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REGRESSION ANALYSIS OF RAINFALL AND RUNOFF PROCESS OF A TYPICAL WATERSHED

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ABSTRACT

The integration strategy for a watershed can be carried out by various procedures. However a first step is usually a resource survey or inventory. This attempts to answer the question of the supply and demand for resources both natural and human resources. Depending upon the area involved, a survey may include socio-economic characteristics, soil characteristics, land capacity/suitability classifications, hydrological assessment including climate characteristics, water use and other parameters as needed. Runoff is one of the important integral part of the integrated watershed management, so for this estimation of runoff is required.

The rainfall-runoff process in a catchment is a complex and complicated phenomenon governed by large number of known and unknown physiographic factors that vary both in space and time. Application of mathematical modeling techniques to the constituent processes involved in the physical processes of runoff generation has led to better understanding of the processes and their interaction. Conventional hydrological models for the prediction of runoff particularly over a basin require considerable hydrological and meteorological data. Collection of these data is expensive, time consuming and difficult process. Remote Sensing technology and Geographical Information Systems (GIS) can augment the conventional methods to a great extent in rainfall runoff studies. Remote Sensing technology and Geographical Information Systems (GIS) can augment the conventional methods to a great extent in rainfall runoff studies.

In the present study a small agricultural watershed rainfall-runoff model was chosen. The advantage of formulating this regression analysis for the watershed is that it enables to generate the runoff. Once the regression analysis is formulated the same can be applied to any watershed to estimate the runoff, even if the sub catchment is ungauged.

Keeping these points in view, the rainfall-runoff model, regression nalysis has been formulated and developed. It contains three modules namely Time of Concentration, Rainfall and Soil Moisture module for the estimation of daily runoff. Pamena – I Watershed, Chevella Mandal, Rangareddy District, Andhra Pradesh, India has been considered for the study.

It is concluded that the regression analysis developed is a fairly good model and it is comparable with the standard models considered in the present study viz., SCS-CN and TR-55 Models.

Key words: Soil Conservation Service, Time of Concentration, Technical release, Mathematical Modeling, Remote Sensing.

1. INTRODUCTION

Watershed management is the rational utilization of land and water resources for optimum production with minimum hazard to natural resources.[14] It essentially relates to soil and water conservation in the watershed which means proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, flood protection and sediment reduction and increasing productivity from all land uses.

The objectives of managing a watershed should be clearly and precisely spelt out so that a correct approach can be developed. [6] There can be various descriptions of the objectives of watershed management, depending on the emphasis given in the proposed management program.

i. To rehabilitate the watershed through proper land use and protection/conservation measures in order to minimize erosion and simultaneously increase the productivity of the land and the income of the farmers.
ii. To protect, improve or manage the watershed for proper water resources development (domestic water supply, irrigation, hydro-power etc.)
iii. To manage the watershed in order to minimize natural disasters such as flood, drought, landslides etc.
iv. To develop rural areas in the watershed for the benefit of the people and economies of the region.
v. A combination of the above.

Watershed modeling is a comprehensive program to determine runoffs using standard techniques. Model flood control structures such as detention basins with various outlet structures, use actual or synthetic rainfall distributions. [4] Watershed modeling includes rainfall maps for the entire area to calculate intensity duration frequency relationships. The rainfall-runoff process in a watershed is a complex and complicated phenomenon governed by large number of known and unknown physiographic factors that vary both in space and time. [8] The rain falling on a catchment undergoes number of transformations and abstractions through various component processes such as interception, detention, transpiration, overland flow, infiltration, interflow, percolation, sub-base flow, base flow etc., and emerges as runoff at the catchment outlet. [10] Application of mathematical modeling techniques to the constituent processes involved in the physical processes of runoff generation has led to better understanding of the processes and their interaction.

2. REGRESSION ANALYSIS

The goal of regression analysis is to determine the values of parameters for a function
that cause the function to best fit a set of data observations that you provide. In linear regression, the function is a linear (straight-line) equation.

As with correlation, regression is used to analyze the relation between two continuous (scale) variables. However, regression is better suited for studying functional dependencies between factors. The term functional dependency implies that X partially determines the level of Y. [2] In addition, regression is better suited than correlation for studying samples in which the investigator fixes the distribution of X.

Regression analysis is used to predict a continuous dependent variable from a number of independent variables. If the dependent variable is dichotomous, then logistic regression should be used. (If the split between the two levels of the dependent variable is close to 50-50, then both logistic and linear regression will end up giving similar results.) [5] The independent variables used in regression can be either continuous or dichotomous. Independent variables with more than two levels can also be used in regression analyses, but they first must be converted into variables that have only two levels. This is called dummy coding and will be discussed later. Usually, regression analysis is used with naturally-occurring variables, as opposed to experimentally manipulated variables, although you can use regression with experimentally manipulated variables.[15] One point to keep in mind with regression analysis is that causal relationships among the variables cannot be determined. While the terminology is such that we say that X "predicts" Y, we cannot say that X "causes" Y.

Assumptions of regression

Number of cases

When doing regression, the cases-to-Independent Variables (IVs) ratio should ideally be 20:1; that is 20 cases for every IV in the model. The lowest your ratio should be is 5:1 (i.e., 5 cases for every IV in the model).

Accuracy of Data

If you have entered the data (rather than using an established dataset), it is a good idea to check the accuracy of the data entry. If you don't want to re-check each data point, you should at least check the minimum and maximum value for each variable to ensure that all values for each variable are "valid." [3] For example, a variable that is measured using a 1 to 5 scale should not have a value of 8.

3. STUDY AREA

Pamena – I Watershed which is the part of Pamena village falls under the agro-climatic zone V of Andhra Pradesh which is designated as North Telangana agro climatic zone. The village is 6 km away from Chevella located on Shabad road and in the southern part of Ranga Reddy district.(Source: Action plan for Watershed Development Program in Pamena – I Watershed, Chevella Mandal, Ranga Reddy District, A.P.). [1] The village lies between longitudes 78º 06’ – 78º 09’ and latitudes 17º 15’30’’ – 17º 17’30’’ falling in Survey of India toposheet no.56 K/3. Pamena-I Watershed has a geographical area of 500 ha. The study area with drainage lines on toposheet no. 56 K/3 with a scale of 1: 25000. The study area on satellite imagery of Indian Remote Sensing (IRS) - 1D, Linear Imaging Self-scanning Sensor (LISS)-III & PAN (Panchromatic) merged map is shown in Figure 1. [13] The distribution of rainfall is unequal and major part of annual rainfall occurs in a few months due to South West monsoon. Early withdrawal of monsoon results in crop failures and makes agriculture a gamble.

4. DATA COLLECTION AND ANALYSIS

Rainfall The rainfall is the source of all water in the form of rain. The watershed mainly experiences the southwest monsoon. The rainfall in the non-monsoon period is insignificant. The average annual rainfall in the basin is 855.00 mm. The south-west monsoon sets in by middle of June. During the monsoon season, heavy to moderate rains alternate with breaks when there is little or no rain. [11] The strength of the monsoon current increases from June to July and remains more or less steady in August and begins to weaken in the month of September**.**

The daily data of rainfall has been collected for the period 1996 to 2005 and the total annual rainfall recorded as 877.6, 741.10, 1050.10, 678.40, 869.40, 840.00, 643.00, 1041.60, 768.00, 1040.60 mm respectively. In this watershed, highest rainfall of 1050.10 mm is recorded in 1998 and lowest of 643 mm in 2002. The watershed experiences predominantly southwest monsoon. The period of June to November has been considered as monsoon period, and December to May has been considered as non-monsoon for hydrological purpose. Monthly Rainfall data for the duration of 10 years i.e. from 1996 to 2005 was presented in Table 1.

Temperature The daily maximum and minimum temperatures in this watershed have been recorded. Daily data has been averaged into monthly data for the period 1996 to 2005. During the ten years (1996 to 2005) the maximum temperature is ranging from a lowest value of

27.8°C (Jan. 1997) to a highest value of 40.9°C (May 1996 & May 2003) and the min. temperature is ranging from 9.6° C (Dec. 2000) to 26.2° C (June2005).

Relative humidity The relative humidity is high mostly during the South-west monsoon and low during the non-monsoon period. The monthly relative humidity is taken as the mean relative humidity of all the days in a given month. During the ten years (1996 to 2005) the relative humidity over the watershed is ranging from a minimum value of 19 % (April 1999 & Feb 2001) to a maximum value of 92 % (September 1996, 1998 & 2005, December 1997 and October 1998).

Wind velocity The watershed is under the influence of South-west monsoon winds with a little influence of North East monsoon winds. The monthly wind velocity is taken as the average of wind velocities of all the days in a month. The wind velocities are observed to be medium throughout the years. The wind velocity is ranging from a maximum of 9.1 kmph during July 1996 & 1997 to a minimum of 0.7 kmph during December 2002. From June to August every year the wind velocity is high, and in the month of July the wind velocity is generally around 7.0 kmph.

Cloud cover The sky is heavily clouded during the South-west monsoons. During the remaining part of the year, the sky is clear or lightly clouded. The daily sunshine hour's data has been collected for a period of 1996 to 2005, and the average monthly sunshine hours per day is calculated by dividing the total sunshine hours recorded during the month by the number of days in the month.

Soils The soils of Pamena –I watershed mainly consist of 48% of black loamy soils, and 44% of black clayey soils with small sandy patches spread over here and there. (Directorate of Census Operations, A.P. 2004 -2005). Due to severe runoff, the soil is cut to great depths causing severe erosion problem as well as loss of nutrients. The excessive rate of erosion is also attributed to the unscientific agricultural practices. In spite of erosion and low fertility, the farmers are practicing cultivation of cotton, sunflower etc. instead of cover crops which is aggravating soil erosion. The farmers are also using high dosage of chemical fertilizers which is not only affecting the quality of soil but also due to high pollution, nitrogen fixing bacteria of soil is lost, ultimately reducing the yield. The high doses of pesticides are also affecting the crop returns.

Runoff Water and its Utilization The village topography is highly undulating with slope ranging from 2 to 8% and the rate of erosion is very high. Most of the rain fall in this area is by South-West monsoon and the mean annual precipitation is 855.00 mm. The onset of monsoon and its distribution is uncertain with breaks at critical periods of crop growth [according to Action plan (1999)] [1]. Heavy down pour occurring in concentrated periods causes severe soil erosion and loss of nutrients. It is observed due to heavy runoff that deep gullies are formed to a depth of 4-6 m.

5. METHODOLOGY

Technical Release - 55 (TR – 55) Model

The model structure, input parameters required for the estimation of daily runoff viz., define the area, specify the flow of runoff to a reach (water path), rain fall data, runoff curve**,** time of concentration and procedure for the estimation of daily runoff were explained in the following sub sections.

Model Structure Technical Release-55 (TR-55) presents simplified procedures for estimating runoff and peak discharges in small watersheds. In selecting the appropriate procedure, consider the scope and complexity of the problem, the available data, and the acceptable level of error.

While this TR -55 gives special emphasis to urban and urbanizing watersheds, the procedures apply to any small watershed in which certain limitations are met. [7] The TR – 55 Model is a Hydrologic model for small watersheds specifically for rainfall – runoff. (USDA, Urban Hydrology for Small Watersheds Natural Resources Conservation Service, Conservation Engineering Division, Technical Release– 55, June1986). [9] TR-55 creates a theoretic rain storm in the computer and assesses how much water runs into the river.

The conversion of rural land to urban land usually increases erosion and the discharge and volume of storm runoff in a watershed. It also causes other problems that affect soil and water. As part of programs established to alleviate these problems, engineers increasingly must assess the probable effects of urban development as well as design and implement measures that will minimize its adverse effects. TR – 55 determines the amount of runoff from smaller watersheds evaluates the size of structure needed to contain runoff and also determines the amount of runoff accumulated from several sub watersheds into an outlet or containment structure.

Time of concentration

Time of concentration is a fundamental watershed parameter. It is used to compute the peak discharge for a watershed. The peak discharge is a function of the rainfall intensity, which is based on the time of concentration. Time of concentration is the longest time required for a drop of water to travel from the watershed divide to the watershed outlet. The Time of Concentration thus calculated using the following equation (1) is taken as input to TR-55 model along with rainfall.

$$t_c = \frac{0.93 L^{0.6} N^{0.6}}{i^{0.4} S^{0.3}} \qquad \text{-------} \quad \textbf{(1)}$$

Where

t_c = Time of Concentration; i = Rainfall intensity; L = Overland flow distance; S = Slope; N = Manning's coefficient

One critical parameter in this model is Time of Concentration (t_c), which is the time, it takes for runoff to travel to a point of interest from the hydraulically most distant point. Normally rainfall duration equal to or greater than t_c is used. Therefore, the rainfall distributions were designed to contain the intensity of any duration of rainfall for the frequency of the event chosen. That is, if the 10-year frequency, 24-hour rainfall is used, the most intense hour will approximate the 10-year, 1-hour rainfall volume.

Parameters required in TR-55 Model

Rainfall and Time of Concentration are the major inputs; in addition there are three parameters namely the area, overland flow and runoff curve number, required as inputs to the model. These three parameters are required for use in TR-55 model to estimate daily runoff from daily rainfall. The concept and description of all these five parameters have been outlined in the following subsections.

Runoff Curve Number

To estimate runoff from storm rainfall, the Runoff Curve Number (CN) method was used. Determination of CN depends on the watershed's soil and cover conditions which the model represents as hydrologic soil group, cover type, treatment, and hydrologic condition.

Curve Number (CN) Calculation

Curve Number is calculated in the following step by step procedure

i) According to Hydrological soil group classification, the soils in the study area belong to Group B.
ii) The Hydrologic condition of the soil is considered to be good.
iii) From the Land use/ Land cover map, different layers such as water, forest, settlements etc., are classified and their area is known.
iv) Runoff curve numbers for different regions are shown in Table 6.3.
v) The land use/ land cover map and soil map were interpreted in command tools of ARC GIS.
vi) The areas of different land use class and soil combinations were obtained.
vii) The weighted value of CN for the watershed is worked out using the formula below.

$$\text{Average curve number} = \frac{\sum(\text{CNi} * \text{Ai})}{\text{A}}$$

Where,

CN_i = Curve Number from 1 to any number N; A_i = Area with Curve Number CN_i.

A = Total area of the watershed.

Soil Conservation Service (SCS) Curve Number Method

Runoff estimation is required for planning and execution of water resource projects. Several methods are available for estimation of runoff. Among them, the USDA Soil Conservation Service Curve Number (SCS – CN) method is the most popular and widely used. Soil Conservation Service (SCS), National Engineering Handbook (1986), Section 4 describes this method. [12] The advantages of this method are its simplicity, predictability, stability and its reliance on only one parameter namely the Curve Number (CN). The land use / land cover classes can be integrated with the hydrologic soil groups of the sub basin in GIS and the weighted CN can be estimated. These estimated weighted CN's for the entire area can be used to compute runoff. The computed runoff values can be checked with the observed data. The main inputs required to the SCS-CN method are delineation of the watershed boundary, preparation of soil map, preparation of land use/land cover thematic map and antecedent moisture condition to estimate daily runoff.

In the SCS - CN method following assumptions are made

i) The initial abstraction is assumed to be equal to 20% of the potential maximum retention (S).
ii) The estimated curve number must be greater than 40.
iii) Rainfall duration should be greater than Time of concentration (t_c).
iv) Rainfall should be uniformly imposed on the watershed.
v) Each watershed subdivision must be hydrologically homogeneous.
vi) The CN values provided in TR-55 manual (SCS, 1986) are developed based on the average antecedent runoff estimation.

Estimation of Daily Runoff using GIS based SCS Method Estimation of runoff is required for planning, developing and managing the watershed resources and irrigation scheduling. The water management may be carried out efficiently by knowing the seasonal and annual runoff from the watershed. There are a number of empirical methods for runoff estimation. Soil Conservation Service-Curve Number method developed by United States Department of Agriculture and Soil Conservation Service (USDA –SCS) to estimate the direct runoff from an ungauged watershed is the most commonly used empirical method. [9] This is popular due to its simplicity, flexibility and requirement of a single parameter called Curve Number (CN) in the computation of runoff. A lumped parameter rainfall-runoff model is constructed based on the basis of the SCS Curve Number technique. The quality of this model is improved by incorporating the spatial variation of watershed characteristics using Remote Sensing and GIS. The runoff curve number AMC II) for hydrologic soil cover complexes and curve number adjustments for antecedent soil moisture conditions (AMC I & AMC II) for Indian conditions are chosen from the information presented in the Handbook of Hydrology (1972). The daily rainfall database of the watershed (1996-2005) and the curve numbers corresponding to different land use and hydrological soil cover complex are given as inputs and the results are obtained. The curve number coverage for AMC II was derived to study the spatial variation of runoff potential of the watershed. By overlaying mini watershed map the weighted CN for each mini-watershed is computed. From the weighted CN values, the runoff potential of mini watersheds are categorized as very high, high, moderate and low.

6. RESULTS AND DISCUSSIONS

Analysis of Rainfall and Comparison of Estimated Runoff from SCS-CN Method with Observed Runoff

Comparison between variation of daily rainfall and daily runoff for the present study area was carried out for the period from 1996 to 2005. On the dates of 3rd, 4th, 7th, 9th, 13th and on 15th August the observed runoff values is less than the estimated SCS-CN runoff. In overall it is found that minimum average runoff i.e. 22.17 mm was estimated in the year 1997 and a maximum average runoff i.e. 54.53 mm was estimated in the year 1998 out of the period of 1996 to 2005 in the study area.

It is found that a minimum runoff 35.89% of rainfall was estimated in the year 1997 and a maximum runoff 62.31% of rainfall was estimated in the year 1998 for the period of 1996 to 2005 in the Pamena –I watershed.

Above minimum runoff occurred because the yearly rainfall in that year was 741.10 mm, which is less compared to other years except in the years of 1999 & 2002. Similarly, the above maximum runoff took place because heavy rainfall occurred in the four months i.e. July, August, September and October 1998. On 18th and 29th of July 1998, rainfall recorded were 56.6 mm and 69.2 mm respectively. The corresponding runoff calculated on these dates was found to be very high i.e. 12.65 mm and 20.48 mm respectively, as the field already reached AMC condition III by that time. On 4th of August 1998, rainfall recorded was 54 mm and the corresponding runoff calculated on this date was high i.e. 11.18 mm respectively. On 21st September 1998, rainfall recorded was 101.4 mm and the corresponding runoff calculated on this data was very high i.e. 44.19 mm respectively. Similarly on 16th October 1998, rainfall recorded was 81.4 mm and the corresponding runoff calculated on this date was high i.e. 28.94 mm respectively due to the same reason mentioned above. Comparison of monthly estimated SCS-CN method runoff and observed runoff in mm is shown in Table 2.

In Pamena-I watershed area, the SCS-CN method resulted in a minimum of 35.89% and a maximum of 62.32% runoff of rainfall in the years 1997 and 1998 respectively. Monthly rainfall and monthly estimated runoff were then converted into corresponding yearly rainfall and yearly runoff. The highest estimated runoff with SCS-CN method is 654 mm against the year 1998 and the highest observed runoff is 589 mm in the year against 635 mm of estimated runoff from the year 2003.In most of the years, the maximum runoff was found to occur against corresponding maximum rainfall in that year except in the years 1999 & 2002. In this Pamena –I watershed area, maximum estimated runoff of 654.40 mm was corresponding to maximum rainfall of 1050.10 mm in the year 1998. But contrary to the above trend of coincidence of the rainfall and runoff in the years 1999 & 2002, depicted a different trend with the runoff of 337.25 mm & 288.58 mm in the same years of 1999 & 2002. The graphical representation of comparison of estimated runoff using SCS-CN method and observed runoff is shown in Figure 2. In this observation the maximum observed runoff was occurred in the year 2003 against the rainfall of 1042 mm, even the maximum rainfall occurs in the year 1998 i.e. 1050 mm.

The correlation between daily estimated runoff using SCS-CN method and daily observed runoff is represents in Figure 3. The correlation pattern between monthly runoff estimated from SCS-CN method and monthly observed runoff is shown in Figure 4. Similarly, Figure 5 show the correlation between yearly runoff estimated from SCS-CN method and yearly observed runoff.

Considering all the years, as a whole, monthly correlation coefficients exhibited a good fit between estimated runoff and observed runoff followed by daily, monthly and yearly correlation. The daily, monthly and yearly correlation coefficients (R^2) for the entire basin are found to be 0.99, 0.98 and 0.97 respectively.

Average runoff estimated from SCS-CN method for all the years as 55.85, 35.90, 62.32, 49.70, 58.92, 56.64, 44.89, 60.98, 50.06 and 61.13 percentage of rainfall for the years 1996 to 2005 respectively. Average runoff for the study area was estimated to be 54.74% of rainfall.

Analysis of Rainfall and Comparison of Estimated Runoff from TR-55 Model with Observed Runoff

Comparison of daily, monthly and yearly variation of rainfall and the corresponding daily, monthly and yearly runoff values were estimated from TR-55 model for the period from 1996 to 2005. From the entire study area and the entire duration of 1996 to 2005, it is found that a minimum monthly runoff of 33% of rainfall was observed in the year 1997 and maximum monthly runoff of 60 % of rainfall was observed in the year 2003. The above minimum runoff took place because the rainfall (741 mm) in that year was less and also, the same was distributed in five months i.e. June, July, August, September and October. Similarly, the above maximum runoff took place because half of the yearly rainfall occurred just in one month i.e. in July 2003.

Maximum and minimum monthly runoff was calculated in different years for Pamena –I watershed and analyzed. In 1996 the maximum runoff was found in the month of September i.e. 62.47 %. . In 1997 the maximum runoff was found in the month of July i.e. 53.22 %. In 1998 the maximum runoff was found in the month of August i.e. 70.20 %. In the year 1999, maximum runoff was found in the month of July i.e. 61.86 %. In the year 2000, the maximum runoff was found in the month of August i.e. 76.7 %. In the year 2001, the maximum runoff was found in the month of October i.e. 59.35 %. In the year 2002, maximum runoff was found in the month of October i.e. 53.66 %. In the year 2003, the maximum runoff was found in the month of July i.e. 76.35 %. In the year 2004, the maximum runoff was found in the month of July i.e. 65.6 %. In the year 2005, the maximum runoff was found in the month of July i.e.

65.6 %. Comparison of monthly estimated TR - 55 runoff and observed runoff in mm is shown in Table 3.

Monthly rainfall and runoff were then converted into yearly rainfall and runoff. Highest runoff through TR-55 method is 624 in the year 2003 i.e. 624 mm, in the same year the highest observed runoff is recorded i.e. 589 mm. Almost equal runoffs are observed in the year 2002, those respective runoffs are 253 mm through TR-55 model and 251 mm in observed runoff. The graphical representation of comparison of yearly estimated runoff using TR-55 method with yearly observed flow is shown in Figure 6. The maximum runoff occurred in the year 2003 as 624 mm against the rainfall of 1042 mm. This is because the maximum rainfall occurred in two months namely July and August only, where as in the year 1998, the maximum rainfall was distributed in four months July, August, September and October. The graphical representation of daily runoff of TR – 55 with the observed runoff is shown in Figure 7. The correlation pattern between monthly runoff estimated from TR-55 model and monthly observed runoff is shown in Figure 8. Similarly, Figure 9 shows the correlation between yearly runoff estimated from TR-55 model and yearly observed runoff for this Pamena –I watershed.

Runoffs estimated from TR-55 method for all the years are 51, 33, 59, 46, 57, 55, 39, 60, 47 and 56 percentages of rainfall for the years 1996 to 2005 respectively. Average runoff of this study area for the duration of 1996 to 2005 was estimated as 51.5% of rainfall.

Comparison of Runoff Estimated from SCS-CN Method and TR-55 Model

Monthly runoff values estimated from SCS-CN method have been compared with those from TR-55 model. Yearly runoff values estimated from SCS-CN method have been compared with those from TR-55 model. In all the years from 1996 to 2005, the maximum runoff was found when the average rainfall was maximum, when it is estimated from TR-55 model and SCS-CN method. In all the years runoff was high in SCS-CN model when compared to TR-55 model. In the SCS-CN model, highest runoff occurred in the year 1998 i.e. 654 mm whereas in TR-55 model runoff in the same year was 615 mm against the rainfall of 1050 mm and this is second highest runoff in TR-55 model. In the TR-55 model the highest runoff occurred in the year 2003 i.e. 624 mm against the rainfall of 1042 mm, even though the maximum rainfall occurred as 1050 mm in the year 1998.

Minimum runoff occurred in the year 1997 i.e. 266 mm in SCS-CN method, and in TR-55 method the runoff was minimum in the same year 1997 i.e. 244 mm against the rainfall 741 mm, even though the rainfall was less in the years 1999 and 2002 i.e. 678 mm and 643 mm respectively. The average runoff estimated for the study area over a period of 10 years has been determined as 54.74% and 51.43% of rainfall from SCS-CN method and TR-55 models respectively. It indicates that SCS-CN method over estimated the average yearly runoff by just 3.31 % compared to TR-55 model.

7. CONCLUSIONS

All the hydrological parameters which are spatially and temporally variable were found to be more accurately estimated through RS and GIS. The average runoff, estimated for the study area over a period of 10 years, has been determined as 54.74% and 51.50% of rainfall from SCS-CN method and TR-55 model respectively. It indicates that SCS-CN method over estimated the average yearly runoff by 3.31 % compared to TR-55 model. The combination of GIS and TR-55 model made the runoff estimation more accurate and fast. Therefore the runoff estimated using TR-55 model was found to be comparable with the observed runoff. The runoff estimated using GIS and RS based SCS-CN method was comparable with the observed runoff and is useful aid for better water management practices.

REFERENCES

1) Action plan for Watershed Development Program in Pamena – I watershed, Chevella Mandal, Ranga Reddy District, A.P., organized by Project Implement Agency (PIA), PROGRESS, Hyderabad.
2) Alan O. Sykes, The Inaugural Course Lecture on "An introduction on Regression Analysis" Chicago Working paper in Law & Economics
3) C:\DATA\StatPrimer\regression.wpd 3\4\04. Pp. 15.1 to 15.6
4) Christian W. Dawson and Robert Wilby (1998), "An artificial neural network approach to rainfall – runoff modeling" Journal of Hydrological Sciences, pp: 47 – 66
5) Cohen, J. & Cohen, P. (1983) Applied multiple regression/correlation analysis for the behavioral sciences. Erlbaum.
6) Gautam. N.C. and Raghavswamy.V, (2003): "Delineation of watershed for land and water resource planning and development", Proceedings of the National conference on Land Use/Land Cover Management Practices, August 21-22, Hyderabad, A.P.
7) Hellweger, Ferdi., (1996). "TABHYD - TR55 Tabular Hydrograph Method in Arc View" U.S. Department of Agriculture, Soil Conservation Service, Engineering Division, September 1996.
8) Hosking J.R.M and Clarke R.T. (1990) "Rainfall-Runoff relations derived from the probability theory of storage". Water Resources Research 26: 1455-1463.
9) James V. Bonta (1992), "Estimating Peak Flows from Small Agricultural watersheds", ASCE, Journal of Irrigation and Drainage Engineering, Vol.118, No. I, pp.122-137.
10) Marilyn Crichlow (2001), "Integrated watershed management", Chapter -9,

Professional development Program, Coastal infrastructure design, construction and Maintenance, Antigua, West Indies, June 18-22, 2001

11) Mc Cuen, R.H. (2004), "Hydrologic Analysis & Design" Prentice Hall, Upper Saddle River, New Jersey, 07458, 3rd Edition.
12) Mishra S.K. and Singh V.P.(1999), "Another look at SCS-CN method", Journal of Hydrological Engineering, ASCE 4: 257-264.
13) Mohd. Ibrahim Seeni Mohd. and Mohd. Adli Mansor (2000), "Application of Remote Sensing and Hydrological Modeling in Flood Prediction Studies". Malaysian Journal of Remote Sensing & GIS, July 2000, Vol. 1.
14) Prem N. Sharma (1998), "An analysis of and lessons from case studies of people's participation in watershed management in Asia" P.O. Box 25, Kathmandu, Nepal.
15) Steyerberg, E.W., Eijkemans, M.J.C.,& Habbema, J.D.F. (1999) Stepwise selection in small data sets: a simulation study of bias in logistic regression analysis. Journal of Clinical Epidemiology, 52, 935-942.

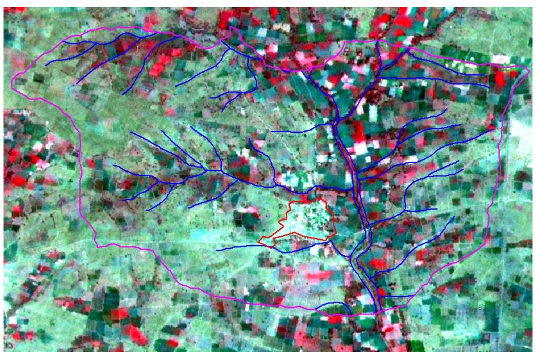


Figure 1:. Study Area on Satellite Imagery

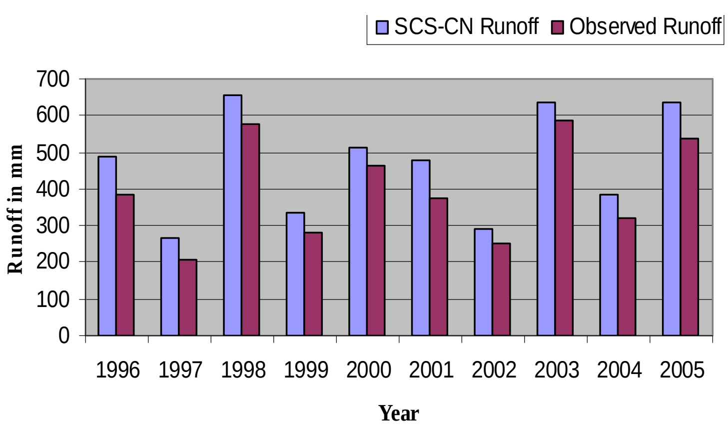


Figure 2: Comparison of estimated yearly SCS – CN run-off with observed run-off

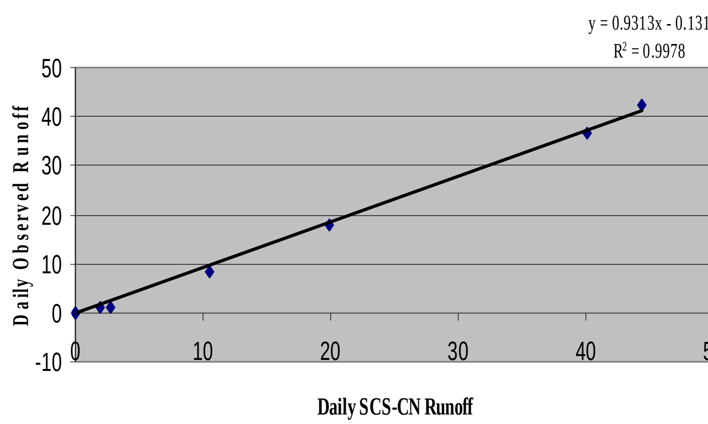
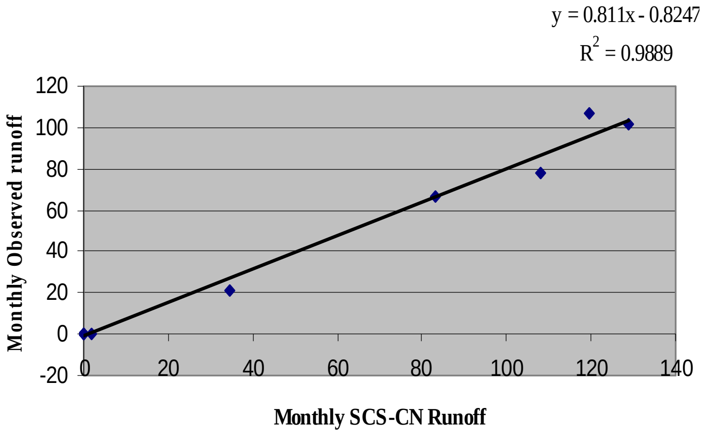


Figure 3: Regression Analysis between daily SCS – CN Run-off and daily observed Runoff of Aug. 2001



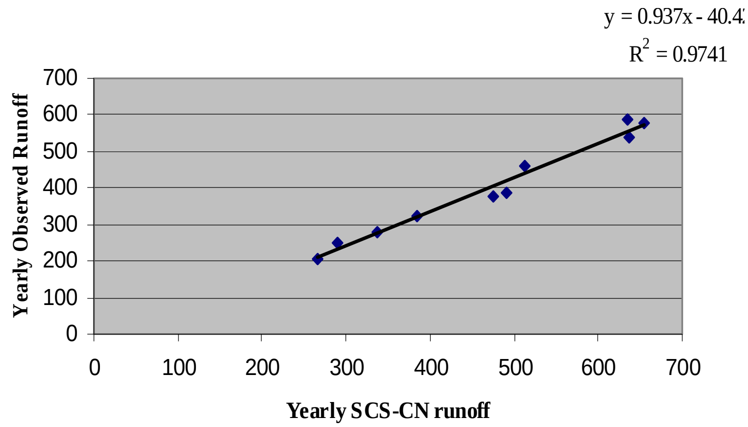


Figure 4: Regression Analysis between Monthly SCS – CN Run-off and Monthly observed Runoff

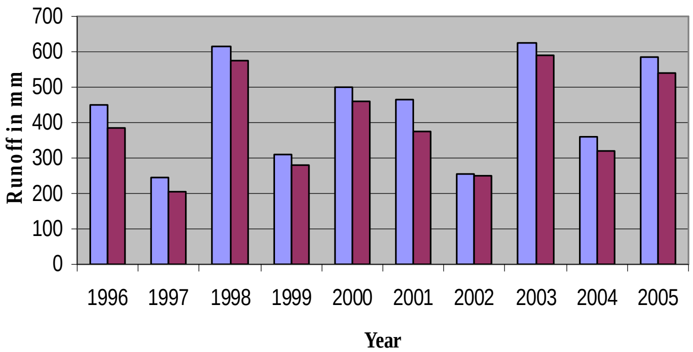


Figure 6. Comparison of estimated yearly TR – 55 runoff with observed runoff

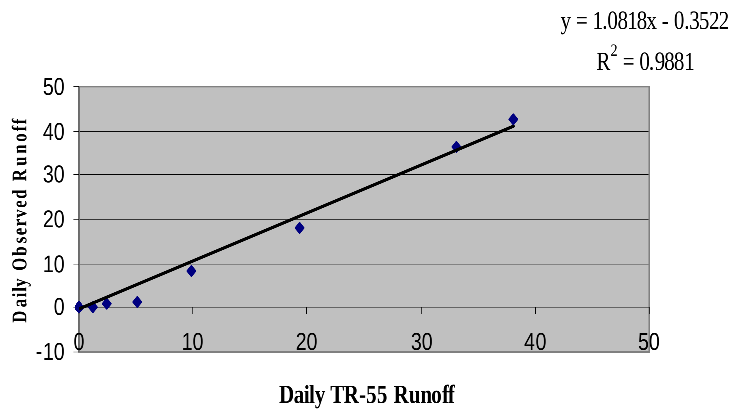


Figure 7. Regression Analysis between daily TR - 55 Run-off and Daily observed Runoff

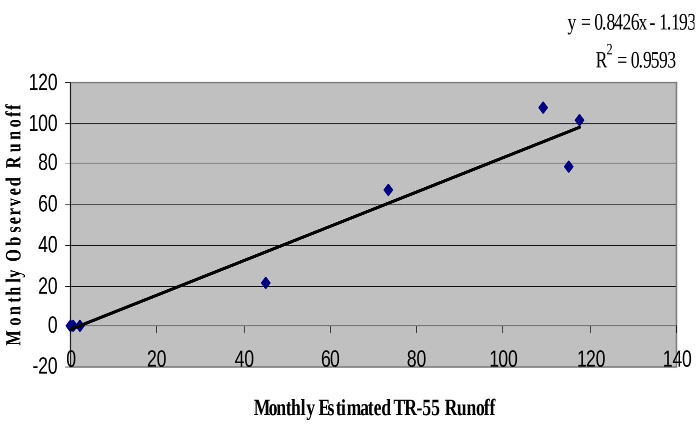


Figure 8: Regression Analysis between Monthly TR - 55 Run-off and Monthly observed runoff

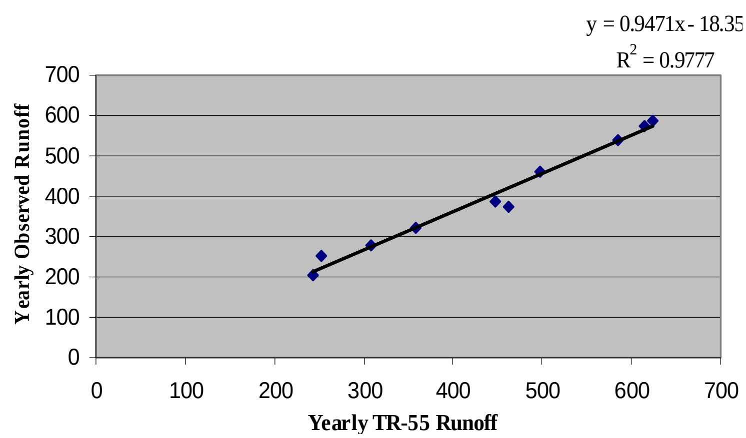


Figure 9. Regression Analysis between yearly TR - 55 Run-off and yearly observed runoff

Table 1: Monthly rainfall data in mm for the years 1996 to 2005

Year/ Month	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Jan	0.00	38.00	0.00	0.00	0.00	1.00	3.20	0.00	7.30	11.00
Feb	0.00	0.00	0.80	2.70	25.20	0.00	3.70	7.40	0.00	12.80
Mar	0.00	52.40	1.20	0.00	0.00	8.40	37.50	167.60	9.40	11.60
Apr	35.60	45.60	3.50	0.00	12.40	89.20	0.00	34.40	35.60	40.80
May	3.40	2.80	52.20	141.70	74.50	0.00	48.40	0.00	114.80	23.40
Jun	129.20	71.00	50.50	69.40	257.50	175.40	99.50	79.70	56.20	39.60
Jul	137.30	131.00	198.10	183.50	97.30	32.00	115.30	305.40	287.60	291.30
Aug	225.00	116.60	283.40	157.00	329.50	188.20	150.00	278.20	53.80	84.70
Sep	212.10	125.10	197.30	55.50	49.80	147.70	26.40	44.00	126.00	273.60
Oct	109.00	73.10	241.20	68.60	21.20	198.10	159.00	124.90	76.70	251.80
Nov	26.00	49.10	21.90	0.00	1.40	0.00	0.00	0.00	0.60	0.00
Dec	0.00	36.40	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00

Source: Agricultural Research Institute (ARI), Rajendra Nagar, Hyderabad.

Table 2 : Comparison of monthly estimated SCS-CN method runoff and observed runoff in mm

Year	**1996**		**1997**		**1998**		**1999**		**2000**	
Month	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff
Jan	0.00	0.00	3.65	2.58	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.01
Mar	0.00	0.00	10.30	7.80	0.00	0.00	0.00	0.00	0.00	0.00
Apr	2.80	1.82	6.86	4.76	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	10.19	6.25	77.88	59.54	24.07	19.78
Jun	67.10	41.08	21.68	16.43	9.29	7.08	20.61	17.28	184.47	165.70
Jul	74.06	69.60	68.64	57.48	128.71	103.67	115.29	101.33	40.93	32.02
Aug	153.76	106.04	56.50	39.40	209.19	196.65	91.37	77.12	253.59	238.82
Sep	141.70	125.40	63.62	49.08	127.97	109.2	12.02	7.19	8.93	5.03
Oct	50.26	41.0	23.10	19.75	169.02	153.16	20.08	16.13	0.01	0.00
Nov	0.44	0.30	8.57	5.01	0.03	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	3.08	2.36	0.00	0.00	0.00	0.00	0.00	0.00

Year	**2001**		**2002**		**2003**		**2004**		**2005**	
Month	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	3.47	1.59	100.86	98.75	0.00	0.00	0.00	0.00
Apr	34.71	21.55	0.00	0.00	2.42	1.13	2.82	1.42	4.75	2.21
May	0.00	0.00	8.22	5.93	0.00	0.00	55.01	37.6	0.13	0.00
Jun	107.91	78.42	42.66	33.57	27.72	20.04	12.42	4.70	4.27	2.85
Jul	1.71	0.32	55.42	47.28	230.32	219.64	213.21	197.20	216.76	197.60
Aug	119.59	107.31	85.16	81.80	204.21	191.00	11.07	7.60	31.36	23.70
Sep	83.14	66.76	0.50	0.15	6.13	3.62	64.38	55.80	199.81	172.50
Oct	128.71	101.6	93.15	81.00	63.45	55.2	25.59	17.15	179.05	139.60
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3: Comparison of monthly estimated TR - 55 runoff and observed runoff in mm

Year	1996		1997		1998		1999		2000	
Month	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff
Jan	0.00	0.00	2.81	2.58	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	2.18	0.01
Mar	0.00	0.00	13.16	7.80	0.00	0.00	0.00	0.00	0.00	0.00
Apr	4.28	1.82	7.42	4.76	0.07	0.00	0.00	0.00	0.84	0.00
May	0.06	0.00	0.00	0.00	13.23	6.25	67.86	59.54	28.00	19.78
Jun	62.60	41.08	17.36	16.43	9.68	7.08	17.85	17.28	162.05	165.70
Jul	72.47	69.60	69.72	57.48	121.39	103.67	113.52	101.33	42.86	32.02
Aug	126.56	106.04	48.48	39.40	198.94	196.65	83.19	77.12	252.77	238.82
Sep	132.50	125.40	63.44	49.08	124.75	109.2	10.43	7.19	8.37	5.03
Oct	47.32	41.0	10.64	19.75	145.69	153.16	15.88	16.13	0.91	0.00
Nov	2.07	0.30	7.36	5.01	1.46	0.00	0.00	0.00	0.01	0.00
Dec	0.00	0.00	3.73	2.36	0.00	0.00	0.00	0.00	0.00	0.00

Year	2001		2002		2003		2004		2005	
Month	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff	Estimated Runoff	Observed Runoff
Jan	0.02	0.00	0.17	0.00	0.00	0.00	0.92	0.00	2.12	0.00
Feb	0.00	0.00	0.16	0.00	0.65	0.00	0.00	0.00	1.84	0.00
Mar	0.57	0.00	11.93	1.59	94.80	98.75	0.78	0.00	1.14	0.00
Apr	44.96	21.55	0.00	0.00	6.50	1.13	7.13	1.42	9.27	2.21
May	0.00	0.00	11.20	5.93	0.00	0.00	63.54	37.6	2.64	0.00
Jun	115.11	78.42	37.20	33.57	23.88	20.04	12.10	4.70	5.88	2.85
Jul	2.30	0.32	29.96	47.28	233.17	219.64	188.70	197.20	191.32	197.60
Aug	109.29	107.31	75.74	81.80	208.99	191.00	10.51	7.60	24.27	23.70
Sep	73.33	66.76	1.12	0.15	3.14	3.62	54.44	55.80	187.42	172.50
Oct	117.58	101.6	85.32	81.00	52.73	55.2	19.60	17.15	158.76	139.60
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00