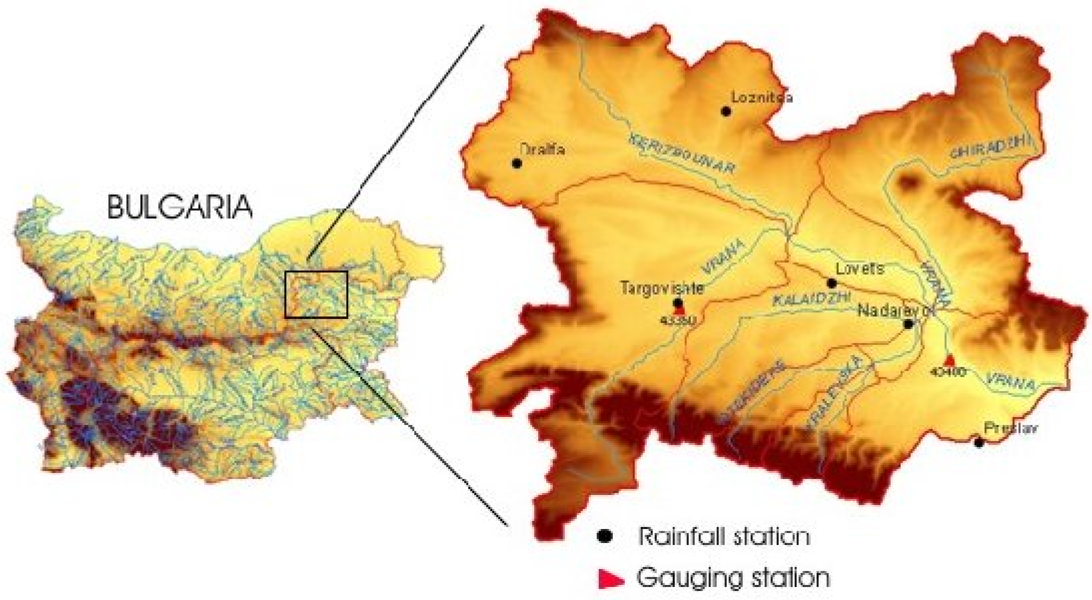

Figure 1. Schematic figure showing the location of the gauging stations and rainfall stations in the Vrana watershed

it picks up several tributaries like the Kerizbunar, Kalaydzhi, Pakosha and Kralevska rivers. The physiographic catchment structure is heterogeneous. The predominant land use is agriculture which covers 53% area of the watershed. Forest and discontinuous urban fabric cover 14% and 6% of the watershed area, respectively. The Vrana basin is influenced by moderate continental climatic conditions. The feeding of the river is mainly rainy and rainy-snowy. The runoff regime in the Vrana catchment is characterized by considerably variability caused by precipitation fluctuations and landscape elements. The within-the-year distribution of the runoff is defined by predominant climatic conditions of the region: cold winter, spring-summer rainfall maximum and dry autumn-winter period. The high flows period occurs from February to the end of June, the low flows period is good noticeable during August – November.

3 MATERIALS AND METHODS

Geographical Information System is used as a preprocessor to the SWAT model. Digital elevation model (DEM) was generated using the digitized contours. DEM along with the digitized drainage was used to automatically delineate (using GIS-based terrain analysis algorithm) the sub-watersheds. Data inputs, including land cover, soil, weather, and groundwater required for the SWAT model were automatically derived by the AGWA tool. The daily weather data (1980– 2003) for Targovishte climate station were used for rainfall and air temperature. This climate station is located centrally within the study area, and should provide representative data.

Major model components describe processes associated with water movement, sediment movement, soils, temperature, weather, and land management. In each spatial sub-units water balance is represented by several storage volumes e.g. canopy storage, snow, soil profile, shallow aquifer and deep aquifer. Surface runoff is calculated using a curve number technique. The curve number varies nonlinearly with the moisture content of the soil. Soil water processes include infiltration, evaporation, plant uptake, lateral flow and percolation to deeper layers. Actual evapotranspiration (ET) is computed as sum of actual evaporation from soil and plants. Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index and rooting depth, and can be limited by soil water content. SWAT has a simple tile flow component in which the user specifies tile depth, the amount of time required to drain the soil to field capacity, and the time lag between the water enters the tile and leaves it and enters the main channel. Tile drainage occurs when the soil water content exceeds the field capacity.

In order to apply the SWAT hydrological model, several data layers were needed: digital elevation model (30-meter resolution, where each pixel or cell represents an average elevation of an actual 30 meters on the ground); land cover (CORINE Land Cover sets based on satellite images taken in 1990 and 2000); soil type (FAO classification); digitized drainage network and flow paths; slope and aspect of the terrain. These data layers were combined into a GIS data base and provided spatial information for the watershed-modeling program. To ensure the layers were geometrically aligned, all layers and images were overlaid and visually inspected for positional accuracy. Data layers were standardized to a common projection (Universal Transverse Mercator - UTM, zone 35N) and spheroid and datum (WGS84).

4 RESULT AND DISCUSSION

The GIS development and applications as a long-term goal in the realization of a new strategy in water management primarily assumes: collecting, systematization, and analysis of topographic, pedological, hydrometeorological and other data. In order to execute the aims of this paper, several data layers were created or acquired for integration into a GIS: Digital elevation model (DEM); Land cover; Soil type. Digital Elevation Model was generated using contours taken from 1:50,000 scale topographic map of the study area is shown in Figure 2 along with the drainage system of Vrana River.

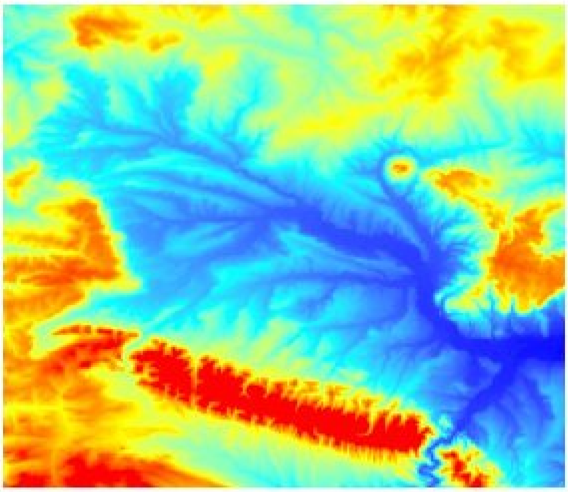

Figure 2. Digital Elevation Model for Vrana watershed

The first step of modeling process through AGWA is the watershed delineation. The key source is the DEM, which is used by the program to create the so-called flow direction and flow accumulation grids. They ensure the framework for the orientation of water movement through the basin and give the opportunity to delineate sub-basin from the user-defined point. We used DEM with 30 m cell size. On the second step the basin is divided into model elements according to the land cover and soil properties of the area. It requires availability of land cover and soil coverage with appropriate attribute data in order to be accepted by the program. Automatic extraction of stream network and boundary demarcation was taken up using the DEM. The basin along with its sub-basins is shown in Figure 3.

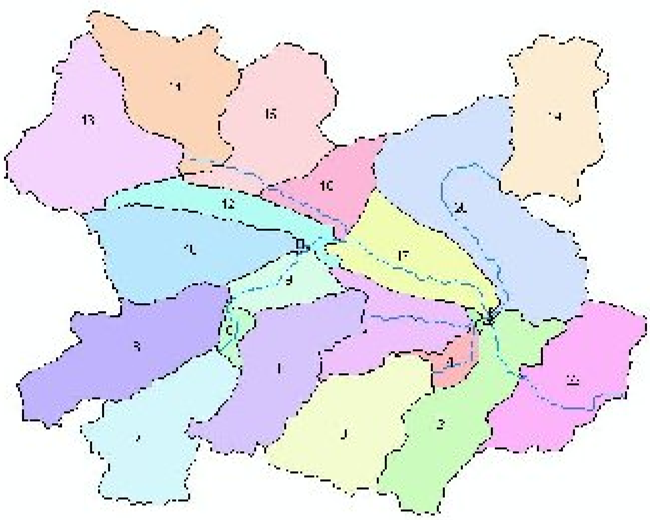

Figure 3. Vrana watershed delineated

Classification of land cover (CORINE) that was processed using remote sensing of Landsat images taken in 1990 and 2000 has been used as input for the modelling. Figure 4 shows the land cover categories.

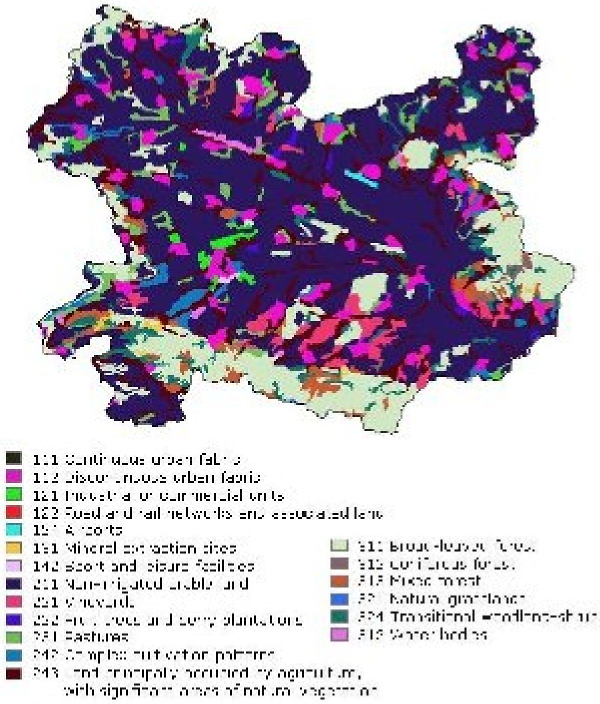

Figure 4. Land cover in the Vrana watershed

Vrana basin has agricultural areas (non-irrigated arable land) as the major land use with 53% coverage followed by forest (broad leaved forest) 14 %, land principally occupied by agriculture with areas of natural vegetation 10%, discontinuous urban fabric 6% and pastures 4%. The CORINE Land Cover classification procured from Bulgarian Environmental Agency is not among the default parameters for the program, but AGWA has an option for land cover defined by the user. It was added as so called look-up table, describing the characteristics of the land cover classes necessary for the modeling process. Digital Soil map procured from United Nations, Food and Agricultural Organization (FAO) has been used (Figure 5).

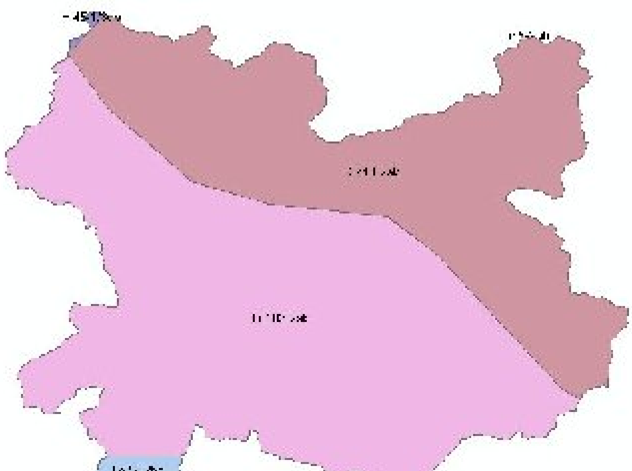

Figure 5. Soils in the Vrana watershed

Based on its topography and existing stream network, the Vrana basin was divided into 22 smaller (Figure 3), hydrologically connected sub-watersheds and their stream reaches using the automatic delineation of AGWA tool. For this the DEM data layer for the region and a pre-digitized stream network data layer were used. A digitized soil information layer (FAO soil data base) and land cover data layer (CORINE data base) were used for further sub-classification of areas in the watershed. All possible combinations of soil types and land use covering more than one percent area were included. Other model parameters such as length and slope of overland flow path, and channel geometry, which relate to physical dimensions of the watershed, were calculated too.
The daily time-series of climate data required for the SWAT include precipitation and maximum and minimum air temperature data. Only one climate station (station of Targovishte) with this information is available in the National Institute of Meteorology and Hydrology (NIMH) database for this watershed. Thus, four additional rainfall stations with daily precipitation data, maintained by the NIMH, were identified in or near the watershed. Other average daily data in month (dew-point temperature, wind speed, and solar radiation) and mean total monthly data were used from the climate station of Targovishte. These monthly average data are used by the weather generator in SWAT to simulate the daily time-series of wind speed, solar radiation, and relative humidity. The potential ET was computed using Penman-Monteith (Monteith, 1965) method.
The hydrologic components of SWAT were calibrated to fit the observed annual streamflow data from a NIMH streamflow gauging station (43400) at Kochovo for years 1991-2002. This period was chosen because it represents a combination of dry, average, and wet years (annual precipitation 392 to 773 mm). The model was run for 14 year period of 1989- 2002 but the first two years (1989 and 1990) were used for stabilization of model runs and simulated streamflow for 1991-2002 only was used for comparison purposes. Values of selected model parameters were varied iteratively within a reasonable range during various calibration runs until a satisfactory agreement between observed and simulated streamflow data was obtained.
During calibration as well as verification agreement between observed and simulated streamflow data, on an annual basis was determined using subjective as well as quantitative measures. The fit between annual observed and simulated streamflows was checked graphically by plotting the time series. Quantitative measures of agreement were based on observed and simulated annual streamflows and their determination coefficient (R^2) and Nash-Sutcliffe model efficiency (NSE) (Nash and Sutcliffe, 1970). The NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. The NSE measures the relative magnitude of the residual variance (“noise”) to the variance of the flows (“information”); the optimal value is 1.0 and the values should be larger than zero (0.0) to indicate “minimally acceptable” performance (Gupta et al., 1999). A value equal to zero indicates that the mean observed flow is as good as the model. Henriksen et al. (2003) categorized NSE into five classes namely; excellent, very good, good, poor and very poor and defined the limits of the classes for each of the efficiency indexes. They proposed a limit of 0.5 for a result between good and poor performance. Liden and Harlin, (2000) and Andersen et al. (2001) also state that a good simulation should have an NSE between 0.5 and 0.95. The calibration result showed that there is a good agreement (R^2=0.62, NSE =0.50) between the simulated and gauged annual flows. The results

showed that SWAT is able to simulate the hydrologic characteristics of the watershed well.

Once the model is calibrated with plausible parameter values, the model is validated to ensure that it can be used for prediction. In the validation process, the model is tested against data different from those used for the calibration. The SWAT model with calibrated parameters was verified by using an independent set of streamflow data that was not used for model calibration. In this study streamflow data for a 7-year period (1982-1988) from the same NIMH gauging station (43400) was used during model verification. The model was run for 9 year period of 1980- 1988 but the first two years (1980 and 1981) were used for stabilization of model runs and simulated streamflow for 1982-1988 only was used for comparison purposes.

The simulated annual flow has been compared with the observed flow at the available gauge discharge station. Figure 6 shows the comparison of simulated versus observed flows.

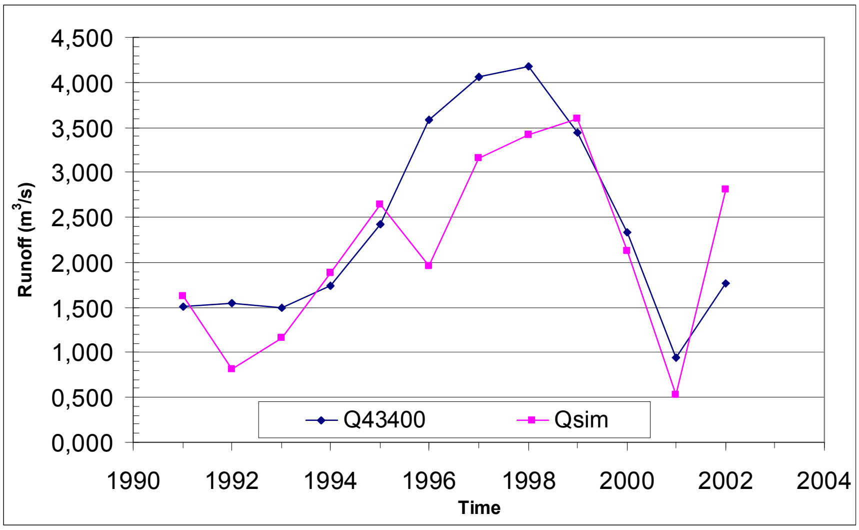

Figure 6. Annual observed versus simulated runoff plot for Vrana watershed

It may be observed that the simulated flow is lower than the observed flow with the exception of years in which the precipitation is above the norm during the vegetation period. In particular this tendency is pronounced in 1992 and 1996 characterized by dry periods and high values of potential evapotranspiration.

5. CONCLUSION

It should be concluded that the application of the AGWA-SWAT model for our conditions is an enormous labour which requires knowledge and skills in different spheres and difficult access to geo-information data base. The obtained results of runoff simulation can be accepted as satisfactory for this stage of the investigation. Further calibration, adjustment and validation would give more precise results and enhance the possibilities for floods hazard assessment as well as their application in other fields of environmental investigations. In the future is necessary to continue this study to obtain the optimal results for watershed management in the study region.

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