RAINFALL-RUNOFF MODELLING OF THE DROBOTFOR WATERSHED USING GIS-BASED SCS-CN METHOD

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Abstract

The Drobotfor basin is situated in the eastern part of Tutova Colinas, in the Bacau County and it is tributary of Zeletin River. The watershed drains a land area of 87.61 sq. km and is characterized by an elongated shape on north-south direction. It has a length of 32.3 km with differences regarding height and relief fragmentation of each sector and a maximum width of 4.25 km in the inferior sector. The land is heavily degraded, especially by erosion. The high torrential degree in the basin denotes the possibility of concentration large amounts of water from rainfall with thunderstorm fallen character with great importance in the area of modelling of the relief. In this study, using a GIS-based approach, the SCS-CN method has been applied to the Drobotfor watershed in order to peak runoff rates for a uniform rainfall. There have been taken into consideration the relevant spatial and hydrological characteristics.

Keywords: *GIS, SCS-CN, Runoff depth, Curve Number*

INTRODUCTION

The hydrological behaviour of a basin is provided for the morphometric characteristics of the drainage basins. Using multivariate statistical analysis help in establishing correlations between the morphometric parameters and the key hydrological variables such as, the catchment area, the time of concentration, the shape of the unit hydrograph, and discharge (Bardossy, 2002). Although these morphometric parameters provide information for hydrological modelling, it, however, must be well defined and able to be derived from the available data using standardized techniques (Willemin, 2000). Unless there is reliable and accurate data about rainfall, the determination of surface runoff will be problematic. The localized meteorological station always fails to provide an accurate coverage of climatic parameters.

This paper aims at determining the runoff using Soil Conservation Service method (SCS) for a rainfall in a small watershed. The method was developed mainly for small watersheds for which only daily rainfall and watershed data are ordinarily available. Simple methods for predicting runoff form watersheds are important in hydrological modelling and they are used in many hydrologic applications, such as flash flood estimation and water resources.

The SCS-CN method is an event-based model developed by the USDA Soil Conservation Service. A curve number (CN) is a land cover index for a given land and soil type to determine the amount of rainfall that infiltrates into the ground and the amount that becomes runoff for a specific storm event (USDA, 1986). The SCS-CN method is the most common technique for estimating storm runoff volume. Many watershed models, including the USDA Agricultural Research Service (ARS) SWAT model, incorporate this method for determining runoff despite some of its limitations including: no explicit accounting for the effect of antecedent moisture conditions, difficulty in separating storm runoff from the total discharge hydrograph, and peak runoff rate is not obvious (Mihalik, et al., 2008).

MATERIALS AND METHODS

GIS and Watershed Characterization

Geographical Information System (GIS) offers a variety of techniques to automatically extract hydrological variables from high-quality digital elevation models (DEMs), such

as flow direction and watershed delineation (El-Magd, et al., 2010).
The version of GIS used in this study was ArcGIS 9.3. Spatial data layers (aerial photography, hydrology, hypsography, soils, topography, and digital elevation models) were collected from a number of sources.
All data sets were projected to the same coordinate system (Stereo 70) and integrated to provide a vector topographic coverage that could be interpolated to a raster digital elevation model (DEM) for use in the runoff modelling. In addition to topography, the hydrology, hypsography, and soils data were each transformed into layers for the GIS to form the datasets useful for delineating and modelling the watershed.
The layers were processed using ArcHydro. ArcHydro is a set of data models and tools that operates within ArcGIS to support geospatial and temporal data analyses. ArcHydro is used to delineate and characterize watersheds in raster and vector formats, define and analyse hydrologic networks, manage time series data. It consists of two key components:

- ArcHydro Data Model
- ArcHydro Tools

These two components, together with the generic programming framework, provide a basic database design and a set of tools that facilitate the analyses often performed in the water resources arena. ArcHydro is intended to provide the initial functionality that can then be expanded by adding to its database structures and functions required by a specific task or application (ESRI).

Soil Conservation Service Curve Number Method

The Soil Conservation Service Curve Number (SCS-CN) method was originally developed to predict direct runoff volumes for given rainfall events and it is documented in the National Engineering Handbook, Sect. 4: Hydrology (NEH-4) (SCS, 1956, 1964, 1971, 1985, 1993, 2004). It soon became one of the most popular techniques among the engineers and the practitioners, because it is a simple but well-established method, it features easy to obtain and well-documented environmental inputs, and it accounts for many of the factors affecting runoff generation, incorporating them in a single CN parameter (Soulix, et al., 2012). The main weaknesses reported in the literature are that the SCS-CN method does not consider the impact of rainfall intensity, it does not address the effects of spatial scale, it is highly sensitive to changes in values of its single parameter, CN, and it is ambiguous considering the effect of antecedent moisture conditions.
The SCS-CN method was originally developed as a lumped model and up to this date it is still primarily used as a lumped model. In natural watersheds, however, spatial variability with regard to the soil-cover complex is inevitable. The method is based on calculating runoff form rainfall depth,

$$Q = \frac{\left(P - 0.2S\right)^2}{P + 0.8S} \tag{1}$$

where: Q = direct surface runoff in mm,
P = storm rainfall in mm, and
S = potential maximum retention

The potential retention S is expressed in terms of the dimensionless curve number (CN) through the relationship:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{2a}$$

In the English metric system (with Q and S in inches) the following definition should be used:

$$S = \frac{1000}{CN} - 10 \tag{2b}$$

The runoff CN is an empirical parameter corresponding to different soil-vegetation-land use combinations.
The SCS-CN method only forecasts the quantity of runoff formed in any point of the catchment but does not model the flow routing or the distribution of runoff through time. Because of this reason the requirements of the method are quite low, only the rainfall depth and an empirical parameter CN are mandatory. The CN value can be obtained from the hydrologic soil group, land-use and moisture conditions of the soil, the last two values being more important. Water infiltration capacity of the soil was classified by the USDA-SCS into four classes called hydrologic soil groups. Every type of soil has a Hydrologic Soil Group (HSG) that indicates

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an infiltration capacity and a rate of water transmission through the soil (USDA- NRCS 2007). The four types of HSGs are presented in table 1.

Table 1. Classification of hydrologic soil groups (USDA-NRCS 2007)

HGS	Characteristics of the hydrologic soil group and infiltration rates
A	Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Infiltration rate > 7.62 mm/h
B	Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Infiltration rate 3.81 - 7.62 mm/h
C	Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Infiltration rate 1.27 - 3.81mm / h
D	Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have clay textures. Soils in this group may have high shrink-swell potential, a water table or a water impermeable layer close to the surface. , infiltration rate from. Infiltration rate 0 - 1.27 mm/h.

Table 2. CN coefficient values (Drobot, 2007)

Land Use		**CN value for Hydrologic Soil Groups**			
Code	**Description**	**A**	**B**	**C**	**D**
1	Urban continuous areas	85	89	92	98
2	Urban discontinuous areas	77	85	90	95
3	Industrial and commercial units	81	88	91	93
4	Transportation networks	83	89	92	93
5	Airports	80	85	88	93
6	Ore extraction areas	80	85	88	93
7	Waste dump	80	85	88	93
8	Construction areas	80	85	88	93
9	Urban green spaces	48	66	76	82
10	Facilities for recreation and sports	51	68	79	84
11	Non-irrigated arable	67	78	85	89
12	Irrigated arable	67	78	85	89
13	Paddy fields	67	78	85	89
14	Vineyards	46	67	78	83
15	Orchards	43	65	76	82
16	Pastures	49	69	79	84
17	Complex agriculture	67	78	85	89
18	Agricultural land with an important percentage of natural vegetation	52	69	79	84
19	Agro-forester lands	52	69	79	84
20	Deciduous forests	42	66	79	85
21	Coniferous forests	34	60	73	79
22	Mixed forests	38	62	75	81
23	Meadows	49	69	79	84
24	Subalpine bushes and shrubs	49	69	79	84
25	Scrubs-forests transition areas	45	60	73	78
26	Beaches, dunes	63	77	85	88
27	Rock	77	86	91	94
28	Dispersed vegetation areas	72	82	83	87
29	Peat (turf)	30	58	71	78
30	Water	-	-	-	-

The HSG values are based on the intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet) and are valid for unfrozen soil. The land cover and land-use are used in conjunction with these HSGs in order to obtain the final value of the Curve Number (CN) parameter. The CN values for different land-use and soil types can be found in table 2.

RESULTS AND DISCUSSIONS

Case Study

The Drobotfor basin is situated in the eastern part of Tutova Colinas, in the Bacau County and is a tributary of Zeletin River. The watershed drains a land area of 87.61 sq km and is characterized by an elongated shape on north-south direction. It has a length of 32.3 km with differences regarding height and relief fragmentation of each sector and a maximum width of 4.25 km in the inferior sector. Its most import subbasin is Pojorata, strongly asymmetric with a length of 10 km and a maximum width of 2.16 km.

The land is heavily degraded, especially by erosion. The high torrential degree in the basin denotes the possibility of concentration large amounts of water from rainfall with thunderstorm fallen character with great importance in the area of modelling of the relief. Along the river are situated a number of localities. The watershed incorporates among agricultural and forested lands, meadows and pastures, vineyard and orchards. The soils are dominated by moderately to somewhat well-drained with sandy clay loam textures on most of the agricultural areas and poorly-drained with sandy clay loam textures in the southwest and northeast.

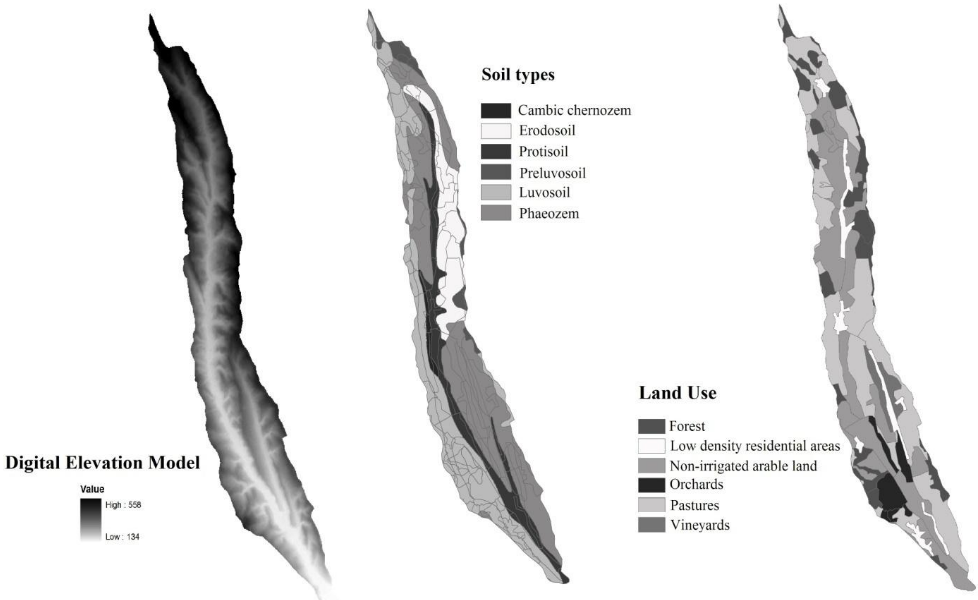

Figure 1. Input layers

The detailed land use map, shown in Figure 1, was analyzed to determine the area of each identified land use. The map was also used to compare impervious to pervious land cover within the watershed, for subsequent rainfall-runoff assessment.

Watershed and subwatershed boundaries were created using ArcHydro Tools and are shown in Figure 2. Boundaries were developed using the enhanced DEM, and flow directions. These boundaries were developed to allow for calculations to be made using the SCS-CN method.

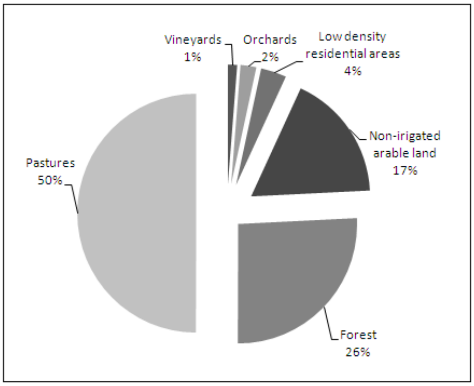

Figure 2. Land uses

Using ArcHydro we have obtained the flow direction grid in witch the values in the cells indicate the direction of the steepest descent from that cell.

Catchment Grid Delineation is a function that creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid. Adjoint Catchment is a function that generates the aggregated upstream catchments from the "Catchment" feature class (Figure 3). For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an "Adjoint Catchment" tag (ESRI, 2002).

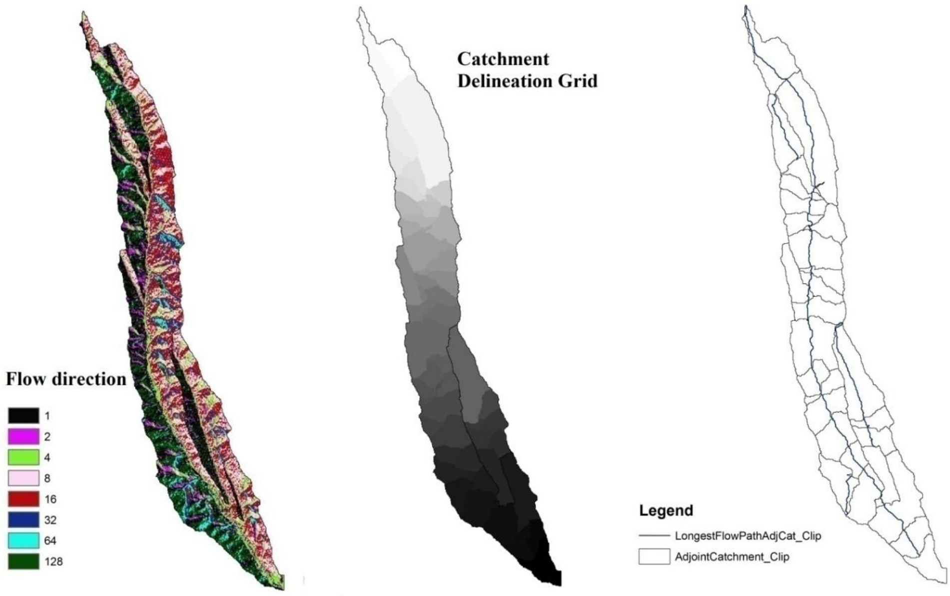

Figure 3.Layers resulted from ArcHydro

Analysing digital terrain data, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the drainage network. The program allows users to visualize spatial information, watershed characteristics, perform spatial analysis, and delineate subbasins and streams. Working with HEC-GeoHMS through its interfaces, menus, tools, buttons, and context-sensitive online help allows the user to expediently create hydrologic inputs for HEC-HMS (US Army, 2013). The two layers, the land-use and hydrological groups of soil have been united for assigning each HGS a land-use and using Table 2 CN was calculated. HEC-GeoHMS creates automatically a grid with the CN (Figure 4).

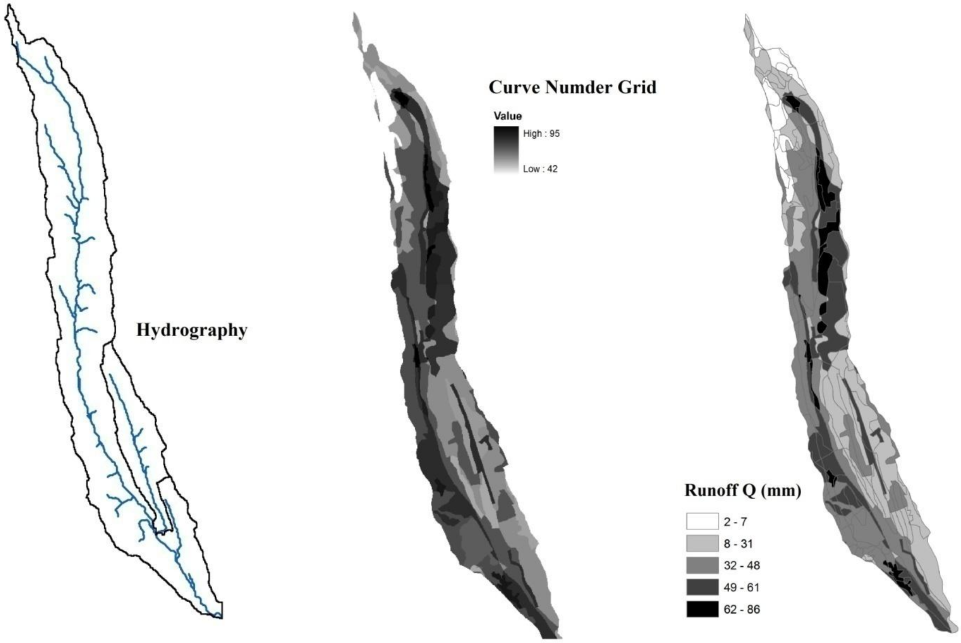

Figure 4. Layers resulted from HEC-GeoHMS

Applying the formula for runoff (eq. 1) for a uniform rainfall of 100 mm it will result a layer for the runoff.

CONCLUSIONS

This study focused on Drobotfor watershed, which is located near the Stanisesti village, evaluated the commonly used rainfall-runoff model (SCS-CN) for predicting direct surface runoff. This study makes use of a detailed land use map and tests the above mentioned model within an elongated torrential basin.
Results on runoff simulations made in the study may provide initial insights into hotspots and ecologically sensitive areas within the Drobotfor watershed. The study provided an initial background for identification of the runoff source areas and many of the parameters (in particular GIS spatial data) necessary for characterizing the watershed, which will be used for further hydrological modelling of water management in the basin.

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