UNIVERSITI PUTRA MALAYSIA

CURVE NUMBER METHOD RUNOFF ESTIMATION IN THE KARDEH WATERSHED, IRAN

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The major problem in the assessment of the relationship between rainfall and runoff occurs when a study is carried out in ungauged watersheds, in particular, the absence of hydro-climatic data. This study aims to determine the runoff depth using NRCS-CN method with GIS and the effect of slope on runoff generation in the Kardeh watershed, located between 59° 26′ 3″ to 59° 37′ 17″ E longitude and 36° 37′ 17″ to 36° 58′ 25″ N latitude, about 42 km north of Mashhad, Khorasan Razavi province, Iran. The US Department of Agriculture, Natural Resources Conservation Service Curve Number (USDA-NRCS-CN) method was applied for estimating the runoff depth in the semi-arid Kardeh watershed. Hydrologic soil group, land use and slope maps were generated in GIS environment. The curve number values from NRCS standard tables were assigned to the intersected hydrologic soil groups and land use maps to generate CN values map. The curve number method was followed to estimate runoff depth for selected storm events in the watershed. Effect of slope on CN values and runoff depth was determined. Estimated runoff depth and slope-adjusted runoff depth were statistically compared with the corresponding observed runoff data. Pair wise comparisons by the *t*-test, Pearson correlation analysis and percent error were used to investigate the accuracy of estimated data and relationship between estimated and observed runoff depth. The results showed that there was no significant difference between the means of observed and estimated runoff depths ($P > 0.05$). Fairly positive correlations were detected between observed with estimated runoff and slope-adjusted runoff depth ($r = 0.55$; $P < 0.01$) and ($r = 0.56$; $P < 0.01$), respectively. About 9 % and 6 % of the estimated and slope-adjusted runoff values were within ±10% of the recorded values, respectively. In addition, about 43 and 37 percent of the estimated and slope-adjusted values were in error by more than ±50 %, respectively. Statistical analysis indicated that percent error of estimated slope-adjusted runoff depth was significantly ($p < 0.01$) lower than the percent error of estimated runoff depth. This decline in percent error can be explained by the role of slope in runoff generation in steep slope watershed. The results of study indicated that the CN is an effective method for homogenous watersheds in terms of land use, soil, and climate rather than heterogeneous ones like Kardeh watershed. In such watersheds it can be employed with about 60 percent accuracy only for management and conservation purposes however and probably not for computation of design floods.

Keywords: Curve Number, Geographic Information System, Kardeh watershed, Slope-adjusted runoff depth

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LIMPASAN KAEDAH CURVE NUMBER ESTIMASI DI KARDEH TADAHAN, IRAN

Oleh

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Penilaian keatas hubungkait diantara turunan hujan dan kelarian air permukaan adalah penting and satu isu yang komplek dalam bidang haidrologi. Masalah utama berlaku apabila sesuatu kajian dibuat keatas hubungankait diantara turunan hujan dan kelarian air permukaan didalam tadahan air yang belum dicerap kerana terdapat banyak kawasan tadahan air tanpa data iklim hairdo. Objektif kajian ini adalah untuk menentukan kedalaman kelarian air permukaan menggunakan kaedah NRCS-CN bersama GIS serta mengkaji kesan kecerunan keatas kelarian aliran air permukaan. Kajian ini dijalankan di Tadahan Air Kardeh, terletak 42 km keutara Mashhad, Jajahan Khorasan, Iran. Kawasan kajian ini berkoordinat diantara 59º 26´ 3˝ ke 59º 37´ 17˝ T longitud dan 36º 37´ 17˝ ke 36º 58´ 25˝ U latitud. Sehubungan itu, Kardeh “USDA_NRCS_CN” (US Department of Agriculture, Natural Resources Conservation Service Curve Number) telah digunakan dalam kajian ini untuk menganggarkan kedalaman kelarian air permukaan dalam satu tadahan air separa kering. Peta kumpulan tanah haidrologi, gunatanah dan

kecerunan dijana dalam persekitaraan GIS. Nilai curve number telah diberikan kepada peta kumpulan haidrologi tanah dan gunatanah yang telah dikhususkan untuk kawasan kajian. Kaedah curve number seterusnya menganggarkan kedalaman kelarian air permukaan untuk “storm events” yang terpilih dalam kawasan tadahan air dikaji. Kesan kecerunan keatas CN number dan kedalaman aliran air permukaan juga telah ditentukan. Anggaran kedalaman aliran air permukaan dan kedalaman air permukaan yang telah ubahsuai dengan nilai kecerunan telah dibandingkan secara statistik dengan data aliran air permukaan sebenar untuk kawasan kajian. Perbandingan “Pair wise” telah dilakukan melalui t-test dan “Pearson correlation analysis” dan “Percent error” untuk mengetahui sebarang hubungkait antara kedalaman kelarian air permukaan anggaran dan nilai sebenar. Keputusan kajian menunjukkan bahawa tidak ada perbezaan yang signifikan antara cara mengamati dan limpasan dianggarkan kedalaman ($P > 0.05$). Cukup korelasi positif dikesan antara diamati dengan anggaran limpasan dan lereng-disesuaikan kedalaman limpasan ($r = 0.5$; $P < 0.01$) dan ($r = 0.56$; $P < 0.01$), masing-masing. Sekitar 9% dan 6% daripada anggaran dan lereng-nilai-nilai ±10% daripada nilai tercatat masing-masing. Dilimpasan disesuaikan dalam samping itu, sekitar 43 dan 37 peratus daripada anggaran dan lereng-nilai-nilai ±50%, masing-masing. Yang disesuaikan dalam kesalahan oleh lebih daripada Analisis statistik menunjukkan bahawa percent error daripada anggaran lereng-kedalaman limpasan disesuaikan secara signifikan ($p < 0.01$) lebih rendah daripada percent error daripada anggaran kedalaman limpasan. Penurunan kesalahan peratus boleh dijelaskan oleh peranan generasi cerun limpasan daerah aliran sungai di cerun curam. Keputusan kajian menunjukkan bahawa CN adalah kaedah yang berkesan untuk homogeneous tadahan dalam hal penggunaan tanah, tanah, dan iklim daripada yang heterogenous seperti Kardeh tadahan. Dalam tadahan itu boleh digunakan dengan akurasi sekitar 60 peratus hanya untuk tujuan pengurusan dan pemuliharaan namun dan mungkin bukan untuk perhitungan desain banjir.

Keywords: Curve Number, Sistem Informasi Geografis, Kardeh tadahan, Cerun-disesuaikan kedalaman limpasan

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I hereby declare that the thesis is my original work except for quotations and citation, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at University Putra Malaysia or at any other institutions.

MAHBOUBEH EBRAHIMIAN

Date:

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LIST OF ABBREVIATIONS

3D	Three Dimensional
AMC	Antecedent Moisture Condition
ANN	Artificial Neural Network
ARC	Antecedent Runoff Condition
CN	Curve Number
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
FHWA	Federal High Way of America
GIS	Geographic Information System
GIUH	Geomorphological Instantaneous Unit Hydrograph
ha	Hectare
hr	Hour
ILWIS	Integrated Land and Water Information System
ICAR	Indian Council of Agricultural Research
LULC	Land Use/Land Cover
mm	Millimeter
min	Minute

NDVI	Normalized Difference Vegetation Index
NCC	National Cartography Centre
NEH-4	National Engineering Hand book Section 4
NRCS	Natural Resource Conservation Service
RS	Remote Sensing
SCS	Soil Conservation Service
SPSS	Statistical Program for Social Science
TIN	Triangular Irregular Network
U.B.C	University of British Columbia
UH	Unit Hydrograph
USDA	United States Department of Agriculture
WHAT	Web-based Hydrograph Analysis Tool

Chapter 1

Introduction

1.1 General

The annual average precipitation of Iran ranges from less than 50 mm in the deserts to more than 1500 mm along the coast of Caspian Sea. The average annual rainfall is 252 mm and approximately 90% of the country is arid or semiarid. Periodic droughts are a normal phenomenon and water shortage is a frequent problem in the arid regions. As such, water is a priority issue at national and individual levels in Iran.

In spite of water deficiency in arid and semiarid areas, there are many flash floods every year in such areas. That is because of high rainfall intensity although unevenly distributed in these areas. In some arid and semi arid regions what causes flood is lack of water resources management. Thus appropriate planning for water resources management is imperative in water deficiency regions. Lack of adequate consideration to watershed management in most areas in Iran not only cause water deficiency in parts of watersheds but also generate sever floods downstream. It has been reported in the past that changes to the upstream portion of watersheds affected hydrologic and hydraulic characteristics of the downstream portion of the basin.

A detail analysis of surface runoff is highly important for flood control, stream flow forecasting and reservoir design. Large amount of precipitation are lost as surface runoff due to lack of watershed management practices, poor vegetation cover, and continuation of inappropriate land use and land degradation.

In addition to the above problems, most basins in Iran do not have sufficient numbers of gauges to record rainfall and runoff volume. Scarcity of reliable recorded data therefore is another serious problem which planners and researchers face for the analysis of the hydrology of the arid regions.

While having runoff data is essential in all watershed development and management plans, very little work has been previously done in the watersheds of Iran in estimating runoff volume from rainfall in ungauged watersheds. Estimating basin runoff in ungauged watersheds is of tremendous importance in Iran.

There are several approaches to estimate ungauged basin runoff. Examples are the University of British Columbia Watershed Model (UBCWM), Artificial Neural Network (ANN), Soil Conservation Service Curve Number model (SCS-CN), and Geomorphological Instantaneous Unit Hydrograph (GIUH). Among these methods, the SCS method (now called Natural Resources Conservation Service Curve Number method (NRCS-CN)) is widely used because of its flexibility and simplicity. In this method, the runoff volume estimation takes into consideration some of the watershed parameters including land use, discharge, soil characteristics; and climatic parameters as rainfall quantity. The method combines the watershed parameters and climatic factors in one factor called the Curve Number (CN).

Conventional methods for runoff measurement are difficult, time consuming and error-prone because of the vastness of basins and inaccessible terrain in many places. Thus, we need to use new tools such as Geographic Information System (GIS), to generate reliable runoff records for conserving soil and water resources in watershed planning.

This study emphasizes the use of GIS technique to develop a data base containing all the information of the study watershed for direct runoff volume estimation using the NRCS-CN model. GIS is used in hydrologic modeling to facilitate processing, management and interpretation of hydrologic data. The ability of GIS to combine different types of data such as land use, land cover, soil and slope has led it to significant increase in hydrological applications. GIS provides efficient tools for data input into database, retrieval of selected data for further processing and software modules which can analyze and manipulate the data in order to generate desired information on specific forms. Integration of GIS and curve number increases the accuracy and provide quick estimation of runoff values. The essence of this study is the application of GIS and NRCS-CN as a simple model to estimate runoff values in the Kardeh basin, Iran.

1.2 Problem statement

Due to serious soil erosion and water deficiency problems in most areas of Iran, natural resources conservation is a vital issue. Despite this pressing issue, few studies have been carried out in rainfall-runoff modeling in Iran. While accurate data is necessary for appropriate management and planning of watershed resources, few drainage basins in

Iran have well-established hydrometric stations. Conventional methods of runoff measurement are costly, time consuming and difficult because of inaccessible terrain in many of the watersheds in Iran. Thus, the use of new tools, for instance GIS, to generate supporting land-based data for conserving soil and water resources in watershed planning is very much needed.

1.3 Objectives

The aim of this study is to evaluate the use of NRCS curve number method for estimating runoff depth in the Kardeh watershed in Iran. The specific objectives include:

i. To determine the ranges of probable CN values for the study watershed.

ii. To determine the effect of slope of watershed on CN values and runoff generation.

Finally the accuracy between estimated and observed runoff data will be tested statistically. If the study finds accurate estimated runoff depth compared with observed runoff, then the result can be applied for adjacent watersheds.

Chapter 2

Literature Review

2.1 Introduction

This chapter is a review of the literature on runoff estimation, with particular reference to the NRCS-CN method. The various factors influencing runoff generation and spatial distribution are discussed in sub sections in an attempt to synthesize key findings of studies with regard to the intent of this study.

2.2 Surface runoff

Surface runoff is the water running over land resulting from the infiltration excess during a rainfall (or snow melt) event. Horton (1933) was the first to study this process, and proposed an infiltration-capacity-based model referred to as the Hortonian overland flow. Later, Dunne (1970, 1978) proposed a saturation-based (saturation excess) runoff generation process and outlined the importance of a rising water table in initiating and sustaining surface runoff (cited by Ajayi, 2004).

Plot-based measurement and the measurement of rainfall intensity with appropriate rain gauges were the basis for better insight into the process of surface runoff and understanding of the factors influencing that process at a small scale.

2.2.1 Factors affecting runoff

The most important factors affecting direct runoff are the rainfall depth and duration, and although climatic, physiographic conditions and land use are also important influences at the catchment scale (Kovář, 2006). The combined effect of rainfall intensity and the physical properties of the soil surface have significance role in surface runoff generation process. These factors interact at the same time and the extent of each of them depends on the conditions of the study area.

2.2.1.1 Climatic factors

There are various factors of climate influencing runoff in a watershed. Some of these factors are:

- Type of precipitation (rain, snow, sleet, etc.);
- Rainfall intensity;
- Rainfall amount;
- Rainfall duration;
- Distribution of rainfall over the drainage basin;
- Direction of storm movement;
- Precipitation that occurred earlier and resulting soil moisture;
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season.

2.2.1.2 Watershed characteristics affecting runoff

Runoff generation process in a watershed can be affected by different characteristics of the catchment including:

- Land use;
- Vegetation;
- Soil type;
- Drainage area;
- Basin shape;
- Elevation;
- Topography, especially the slope of the land ;
- Drainage network patterns;
- Ponds, lakes, reservoirs, sink, etc. in the basin, which prevent or delay runoff from continuing downstream.

2.2.2 Runoff depth estimation methods

The assessment of relationship between rainfall and runoff is an important and complex issue in hydrology. In this respect, much research has been carried out and different methods have been presented to estimate runoff depth at watershed scale (Table 2.1).