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Review-Hydrological forecasting by using SCS-CN Modeling

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Abstract - The generation of runoff is triggered by the rain intensity and soil moisture status, and is calculated as the net precipitation times a runoff coefficient, which depends upon slope, land use and soil type. The runoff curve number (CN) is a key factor in determining runoff in the NCRS (National Resource Conservation Service) based hydrologic modeling method. The Soil Conservation Service Curve Number (SCS CN) also known as hydrologic soil group method was used in this study. This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate result. From this study, hydrological forecasting will be done by using SCS CN modeling and also incorporating it with GIS and remote sensing.

***Index Terms –** Soil conservation System, Curve Number, Antecedent moisture condition*

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I. INTRODUCTION

Water assets are vital renewable assets that are the premise for presence and advancement of a general public. Appropriate use of these assets requires evaluation and administration of the amount and nature of the water assets both spatially and transiently. Water emergencies brought about by deficiencies, surges and decreasing water quality, among others, are expanding in all parts of the world. The development of populace requests for expanded local water supplies and, in the meantime, comes about with a higher utilization of water because of extension in farming and industry. Bungle and absence of learning about existing water assets and the changing climatic conditions have outcomes of an irregularity of supply and request of water. The issue is proclaimed in semi-parched and dry zones where the assets are constrained. Surface water being simple, direct and in this way less costly to misuse in contrast with different sources like groundwater or desalinization makes it the significant wellspring of water supply for watering system, industry and household employments. The surface water, as lakes and waterway release (spillover) is predominately acquired from precipitation subsequent to being created by the precipitation overflow forms. Keeping in mind the end goal to settle on choices for arranging, plan and control of water asset frameworks, long overflow arrangement are required. The last are not frequently accessible with sensible length. Then again, for surge control and repository regulation future, streams should be anticipated with precipitation spillover models. Various precipitation overflow models exist for era of stream, determining and different purposes.

The issue of assessing overflow from a tempest occasion is one of the key focuses in hydrologic demonstrating. Estimation of Direct precipitation spillover is constantly effective yet is unrealistic for the greater part of the area at coveted time. Established systems as the judicious strategy or the Soil Conservation Service bend number methodology are still generally utilized as a part of practice. Because of the many-sided quality of the hydrological forms and the bowl attributes, physically based disseminated models utilizing GIS and Remote detecting strategies are getting to be prominent. Utilization of remote detecting and GIS innovation can be utilized to beat the issue of routine strategy for evaluating overflow brought on because of precipitation. In this paper, altered Soil conservation System (SCS) CN model is utilized for precipitation overflow estimation that considers parameter like slant, vegetation spread, range of watershed.

A. Rainfall runoff model

A rainfall-runoff model is a mathematical model describing the rainfall - runoff relations of a catchment area, drainage basin or watershed. More precisely, it produces the surface runoff hydrograph as a response to a rainfall hydrograph as input. In other words, the model calculates the conversion of rainfall into runoff. A rainfall runoff model can be really helpful in the case of calculating discharge from a basin. The transformation of rainfall into runoff over a catchment is known to be very complex hydrological phenomenon, as this process is highly nonlinear, time-varying and spatially distributed. Over the years researchers have developed many models to simulate this process. Based on the problem statement and on the complexities involved, these models are categorized as empirical, black-box, conceptual or physically-based distributed models. Physically based distributed models are very complex and required too many data and tedious for the application purpose. The conceptual models attempt to represent the known physical process occurring in the rainfall-runoff transformation in a simplified manner by way of linear or nonlinear mathematical formulations but their implementation and calibration is complicated and time consuming. While black-box models, which establish a relationship between input and the output functions without considering the complex physical laws governing the natural process such as rainfall-runoff transformation. The unit hydrograph, which is a linear rainfall-runoff model, is one well-known example of such a relationship.

In this report hydrological forecasting will be done using SCS MODEL and with it incorporating GIS & Remote sensing in it.

A. Input required for all models

The inputs required for making of rainfall runoff models can be as follows;

- Rainfall time series
- Drainage area
- Evaporation rate
- Infiltration rate

Watershed characteristics that might be represented in rainfall runoff models are as follows;

- Soil hydrologic properties
- Vegetation cover
- Watershed topography
- Stream channel network
- Characteristics of groundwater aquifers
- Antecedent soil moisture content

B. Objectives

The main objectives of this study is to analyse and forecast the hydrological parameters involved in hydrological cycle using scs-cn model and incorporating it with GIS and remote sensing
The objective of the study can be summarized as follows.

- Anlaysis of rainfall runoff relationship.
- Study of influence of different factors on runoff.
- Compute runoff model using SCS-CN.

II. LITERATURE SURVEY

A. The Hydrological Cycle

The central focus of any hydro-meteorological study is the hydrological cycle shown in Figure 2.1. The hydrological cycle has no beginning or end and its many processes occur continuously (Chow et al., 1988). In describing the cycle, the water evaporates from ocean and land surface to become part of atmosphere; water vapour is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans. Precipitated water may be intercepted by vegetation, becomes overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow and discharges into streams as surface runoff. The infiltrated water may percolate deeper to recharge groundwater, later emerging as spring and seeping into streams to form surface runoff and finally flowing into the sea or evaporating into the atmosphere as the hydrological cycle continues.

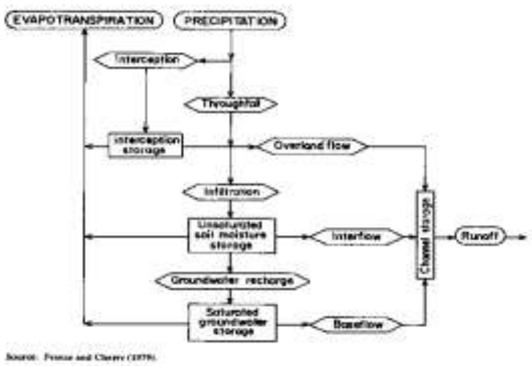

Figure 2.1 Elements of the hydrologic cycle (freeze and cherry 1979)

It is noted that though the concept of the cycle seems simple, the phenomena are enormously complex and intricate. It is not just one large cycle but it is rather composed of many interrelated cycles of continental, regional and local extent. The major achievement and objectives of the rainfall runoff modelling is thus to study a part (section) of the hydrological cycle, namely the land phase of the hydrological cycle on a catchment scale. Then the problem becomes to express the runoff from the catchment as a function of the rainfall and other catchment characteristics.
Considering the land phase of the hydrological cycle, any conceptual model predicates its effort on an expansion of the basic water balance or continuity equation that is:

$$I - O = \frac{ds}{dt} \qquad (2.1)$$

where I is the input to the system (Precipitation), and O is output from the system (evaporation, stream and groundwater flow) and the ds/dt is the change in soil moisture. The main processes encompassed are precipitation, evapotranspiration, interception, infiltration, subsurface flow and streamflow. It is evident that before any modelling effort can be performed, one has tounderstand the above physical processes, their extent of effect on the abstraction from or addition of water to a catchment.
SINCE rainfall data is generally in abundance in comparison to runoff data, the attempt has always been to convert rainfall to runoff. Probably the first try to create a model that estimates maximum discharge was made over 150 years ago. Hydrologists of that time did not have modern calculation methods and their capacity of solving mathematical problems was limited. The Irish engineer Thomas James Mulvaney (1822-1892) published a simple equation to determine the maximum discharge for a quantity of rainfall in a catchment.
For many water resources projects, it is important to predict a runoff hydrograph for a given rainfall. The prediction can be carried out using a deterministic rainfall runoff model. There is however, a wide variety of deterministic rainfall runoff models with different levels of complexity. These models can be classified into empirical, conceptual and physically based, where empirical models are the simplest and physically based models are the most complex. Owing to the wide variety of models available, there is confusion over which is the best type of model to use.

B. Types of models

Hydrological models can be classified in many ways. Depending upon the phenomenon of importance , they are classified as event based models i.e. to stimulate a flood peak resulting due to single or multiple storms events or continuous models i.e., to stimulate the flow processes over a season or over a number of years preferably to develop rainfall runoff relationship on daily basis. The other classification is based on the mathematical theory being applied and are classified as deterministic models which seek to stimulate the physical processes in the catchment wherein rainfall gets transformed into runoff or stochastic models wherein the hydrological time series of a single or several variables such as rainfall , evaporation , stream flow etc., involving distribution in probability are applied . Also, a combined or hybrid models wherein bothdeterministic and stochastic approaches are selectively being employed are proving to be more successful

C. Modeling concept and classification

Based on the assumptions and concepts formulating the structure of the transformation (Operator) the resulting models may have different forms. According to Clarke, 1973 mathematical models may be classified in to four main groups.
1) Stochastic - Conceptual
2) Stochastic - Empirical
3) Deterministic - Conceptual
4) Deterministic – Empirical

D. Rational model

The equation (1.1) published by Mulvaney in 1851 is the following:

$$Q = C \cdot A \cdot R \qquad (1.1)$$

The equation only predicts the hydrograph peak, not the whole hydrograph. The maximum discharge Q is predicted by the equation for a rainfall with the duration at least equal to the concentration time of the catchment.
The input variables are:

- Catchment Area A
- Maximum catchment average rainfall intensity R
- An empirical coefficient C. The coefficient is the proportion of rainfall that contributes to runoff.

E. Unit hydrograph

Unit hydrograph is a mathematical model of the response of catchment o various effective storms.
Following points are taken into account for Unit Hyydrograph:

- Whole hydrograph rather than just peak flow
- Requires estimate of excess rainfall as input
- Shape of hydrograph determined for "unit" storm (e.g. 1-inch excess RF)
- Hydrograph re-scaled for larger/longer storms

F. Conceptual linear reservoir models

Conceptual models depend heavily on theory to interpret phenomena rather than to represent the physical processes, e.g. the models based on the probability theory

- Flow equation: Q = A x S

Where Q = runoff or stream discharge;
A= response factor; and S = water storage

- Continuity equation: R = Q + ds/dt

Where R = recharge;
ds = change inStorage; and
dt = time increment

- Runoff equation: Q2 = Q1 e-A(t2-t1) + R e-A(t2-t1)

G. Physically-based models

Physical models are developed on the principles of simplitude applied to small scale models. A laboratory model of a dam spillway on a scale of 1: 80 may be a physical model of a reservoir.
Following are the physically based models:

- Stanford watershed model (Crawford and Linsley1966)
- MIKE-SHE
- DHSVM

H. TOP MODEL (Bevenand Kirkby1979)

TOPMODEL is a rainfall runoff model that bases its distributed predictions on an analysis of catchment topographythe model predicts saturation excess and infiltration excess surface runoff and subsurface stormflow.
Following are the points taken into consideration:

- Based on water accumulation concept
- Topographic Index (TI)
- TI = ln [contributing area / tan (slope)]

I. Application of rainfall-runoff models

The tasks for which rainfall-runoff models are used are diverse, and the scale of applications ranges from small catchments, of the order of a few hectares, to that of global models (Weather, Sorooshian and Sharma, 2008).Typical tasks for hydrological simulation models include: modelling of gauged catchments (e.g. modelling of river behaviour, real-time flood forecasting, adjusting and evaluation of water resource management); runoff estimation of ungauged catchments; effects of rivers' activity (erosion, sedimentation); prediction of catchment response to changed conditions (e.g. land use change, climate change) and water quality investigations (e.g. nutrients, migration of microbes, salinity and alkalinity of soils, acid precipitation, nonpoint source pollution).In contemporary practise, rainfall-runoff models are standard tools routinely used for hydrological investigations in engineering and environmental science. Also the topic of watershed management gains an increased attention. Some of the models are also employed in military operations (Singh and Frevert, 2006).

J. The SCS curve number method

The **SCS curve number** method is a simple method used on large scale for determination of the approximate runoff value corresponding to a certain rainfall quantity in a certain area. Although the method is designed for a single storm, it can be scaled to calculate the annual values for runoff in an area.
The SCS-CN method was developed in 1954 and it is documented in Section 4 of the National Engineering Handbook (NEH) published by Soil Conservation Service (now called the Natural Resources Conservation Service), U.S. Department of Agriculture in 1956. The origin of the method was probably based on the proposal of Sherman (1942, 1949) on plotting direct runoff versus storm rainfall. The subsequent work of Mockus (1949) focused on estimating surface runoff for ungauged watersheds using in-formation on soil, land use, antecedent rainfall, storm duration, and average annual temperature. Andrews (1954) also developed a graphical procedure for estimating runoff from rainfall for combinations of soil texture and type, the amount of vegetative cover, and conservation practices.
All of these are combined into what is referred to as the soil-cover complex or soil vegetation- land use complex (Miller and Cronshey 1989). Thus, the empirical rainfall-runoff relation of Mockus (1949) and the soil-vegetation-land use complex of Andrews (1954) constituted the basis of the SCS-

CN method described in the Soil Conservation Service (SCS) National Engineering Handbook Section 4 (USDA-SCS 1985). The runoff curve number (also called a curve number or simply CN) is an empirical parameter corresponding to different soil-vegetation-land use combinations. The SCS Curve number 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 named the Curve Number are mandatory. The Curve Number (CN) value can be obtained from the hydrologic soil group, landuse and moisture conditions of the soil, the
last two values being more important.

The SCS-CN method is based on the water balance equation and two fundamental hypotheses (Mishra and Singh 2003).

The water balance equation states that:

$$P = Ia + F + Q \quad (1.4)$$

The first hypothesis states that the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention:

$$\frac{Q}{P-Ia} = \frac{F}{S} \quad (1.5)$$

The second hypothesis states that the amount of initial abstraction is some fraction of the potential maximum retention.

$$Ia = \lambda S \quad (1.6)$$

Where:

P = total precipitation (mm) ;

Ia = initial abstraction (mm);

F = cumulative infiltration excluding Ia (mm);

Q = direct runoff (mm);

S = potential maximum retention or infiltration;

The current version of the SCS-CN method presented in NEH4 considers λ equal 0.2 for the usual practical applications. As the initial abstraction component accounts for factors like surface storage, interception and infiltration before runoff begins, λ can also take other values depending on the application. In theory, λ can take any value between 0 and ∞ (Mishra and Singh1999) but most of the current applications use the suggested value of 0.2. Combining equations (1.5) and (1.6), the main equations for the SCS Curve Number Method are obtained:

$$Q = \frac{(P-Ia)^2}{(P-Ia+S)} \quad (1.7)$$

$$Ia = 0.2 \times S \quad (1.8)$$

By replacing Ia in equation (3), an equation with only two parameters is obtained.

$$Q = \frac{(P-0.2\,xS)^2}{(P-+0.8\,S)} \quad (1.9)$$

The potential maximum soil retention, S, can be obtained according to the CN value.

$$S = \frac{25400}{CN} - 254 \quad (1.10)$$

The equations are based on the trends observed in data obtained from the study areas, so they are empirical equations rather than equations based on physical laws. The CN is a Hydrologic parameter that relies implicitly on the assumptions of extreme runoff events and Represents a convenient representation of the potential maximum soil retention, S (Ponce and Hawkins 1996). The Curve Number (CN) is used in the determination of S and values for the CN for different land use, soil types and soil moisture conditions can be found in tables (table 1.2). The origin of the original CN array tables seems to be lost; Rallison (1980) and Fennessey(2001b) have published the only known papers indicating what watersheds the original data may have come from.

However, there also appears to be a misconception as to the scale of data that were actually used to develop the CN array table, or the CN's accuracy for use in making peak runoff rate estimates. The lack of information on the origins of the method and the lack of scientific testing of the results raises some doubts when very accurate results are needed, but the method is used everywhere in the world when a simple way to estimate some discharge values is needed.

The SCS Curve Number method was implemented in GIS by different authors (Crăciunet al.; Halley et al.; Zhan and Min-Lang) using the ArcView or ArcGIS products. The usage of GIS systems for the SCS Curve Number method allows for automatic calculation of the CN parameter based on spatially distributed data obtained from measurements in the field or through remote sensing.

Water infiltration capacity of the soil was classified by the USDA-SCS into four classes called hydrologic soil groups (Mihalik et al. 2008; Matziaris et al. 2005) Every type of soil has a Hydrologic Soil Group (HSG) that indicates an infiltration capacity and a rate of water transmission through the soil. The four types of HSGs are presented in table 1.1. The HSG valuesare based on the intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet) and are valid for unfrozen soil. When assigning a HSG to a soil, bare soil surface is considered. 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.

K. Soils

In determining the CN, the hydrological classification is adopted. Here soils are classified into four classes A, B, C and D based on the infiltration and other characteristics. The important soil characteristics that influence the hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and the permeability. Following is a brief description of four hydrologic soil groups:

- Group A (LOW RUNOFF POTENTIAL): Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sand or gravels. These soils have high rate of water transmission.
- Group B (MODERATELY LOW RUNOFF POTENTIAL): Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.

- Group C (MODERATELY HIGH RUNOFF POTENTIAL): Soils having low infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.
- Group D (HIGH RUNOFF POTENTIAL): Soils having low infiltration rates when thoroughly wetted and consisting chiefly of clay soils with high swelling potential, soil with permanent high water table, soils with clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

L. Antecedent moisture condition (AMC)

AMC refers to the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial abstraction and infiltration and are governed by AMC. For purposes of practical application three level of AMC are recognized by SCS as follows:

- AMC-I: Soils are dry but not to wilting point. Satisfactory cultivation has taken place.
- AMC-II: Average conditions
- AMC-III: Sufficient rainfall has occurred within the immediate past five days. Saturated soil conditions prevail.

TABLE 2.1: ANTECEDENT MOISTURE CONDITIONS (AMC) FOR DETERMINING THE VALUES OF CN

AMC TYPE	**Total rain in previous 5 days**	
	Dormant season	**Growing season**
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

TABLE 2.2. RUNOFF CN FOR DIFFERENT HYDROLOGIC SOIL

Cover			Hydrologic groups			
Land use or cover	Treatment or practice	Hydrologic condition	A	B	C	D
1	2	3	4	5	6	7
Fallow	Straight row	-----	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
Row crops	Straight row	Good	67	78	85	89

III. CONCLUSION:

According to the study closed Soil conservation System (SCS) CN model can be utilized for precipitation overflow estimation that considers parameter like slant, vegetation spread, zone of watershed rather than customary techniques and could likewise give better results by utilizing Remote detecting and GIS.

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