CS/AR-5/2000-2001

APPLICABILITY OF SCS RUNOFF METHOD TO DIFFERENT AGROCLIMATIC REGIONS

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2000-2001

PREFACE

Hydrologists are frequently concerned with the estimation of runoff from rainstorms for the purpose of structural design, environmental impact assessment, water resources and land management, etc. As such, in the hydrologic studies there are no formulae, which can be universally applied to accurately predict the runoff volume from rainfall. Therefore, a number of research studies and experiment have been carried out to derive the formulae for different areas according to the local conditions and thus, the relation between rainfall and runoff volume has been presented by many empirical and semi-empirical relationship and models. Many computer models in water resources use SCS curve number methodology to determine rainfall excess from rainfall events. This method was developed by the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) for small watersheds in 1954. Dimensionless Curve Number (CN) reflects runoff potential and depends on hydrologic soil group, land cover type, hydrologic condition and antecedent moisture condition. CN is used for evaluating effects of changes in land use and land treatment on direct runoff.

For a small catchment with sufficient historical P-Q data, curve numbers can be estimated by ordering selected P-Q pairs. These calculated CN values tend to approach an asymptotic value for larger rainfall values and this asymptotic curve number can be assumed as the curve number for the catchment (Hawkins, 1993).

In the present study, efforts have been made to estimate an initial abstraction coefficient for six watersheds in various agro-climatic zones of Karnataka state namely, Dandavati, Varada, Honnammanahalla, Barchinala, Yettinahole and Jadkalhole from rainfall-runoff events by asymptotic fitting of curve numbers calculated from observed rainfall-runoff data. The calculated curve number values have been used further to estimate the initial abstraction coefficient for the study watersheds.

This study has been carried out by Sh. Dilip G. Durbude, Scientist 'B' and B. Venkatesh, Scientist 'C', of NIH Regional Centre, Belgaum, as a part of the work programme for the year 2000-2001.

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ABSTRACT

The most generally available data in India are the rainfall amounts measured by non-recording rain gauges and for such data, USDA, Soil Conservation Service (SCS) Curve Number method is a well accepted tool in Hydrology for the estimation of design floods for small hydraulic structures and for other rainfall-runoff analyses. This is a simple, predictable, and stable conceptual method. The Curve Number (CN) is a measure of water retention in the watershed. The SCS method assumes the initial rainfall abstraction as the fraction of potential maximum retention of the soil. The initial abstraction coefficient was developed for small experimental watersheds in USA. The same coefficient may not hold good for Indian conditions. Therefore, in the present study, it is proposed to establish the initial abstraction parameter in the SCS method and to assess the influence of various hydrological parameters in generating direct runoff from the watersheds in hard rock region under different physiographic and climatic conditions.

Observed rainfall-runoff event data has been used to estimate the average curve number for six small hard rock catchments, namely, Dandavati, Varada, Honnammanahalla, Barchinala, Yettinahole and Jadkalhole. Natural and frequency matched data sets were used for the analysis. The calculated curve number values have been further used to estimate the initial abstraction coefficient for the study watershed.

1.0 INTRODUCTION

Water is an important renewable natural resource associated throughout the history of great civilization of mankind. It controls the human developmental activities. Hydrologists are frequently concerned with the estimation of runoff from rainstorms for the purposes of structural design, environmental impact assessment, water resources and land management etc. Planning and execution of water resources projects require runoff estimates from storm events. Generally, in a river basin, number of rain gauges are always more than the number of stream gauges which results in a longer rainfall records than the stream flow records. This leads to a situation in which it will be necessary to evolve some methodology to calculate runoff from the available rainfall records. As such in the hydrologic studies there are no formulae, which can be universely applied to accurately predict the runoff volume from rainfall. Therefore, a number of research projects and experiments have been carried out to derive formulae for different areas according to local conditions and thus the relation between rainfall and runoff volume has been presented by many empirical and semi empirical formulae. One of the simplest rainfall-runoff models is the linear model correlating runoff to rainfall. But important runoff producing mechanisms such as rainfall intensity, infiltration rate, antecedent moisture condition, etc. are not reflected in this type of model. There are varieties of other models, which account for the effect of these factors. Also, the generally available data in India are the amounts measured by non recording raingauges and for such data, rainfall-runoff relationship was developed by the U. S. Department of Agriculture, Soil Conservation Service (SCS), now known as Natural Resource Conservation Service.

In 1954, the USDA Soil Conservation Service (SCS) proposed the curve number method to determine outflow hydrographs for use in small structural design and appraisal of land use changes. This procedure is based on a non-linear rainfall-runoff relation that uses (i) a land condition factor called 'curve number' to calculate the depth of rainfall excess, and (ii) a triangular unit hydrograph to route rainfall excess to produce an outflow hydrograph. The curve number is a function of hydrologic soil type, land use and treatment, ground surface condition, and antecedent moisture. This method has been described in the SCS National Engineering Handbook, Section 4: Hydrology (NEH-4). It is a well established method in hydrological engineering and environmental impact analysis. Its popularity is rooted in its convenience, simplicity, authoritative origin, and responsiveness to four major catchment properties; soil type, land use/ land treatment, surface condition, and antecedent moisture condition.

The curve numbers (CN) associated with the soil cover complexes are median values, roughly representing average conditions on a watershed. These values are evolved based on the data from research watersheds, where experiments were conducted to determine the runoff for different soil and cover conditions.

The fundamental hypotheses of the SCS CN method are as follows;

(i) Runoff starts after an initial abstraction has been satisfied. This abstraction mainly consists of interception, surface storage, evaporation, and infiltration, and

(ii) The ratio of actual retention of rainfall to the potential maximum retention S is equal to the ratio of direct surface runoff to rainfall minus initial abstraction.

The method is based on proportionality between retention and runoff in the following form;

$$F/S = Q/P \qquad (1)$$

where, F is actual retention (P – Q - Ia); and S = potential retention. This relation states that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. For practical applications, the above equation can be improved by incorporating initial abstraction. The initial abstraction consists mainly of interception, infiltration, and surface storage, all of which occur before runoff begins. Then the above equation can be rewritten as:

$$(P - Ia - Q)/S = Q/(P - Ia)\text{, or}$$

$$Q = (P - Ia)^2/(P - Ia + S) \qquad (2)$$

where, Q is the runoff volume uniformly distributed over the drainage basin, P is the mean precipitation over the drainage basin and Ia is the initial abstraction.

The watershed storage index S, is conveniently expressed in terms of a dimensionless index, runoff curve number as:

$$CN = 1000/(10 + S)\text{, where S is in inches}$$

$$\text{or } CN = 25400/(254 + S)\text{, where S is in mm.} \qquad (3)$$

Curve numbers are dimensionless, and can vary from 0 (no runoff) to 100 (all rainfall becomes runoff). Design estimates of CN based on soil, and land use are given in SCS National Engineering Handbook, Section IV (NEH-4).

Even though this methodology has been developed for small agricultural watersheds in USA, its simplicity attracted many researchers in India and other countries. This method has been subjected to large number of improvements and changes to suit the conditions prevalent in the user country. The runoff curve number for different hydrologic soil cover complexes for Indian conditions are given in Handbook of Hydrology (1972), Soil Conservation Division, Ministry of Agriculture, Govt. of India.

The initial abstraction Ia can be expressed as a function of S, and SCS have recommended, Ia = 0.2 S from their field experiences. Physically, this means that for a given storm, 20 % of the potential maximum retention is the initial abstraction before runoff begins. Presumably, 0.8 S represents other retention losses including interception, infiltration, evaporation, and depression storage after runoff started.

Therefore, SCS rainfall-runoff relation becomes:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \qquad (4)$$

Evidently, this is a one parameter model with S or CN as the parameter. This parameter depends upon characteristics of the soil-vegetation-land use (SVL) complex and antecedent soil moisture condition on a watershed. SCS developed three antecedent moisture conditions and labeled them as AMC-I, II, and III. AMC-I represents dry condition of soil, AMC-III represents saturated soil and AMC-II is the average condition.

Vandersypen et al. (1972) developed the following relationship between initial abstraction and potential maximum retention, for Indian conditions.

For black soil region (AMC I) and for all other regions, Ia = 0.3 S.

Therefore the SCS rainfall-runoff relationship becomes:

$$Q = (P - 0.3S)^2 / (P + 0.7S) \qquad (5)$$

For black soil region (AMC-II and III), Ia = 0.1 S and, therefore, the rainfall-runoff equation becomes:

$$Q = (P - 0.1S)^2 / (P + 0.9S) \qquad (6)$$

This equation is used with the assumption that the cracks, which are typical of black soil when dry are filled.

As such, this method assumes an initial rainfall abstraction as the fraction of total maximum retention of the soil. This factor was developed for the small experimental watersheds in USA. The same fraction may not hold good for most of the Indian conditions. Therefore, in the present study, it is proposed to establish the initial abstraction parameter in the SCS method and to assess the influence of various hydrological parameters in generating direct runoff from the watersheds in hard rock region under different physiographic and climatic conditions. Six small watersheds from various agro-climatec zones of Karnataka state are selected for the estimation of initial abstraction coefficient from the historical rainfall-runoff data set. These watersheds are: Dandavati, Varada, Honnammanahalla, Barchinala, Yettinahole and Jadkalhole.

2.0 REVIEW OF LITERATURES

The SCS curve number method is an infiltration loss model, although it may also account for interception and surface storage losses through its initial abstraction feature. This method is not intended to account for long term losses such as evapo-transpiration.

The curve number methodology was originated as the result of a large number of infiltration tests carried out by SCS in late 1930s and early 1940s. These tests were conducted to evaluate the effects of watershed treatment and soil conservation measures on the rainfall-runoff process. Sherman (1942, 1949) had proposed plotting direct runoff versus storm rainfall. Based on this idea, Mockus (1949), suggested that surface runoff estimates for ungauged watersheds could be made using the information on soils, land use, antecedent rainfall, storm duration, and average annual temperature. He combined all these factors into an empirical parameter 'b' characterising the relationship between rainfall depth P and runoff depth Q; $Q = P(1 - 10^{-bP})$ (Rallison, 1980). Andrews (1954), using infiltration data from Texas, Oklahoma, Arkansas, and Louisiana, developed a graphical procedure for estimating runoff from rainfall for several combinations of soil texture, type and amount of cover, and conservation practices. The combination was referred to as 'soil-cover complex' (Miler and Croshney, 1989).

Mockus' empirical rainfall-runoff relationship and Andrews' soil-cover complex were the basics of the conceptual rainfall-runoff relationship put forward by SCS. This method, since then referred to as the runoff curve number method, had the following significant features (Ponce and Hawkins, 1996):

1. The runoff depth Q is bounded in the range $0 \leq Q \leq P$, assuring its stability.

2. As rainfall depth P grows unbounded ($P \rightarrow \infty$), the actual retention ($P - Q$) asymptotically approaches a constant value S. This constant value, referred to in NEH-4 as potential maximum retention or potential retention, characterises the watershed's potential for abstracting and retaining water and therefore its runoff potential.

3. A runoff equation relates Q to P, and a curve number parameter CN, in turn, relates to S.

4. Estimates of CN are based on hydrological soil group, land use and treatment classes, hydrologic surface condition, and antecedent moisture condition.

The SCS rainfall-runoff relationship, $Q = (P - Ia)^2/(P - Ia + S)$, has two parameters; S and Ia. To remove the necessity for an independent estimation of initial abstraction, a linear relationship between Ia and S was suggested by SCS; $Ia = \lambda S$, where λ is the initial abstraction ratio. From the experiments conducted in watersheds less than 10 acres in size, it is found that 50 % of the data points were lying within the limits of $0.095 \leq \lambda \leq 0.38$. From this analysis, SCS adopted a standard value for initial abstraction ratio as 0.2. However, values varying in the range of 0.0 - 0.3 have been documented in a number of studies encompassing various geographical locations.

Potential retention is a measure of the ability of a given site to abstract and retain storm rainfall, provided the level of antecedent moisture has been factored into the analysis. In other words, potential retention and its corresponding curve number are intended to represent the capacity of a given site to abstract and retain storm rainfall. It also reflects (i) the recent history of antecedent rainfall, or lack of it, which may have caused the soil moisture to depart from an average level, (ii) seasonal variation in runoff properties, and (iii) unusual storm conditions. The major factors that influence CN value are the hydrologic soil group, land use/treatment class, hydrologic condition, and antecedent moisture condition.

SCS classified all soils into four hydrologic soil groups (A, B, C, and D) according to their infiltration rate, which is obtained for bare soil after prolonged wetting. Among these, the group A is having the lowest runoff potential and high infiltration rates and group D soils are having highest runoff potential with lowest infiltration rates

Treatment is a cover type modifier used in the SCS table to describe the effect on CN of the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced or no tillage.

Hydrologic condition indicates the effect of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. A good hydrologic condition indicates that the soil usually has a low runoff potential for the given hydrologic soil group, cover type, and treatment.

Antecedent moisture condition is an index of runoff potential for a storm event. The AMC is an attempt to account for the variation in CN at a site from storm to storm.

As any other conceptual model, the curve number method also works with the mean values, implying that there is a room for some variability. Due to this, the same watershed can have more than one curve number or a set of curve numbers. Among the likely sources of this variability are:

1. The effect of spatial variability of storm and watershed properties

2. The effect of temporal variability of the storm, ie., the storm intensity

3. The quality of the measured data, ie., the P-Q sets

4. The effect of antecedent rainfall and associated soil moisture

The latter was recognised very early as the primary or tractable source of the variability, and thus, the concept of antecedent moisture condition (AMC) originated.

The NEH-4 runoff curve numbers were developed from recorded rainfall-runoff data, where hydrologic soil group, land use/treatment class, and surface condition were known. The P-Q data was plotted and the CN corresponding to the curve that separated half of the plotted data from the other half was taken as the median curve number for the given site. The natural scatter of points around the median curve number was interpreted as a measure of the natural variability of soil moisture and associated rainfall-runoff relation.

To account for this variability, the P-Q plots were used to define enveloping or near-enveloping CN values for each site. These enveloping curve number values are considered as the practical upper and lower limits of expected CN variability for the given combination of soil cover complex. Thus, antecedent moisture condition was used as a parameter to represent the experienced variability. The curve number lying in the middle of the distribution is the median curve number, corresponding to AMC 2 (average runoff potential). This is the standard curve number given in the SCS tables. The low value is the dry curve number of AMC 1 (lowest runoff potential) and the high value is the wet curve number of AMC 3 (highest runoff potential).

Diego and Wilson (1973) analysed a mathematical model for estimating maximum volumes of runoff by the U.S. Soil Conservation Service in order to determine its applicability to small Piedment watershed. Singh (1981) has suggested a procedure for extension of the SCS curve number technique for calculating the amount of runoff in the case of reclaimed soils. Hjelmfelt et al. (1982) found that the AMC conversion table described the 90 % (AMC 1), 50 % (AMC 2), and 10 % (AMC 3), cumulative probabilities of exceedence of runoff depth for a given rainfall. In other words, they found that AMC 2 represented the central tendency, while AMC1 and AMC 3 accounted for dispersion in the data. Hawkins et al. (1985) interpreted the AMC categories as error bands or envelopes indicating the experienced variability in rainfall-runoff data. Shrivastava and Bhatia (1992) have tested a runoff model developed by Soil Conservation Service U.S.A. The observed and predicted runoff values were statistically analysed by finding a product moment correlation coefficient and coefficient of determination, which showed a good correlation between the measured and predicted values of runoff. Therefore the runoff model developed by SCS can be used for runoff estimation.

To decide about the level of AMC to be used in a given case, NEH-4 has given a table based on total 5-day antecedent rainfall, for dormant and growing season. However, the table does not account for regional differences or scale effects. An antecedent period longer than 5 days would probably be required for larger watersheds. By considering this, SCS has deleted the table in the new version of Chapter 4, NEH, released in 1993. So in practice, the determination of AMC is left to the user, who must evaluate whether a certain design situation warrants AMC 1, AMC 2, or AMC 3.

Ponce and Hawkins (1996), enumerated the advantages and disadvantages of the method as:

The advantages are:

1. It is a simple, predictable, and stable conceptual method for the estimation of direct runoff depth based on storm rainfall depth.

2. It relies on only one parameter, the runoff curve number, which varies as a function of four major runoff producing watershed properties; hydrologic soil group, land use and treatment class, hydrologic surface condition, and antecedent moisture condition.

3. It is the only methodology that features readily grasped and reasonably well documented inputs.

4. It is a well established method, having been widely accepted for use in various countries.

The disadvantages are:

1. The method was originally developed using regional data, mostly from the midwestern USA. So some caution is necessary when it is applied to other geographic or climatic regions.

2. For lower curve numbers and/or rainfall depths, the method is very sensitive to curve number and antecedent moisture condition.

3. The method is best suited for agricultural sites, for which it was originally intended, and has since been extended to urban sites. The method rates fairly in applications to range sites, and generally does poorly in application to forest sites. The implication here is that the method is best suited for storm rainfall-runoff estimates in streams with negligible baseflow, ie., those for which the ratio of direct runoff to total runoff is close to one.

4. The method has no explicit provision for spatial scale effects. Without catchment subdivision and associated channel routing, its application to large catchments (greater than 250 sq. km.) should be viewed with caution.

5. The method fixes the initial abstraction ratio at 0.2. In general, however, this ratio could be interpreted as a regional parameter.

3.0 STUDY AREA

Karnataka has a land area of 19,2204 sq km, spreading between latitudes 11°31′ and 18° North and longitudes 74°12′ and 78 °40′ East. A coastal strip of 10 -15 km width borders the Arabian Sea, and the Western Ghats mountain belt of 30 - 50 km width (rising to 1000 -2000 m) running parallel to the coast, and gently inclined plateau with drainage further to the east. The rainfall varies from 6000 mm in the west to 375 mm in the northeast, resulting in the diversity of vegetation types. The rainfall received derives mainly from the southwest monsoon between June to September. Considering the wide variation in rainfall and other hydro meteorological parameters across the State, the whole is divided into nine Agro-climatic Zones, i.e., North-eastern Transition Zone, North-eastern Dry Zone, Northern Dry Zone, Central Dry Zone, Eastern dry Zone, Southern Dry Zone, Southern Transition Zone, Hilly Zone and Coastal Zone (figure 1).

For the estimation of initial abstraction coefficient by using Hawkins technique and asymptotic fitting of curve number from the rainfall and runoff data set, seven watersheds from various agro-climatic zones were selected. The following table shows the watersheds belonging to various Agro-climatic regions.

Table 1. List of the Watersheds under Various Agro-climatic Regions

SR. No.	Name of the Watersheds	Gauging Station	Agro-climatic regions
1.	Dandavati	Sorab	Southern Transition Zone
2.	Sagar	Sagar	Southern Transition Zone
3.	Honnammanahalla	Attigundi	Hilly Zone
4.	Barchinala	Barchi	Hilly Zone
5.	Yettinahole	Harley Estate	Hilly Zone
6.	Jadkalhole	Jadkal	Coastal Zone

The description of each watershed is given below.

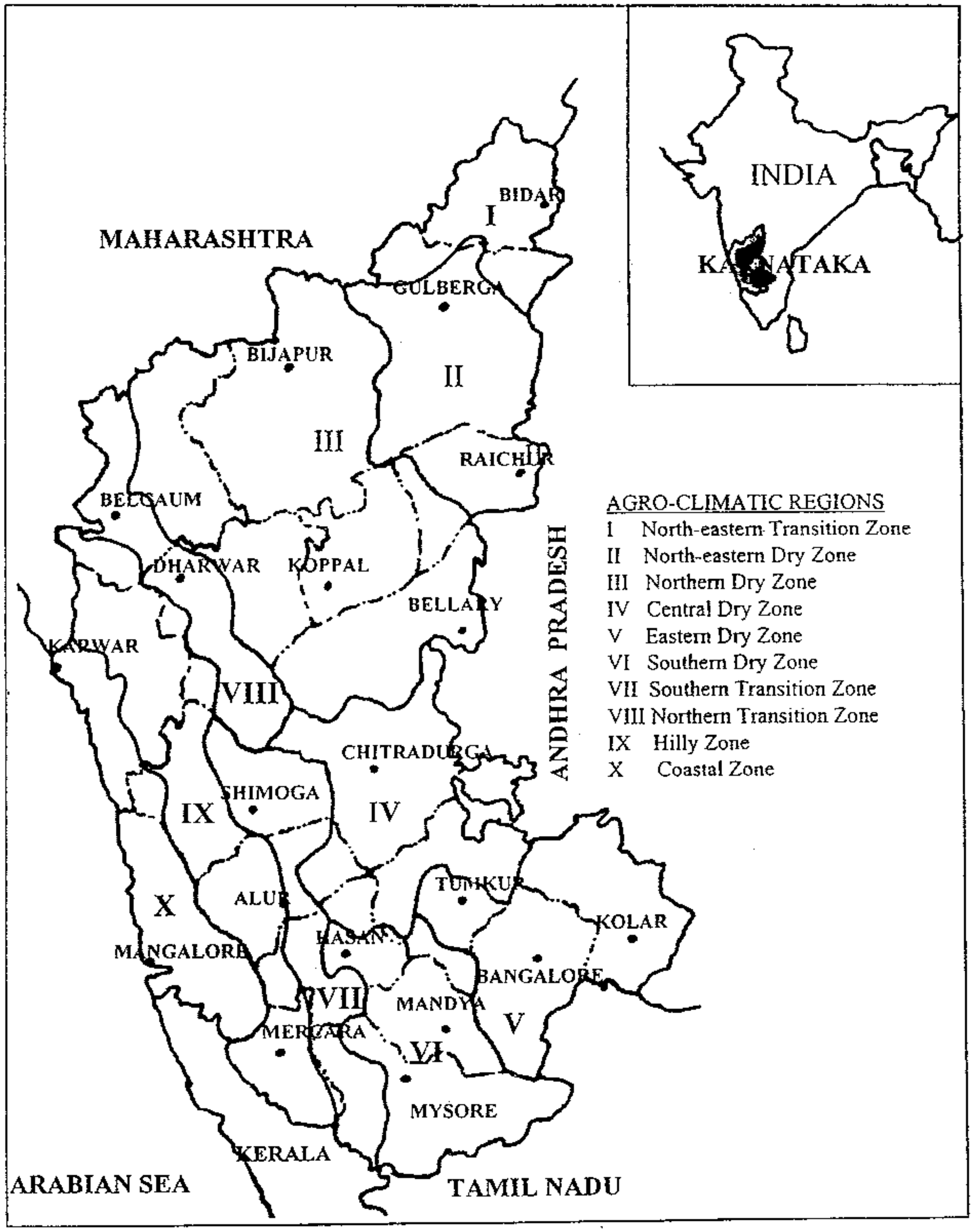


Figure 1. Agro-Climatic Regions of Karnataka State

3.1 Dandavathi

The Dandavathi watershed upstream of the Sorab is coming under the Southern Transition Agro-climatic region. It is situated in the Western Ghats and is a sub-basin of the Krishna basin. The location of the catchment of the watershed is shown in figure 2.

Dandavathi originates from Karjikoppa in the foot-hills of western ghat at an altitude of about 832.5 m and 16 km south of Sorab in Shimoga district of Karnataka State. The river flows in a northerly direction and joins the Varada River, which is a tributary of Krishna. The total catchment area of the watershed is 96 sq. km. The catchment area lies between 74°58' and 75°16' East longitudes and 13°38' and 13° 46' North latitudes along the border of Sorab and Sagar taluks.

The catchment has four distinct seasons in the year, such as, cold weather, hot weather, southwest monsoon and post monsoon. The red and gravely soils are the principal soils found in the study area. The stream gauge site maintained by WRDO is located at Sorab at an elevation of 567.275 m. Rainfall records are available from raingauges stations situated at Sorab and Kuppe. Average annual rainfall for this area is 1800 mm.

3.2 Sagar

It is also coming under the Southern Transition Zone and situated in the Western Ghat. The location of the catchment is shown in the figure 3. It is a sub-basin of Varda River, which is tributary of Krishna. Its originate from the foothill of western ghat and nearly 10 kms from the Sagar in the Shimoga district of Karnataka. The total catchment area of the watershed is 75 sq. km. The catchment area lies between 74°50' and 75°10' East longitudes and 13°48' and 14° 1' North latitude along the boarder of Sagar and Sorab taluk. The stream gauge site is maintained by WRDO is located at Sagar at an altitude of 576.68 m. Rainfall records are available from rain gauge stations situated at Sagar and Kogaru. Average annual rainfall for this area is 1963 mm.

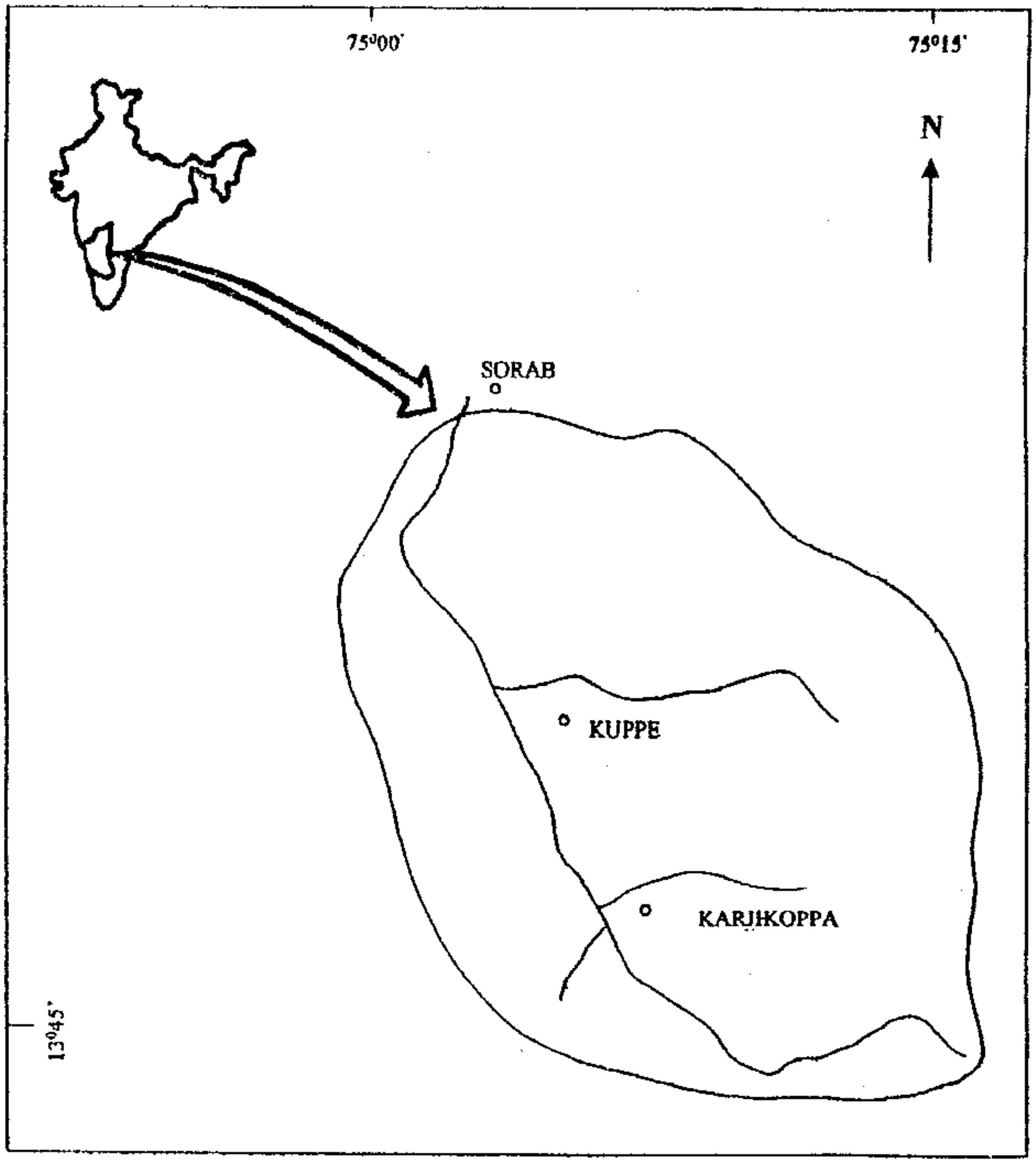


Figure 2. Location Map of Dandavati Watershed

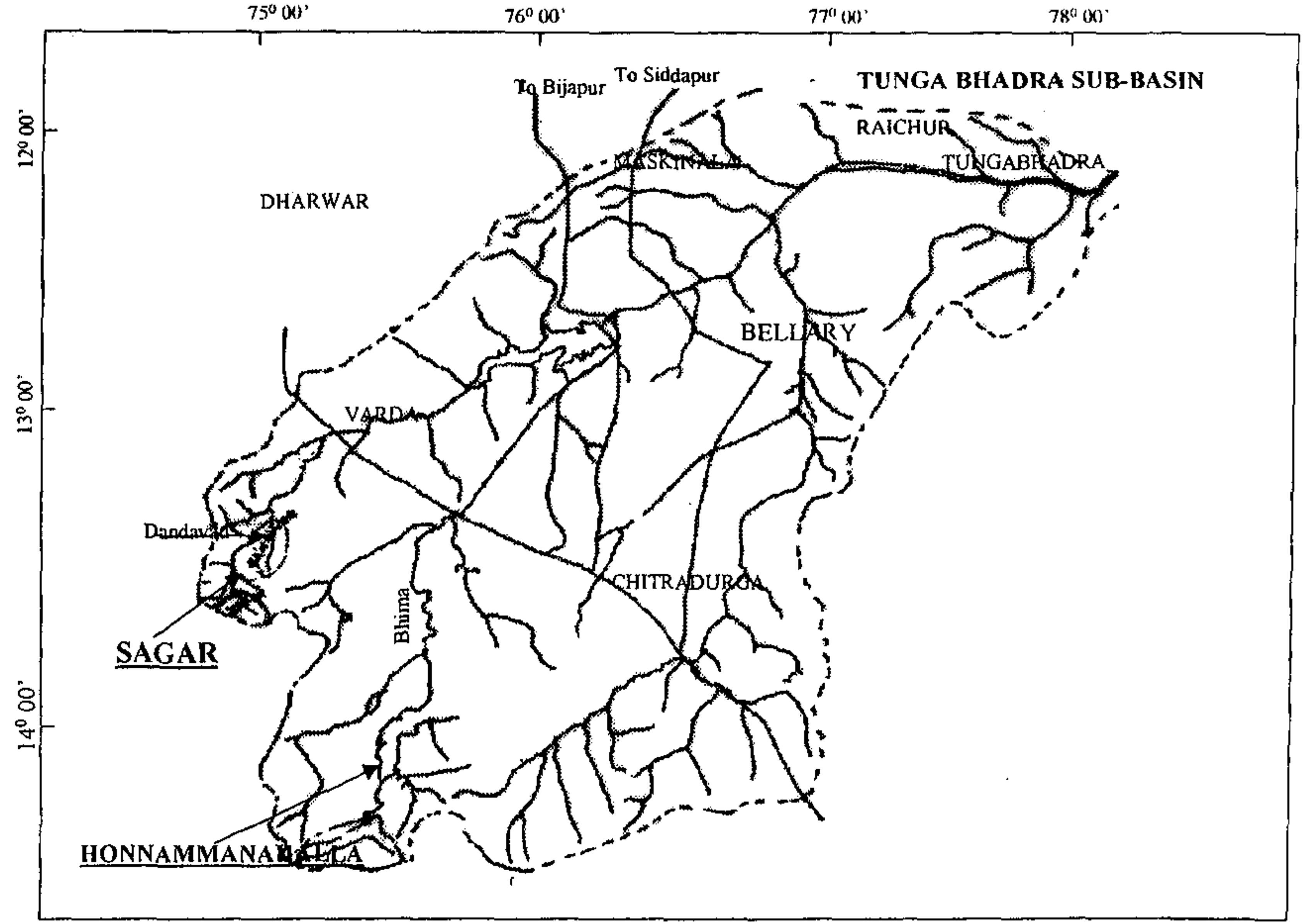


Figure 3. Location Map of Sagar and Honnammanahalla Watersheds

3.3 Honnammanahalla

The watershed Honnammanhalla is coming under the Hilly Agro-climatic zone of Karnataka State. It is situated in the Western Ghat and is a part of Krishna Basin. The location of the catchment is shown in the figure 3. Its also originate from the hilly region of the western ghat and nearly 6 kms from the Attigundi in the Chickamangalur district of Karnataka state. The total catchment area of the watershed is 4.51 sq. km. The catchment area lies between 75°38' and 75°44' East longitudes and 14°32' and 14°38' North latitude along the boarder of Chickmangalur taluk. The stream gauge site is maintained by WRDO is located at Attigundi at an altitude of 1438.70 m. Rainfall records are available from rain gauge station situated at Attigundi and Sringeri. Average annual rainfall for this area is 1833 mm.

3.4 Barchinala

The Barchinala watershed upstream of Barchi is located in the leeward side of western ghat and is a sub-basin of Kali River as shown in figure 4. It is also coming under the Hilly Agro-climatic region of the Karnataka State.

Barchi nala originates from Thavargatti in Belgaum District at an altitude of about 734m, 20 km north of Dandeli and flows through North Kanara district of Karnataka State. The catchment is relatively short in width and river flows on a southerly direction and joins the main Barchi river near the gauging site. The geographical area covered by Barchi watershed is 14.5 sq. km. The watershed lies between 74°36' and 74°39' East longitudes, and 15°18' and 15°24' North latitudes.

High land region consists of dissection of high hills and ridges forming part of the foot hills of western ghats. It consists of steep hills and valleys intercepted with thick vegetation. The slopes of the ghats are covered with dense deciduous forest. The brownish and fine grained soils are the principal types of soils found in this area.

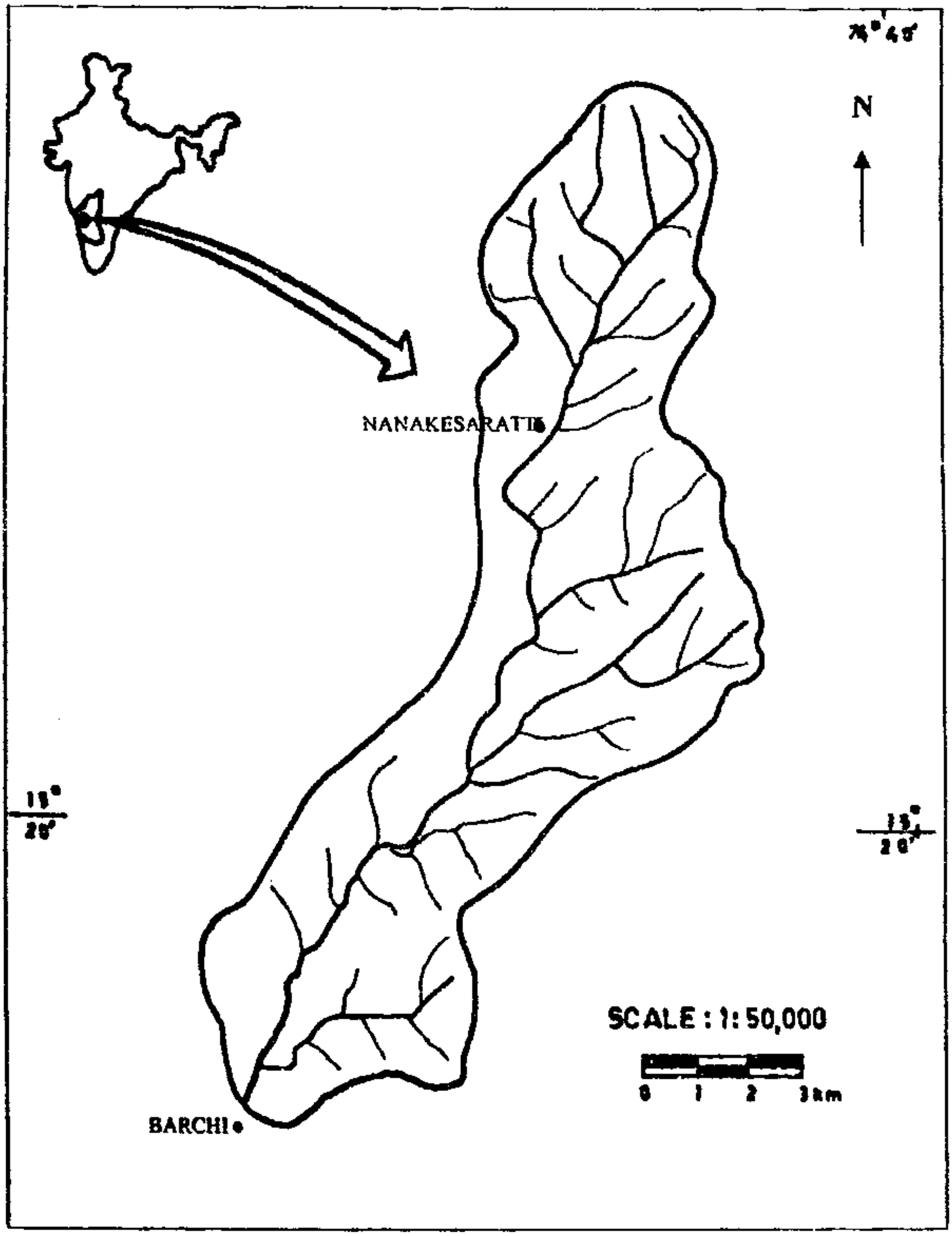


Figure 4. Location Map of Barchinala Watershed

The stream gauge site is located at an elevation of 480 m, where the nala crosses Dandeli-Thavargatti road, about 5 km from Dandeli. The stream is a 4th order stream. This stream joins main Barchi river downstream of the gauge site. A full fledged meteorological station, maintained by WRDO, is located near the gauging site. Average annual rainfall for the watershed is 1500 mm and the area receives majority of this rainfall during south-west monsoon period.

3.5 Yettinhole

The Yettinhole watershed is coming under the Hilly agro-climatic zone of the Karnataka State. It is situated in the Western Ghat. The location of the catchment is shown in the figure 5. It originate from the hilly region of Western Ghat and 4 kms from the Harley Estate in the Hassan district of Karnataka state. It is a sub-basin of Netravati river. The total catchment area of the watershed is 26 sq. km. The catchment area lies between 75°50' and 75°55' East longitudes and 12°51' and 12° 56' North latitude along the boarder of Sakaleshpur taluk. The stream gauge site is maintained by WRDO is located at Harley Estate at an altitude of 887.75 m. Rainfall records are available from rain gauge stations situated at Harley and Maranhalli. Average annual rainfall for this area is 3918 mm.

3.6 Jadkalhole

The watershed Jadkalhole is coming under the Coastal zone of the Agro-climatic region of the Karnataka State. It is situated in the Western Ghat. The location of the catchment is shown in the figure 5. Its originate from the hills of the Western Ghat and 3 kms from Jadkal in the Dakshinakanada district of Karnataka. It is a sub-basin of Kollur river flowing westward direction towards the Arabian Sea. The total catchment area of the watershed is 90 sq. km. The catchment area lies between 74°45' and 74°48' East longitudes and 13°47' and 13° 56' North latitude along the boarder of Coondapur and taluk. The stream gauge site is maintained by WRDO is located at Jadkal at an altitude of

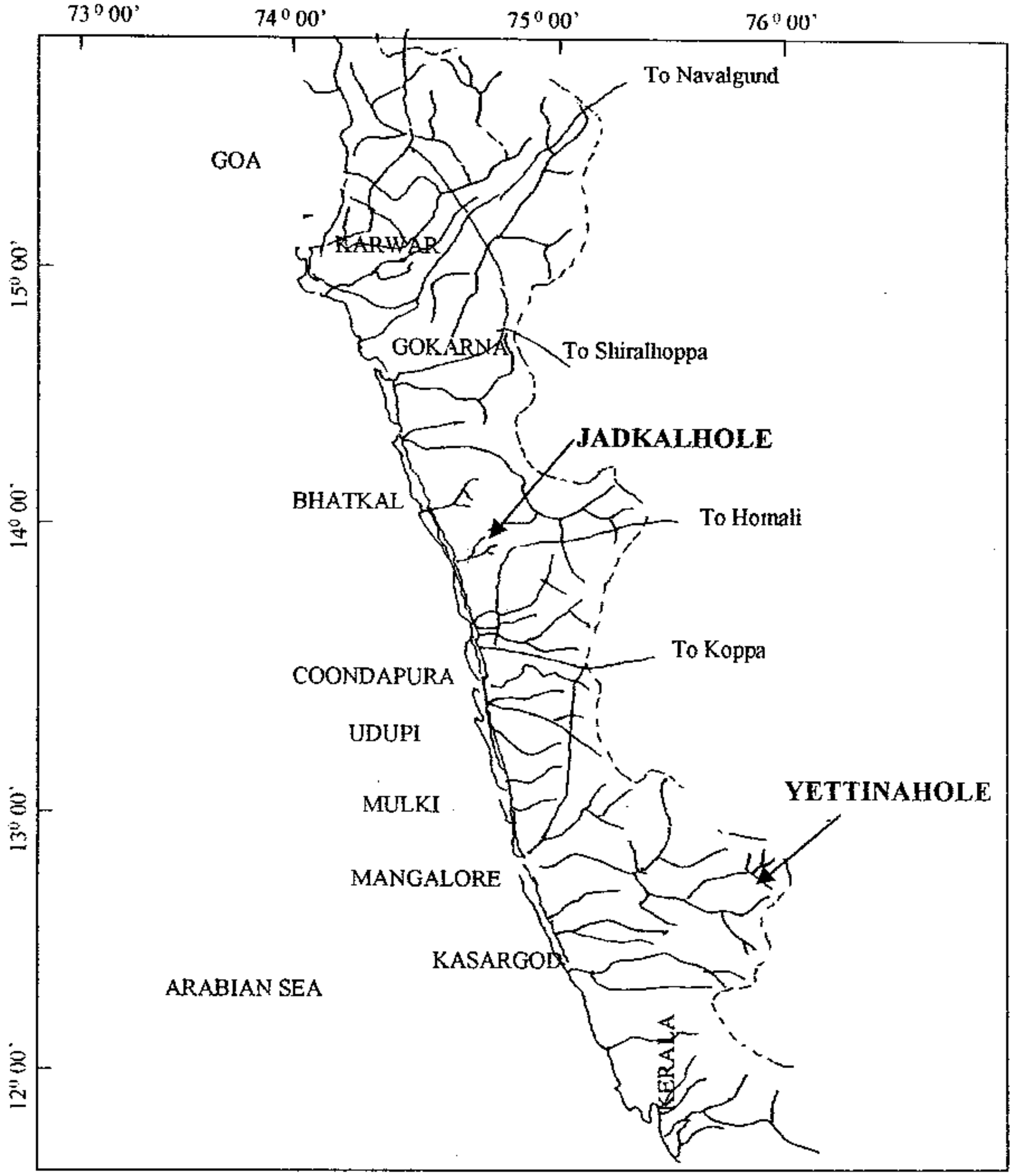


Figure 5. Location Map of Yettinahole and Jadkalhole Watersheds

72 m. Rainfall and records are available from rain gauge stations situated at Coondapur and Kollur. Average annual rainfall for this area is 3698 mm.

4.0 METHODOLOGY

Since the curve numbers given in the SCS tables (NEH-4) were derived from conventional analysis of data from small experimental watersheds in USA, its use for our conditions may lead to erroneous estimation of curve numbers and in turn runoff depths. Hence, it is advantageous to have some alternate method for the estimation of runoff curve number. The objective is to verify the curve number values given in the standard SCS tables and to extend the methodology to soil cover complexes and geographic locations not covered by the NEH-4. Because of the sensitivity of the method to CN values and the unreliability of CN estimates from standard tables, reassurance and safe reference should be taken from local real data situations, by determining curve numbers for local watersheds from recorded storm rainfall-runoff.

Since the method's inception, several investigators have attempted to determine runoff curve numbers from small watershed rainfall-runoff data, which can be used for homogeneous regions. An established procedure to estimate CN values from rainfall-runoff data is to solve for S from SCS rainfall-runoff equation, as follows:

$$S = 5(P + 2Q - \sqrt{4Q^2 + 5PQ}), \text{ for Ia} = 0.2\text{ S} \qquad (7)$$

For a given P and Q pair, the potential retention S can be calculated using the above equation, and the corresponding CN can be calculated using $CN = 1000/(10 + S)$. For areas where Ia = 0.1 S or 0.3 S, the expressions for the calculating S from the observed rainfall-runoff pairs are as follows;

For Ia = 0.1 S,

$$S = 5(2P + 9Q - \sqrt{81Q^2 + 40PQ}) \qquad (8)$$

and for Ia = 0.3 S,

$$S = 0.56(6P + 7Q - \sqrt{49Q^2 + 120PQ}) \qquad (9)$$

There are several ways to select the P-Q pairs for analysis. The standard method utilises daily rainfall and corresponding runoff volume for the annual floods at a site. When the annual flood series is not available for a longer period, it is possible to select storm event data. This incorporates rainfall-runoff events with return period less than one year. This procedure has the advantage that it results in a considerable range of rainfall and runoff values for analysis.

Another approach is the frequency matching method. The storm rainfall and direct runoff depths are sorted separately, and then realigned on a rank basis to form desirable P-Q pairs of equal return period. The individual runoff values are not necessarily associated with the original rainfalls. For all return periods, the CN is taken to be consistent. Thus, when treating rainfall and runoff data, the N-year return period rainfall should be paired with N-year return period runoff. Here, the CN method may be seen as a transformation between a rainfall-depth distribution and a runoff depth distribution.

When curve numbers are calculated from real storm data, a secondary relationship emerges between CN and the storm rainfall depth. Different watersheds with varying rainfall-runoff relationship show different types of variation of curve number values with increasing precipitation values. The first variation is the complacent behaviour, in which the observed CN values decline steadily with increasing rainfall depth and show no appreciable tendency to achieve a stable value. In this case, curve number cannot be safely determined from data, because no constant value is clearly approached.

The second variation is the standard behaviour, which is the most common scenario. Here, the observed CN declines with increasing storm size and approaches and/or maintain a near constant value with increasingly larger storm. The runoff itself may arise from a variety of source process, including overland flow and rapid subsurface flows.

The third variation is violent behaviour, in which the distinguishing feature is that the observed curve numbers rise suddenly and later asymptotically approach a constant value. There is often accompanying complacent behaviour at lower rainfalls. From a source-process standpoint, this could be a threshold phenomenon at some critical rainfall depth value. The above three types of variations are shown in figure 6.

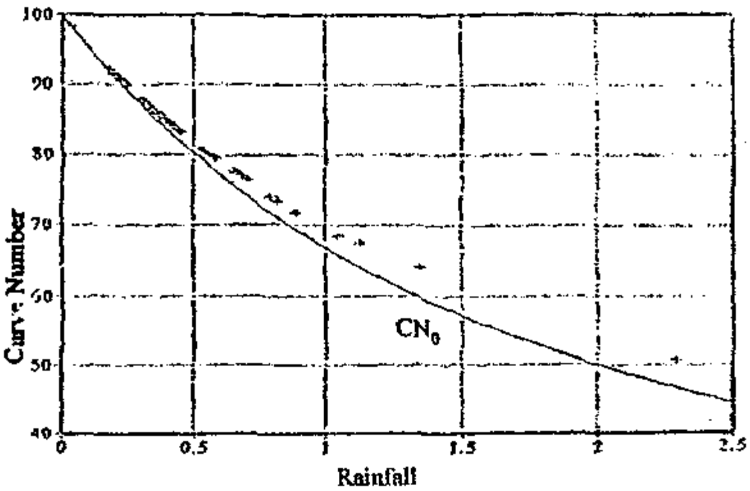
In the P-CN variations as shown in figure 6, there is a CN value for which any rainfall value less than a threshold P will yield no runoff. This is denoted as CN_0 curve, where $CN_0 = 100 / (1 + 0.5 P)$, for Ia = 0.2S. CN_0 is defined for a given P for which the initial abstraction is just satisfied. Any smaller P for that CN will give no runoff and likewise any CN smaller than CN_0 will give no runoff for the same P. The area below CN_0 line is considered as domain of no runoff (Hawkins 1979).

In most of the cases, these calculated CNs approach a constant value with increasing rainfall. This asymptotic constant value CN_∞ is used to identify the curve number for a watershed. The equation;

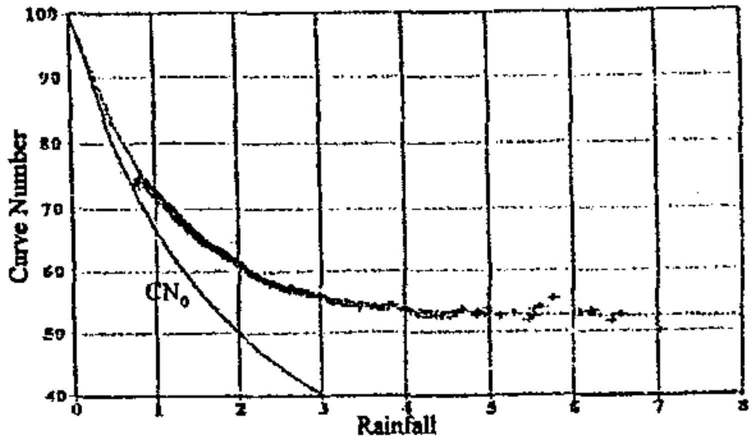
$$CN(P) = CN_\infty + (100 - CN_\infty)\,\mathbf{exp}(-kP) \qquad (10)$$

has been found to fit (P-CN) data set, where CN_∞ is the constant curve number value as $P \rightarrow \infty$ and k is a fitting constant. This equation may be fitted by a least square procedure to calculate CN_∞ and k. Although, this is an entirely curve fitting approach, it has been found to be appropriate for a wide array of watershed data sets.

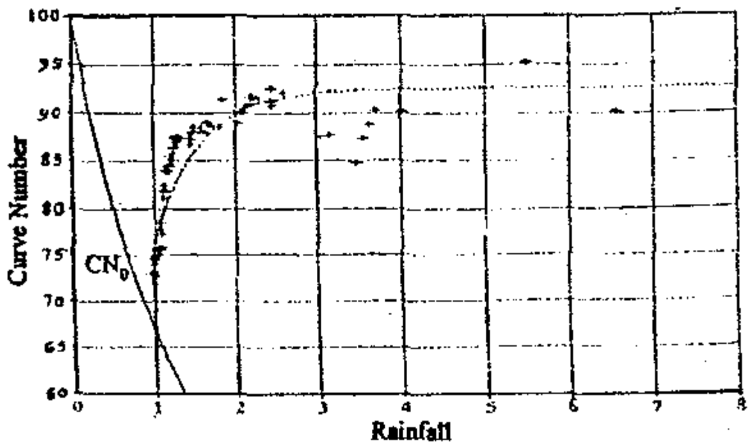
The asymptotic constant value is used in identifying the CN for a watershed. Thus, where no constant value is approached, as in complacent situations, no CN_∞ can be determined. The problem is then reduced to an objective determination of that asymptote for the standard and violent situations. When the data exhibit complacent behaviour, asymptotic fit can still be possible by assuming that the data set is merely the lower rainfall end of the standard behaviour pattern. Then the watershed may perform in the extrapolated standard pattern when larger storms are eventually encountered. By considering this, a value of CN_∞ may indeed be calculated, but it will be much lower



Complacent Behaviour



Standard Behaviour



Violent Behaviour

Figure 6. Different Variations of CN with P (Hawkins, 1993)

than any CN experienced in the data set. Complacent behaviour can also be a beginning of the violent behaviour, since there is no way of knowing which response path might be active at higher rainfalls. So, it is advisable that the complacent data set should not be extrapolated to assume constant CNs in the standard pattern. This situation suggests that the watershed does not respond in accord with the CN equation, at least not within the range of the data set encountered.

The violent pattern applies to the observed CNs, that suddenly increase and then approach a constant value with increasing storm size. In this case, the equation,

$$CN(P) = CN_{\infty}\{1 - \exp(-kP)\} \qquad (11)$$

has been found to fit P-CN data set. This pattern is sometimes preceded with a complacent pattern at lower rainfall, but only the non-complacent data points should be used in the above equation. The calculated curve number values have been further used to estimate the initial abstraction coefficient for the study watersheds. The relationship developed from the various sets of observed runoff and the calculated runoff gives the initial abstrction coeffcient for the watersheds under study.

Base Flow Separation Method

In the present study, a procedure suggested in low flow studies report (Gustard et al., 1992) to estimate the Base Flow Index using the mean daily discharge data is used. BFI can be thought of as measuring the proportion of the river runoff that derives from stored sources. A computer program is applied to smooth and to separate the recorded or observed flow hydrogrpah from which the index is calculated as the ratio of the flow under the separated hydrograph to the flow under the total hydrograph. The procedure for calculating BFI is as follows

1. Divide the mean daily flow data into non-overlapping blocks of five days and calculate the minimum for each of the block and they may be called as Q1, Q2, Q3,…….Qn

2. Consider in turn (Q1,Q2,Q3), (Q2,Q3,Q4), (Qi-1, Qi, Qi+1) etc. In each case if 0.9 times central value is less than other values, then the central value is an ordinate for the baseflow line. This procedure is continued till all the data are analysed to provide a derived set of base flow ordinates QB1, QB2, QB3,....... QBn which will have different time periods between them.

3. By linear interpolation between each Qbi values as found above, daily value of QB1 to QBn are estimated

4. If QBi is greater than Qi then QBi is made equal to Qi

5. The volume beneath the base flow line thus separated VB is calculated between the first and last points QB1 to QBn.

6. The volume beneath the recorded mean daily flow Qi and Qn is calculated as VA for the period QB1 to QBn.

7. The base flow index is derived as the ratio of VB and VA

5.0 ANALYSIS AND RESULTS

5.1 Asymptotic Estimation of Curve Number

As mentioned in previous sections, SCS curve number methodology is the simplest and most popular methodology for the estimation of storm runoff. In this method, selection of proper curve number for a particular watershed is of utmost importance since the runoff output is sensitive to the curve number value. The asymptotic estimation of curve number is advantageous over the conventional method, as it uses the real rainfall-runoff data sets. There are also ways to check the stability of the fit and to assess the degree of accuracy of the results obtained.

In the present study, six watersheds falling under the hard rock region of the country, especially in Karnataka State were selected to estimate the initial abstraction coefficient for each watershed. Rainfall-runoff records were collected for a reasonably long period, to cover wide variations in the storm pattern. Using the daily rainfall records, various storms were separated and the corresponding runoff amounts were taken from the runoff records. Since the SCS method basically handles surface runoff, the base flow separation has been done by the procedure as mentioned in the methodology for base flow separation.

Once the rainfall-runoff events have been separated, the first step is to order the data, i.e., sort the rainfall and runoff depths independently in descending order and rematch them. Since each of the ordered items is of the same return period, this assures frequency matching between rainfall and runoff. For this study, both natural and ordered P-Q data sets were used for the estimation of curve number. The second step is to determine curve numbers for different initial abstraction rates. Third step is the asymptotic definition, in which a classification is made and the average curve number is determined by least square fitting using a basic programme developed by Hawkins (1993)

Since it is difficult to properly determine the value of initial abstraction coefficient, the rainfall-runoff pairs were used to estimate curve numbers for eight initial abstraction coefficients, 0.1 S, 0.15 S, 0.2 S, 0.25 S, 0.3 S, 0.35 S, 0.4 S, 0.5 S, and 0.6 S. The asymptotic curve numbers for the six watersheds for these abstraction rates are given in table 2. From the table it can be seen that ordered data set is giving a higher CN value. This is because in ordered data set, higher rainfall is matched with a higher runoff which will give a larger CN value compared to natural data set in which the higher rainfall values may be matched with lower runoff values. It can also be seen from the table that an initial abstraction rate of 0.6 S gives the larger CN_∞ value for all the watersheds.

Dandavati

Daily data for raingauge stations at Sorab and Kupe was considered for the analysis. 44 storms and the corresponding runoff recorded at sorab were selected for the period of 1988 to 1996. All the storms were from monsoon season. Base flow was separated from individual runoff to calculate the direct runoff.

For the selected rainfall-runoff values, CN_∞ values were calculated for both natural and ordered data sets. Curve number values for this data set shows a standard behaviour, as can be seen from figure 7 and figure 8 (variation of natural and ordered data set for Ia = 0.2). The variation of curve numbers calculated for all the initial abstraction coefficients are similar to that shown in figure 7 and figure 8.

The results from the least square fit are shown in table 3. The factor k is the fitting coefficient in the asymptotic equation as stated in the methodology section. Other parameters given in the table will be explained in the succeeding discussion. It can be seen from the table that ordered data set yields better r-squared value. In the ordered data set, the rainfall and runoff pairs are matched as per the return period. This will reduce the scatter in the calculated CN values and results in a better fit.

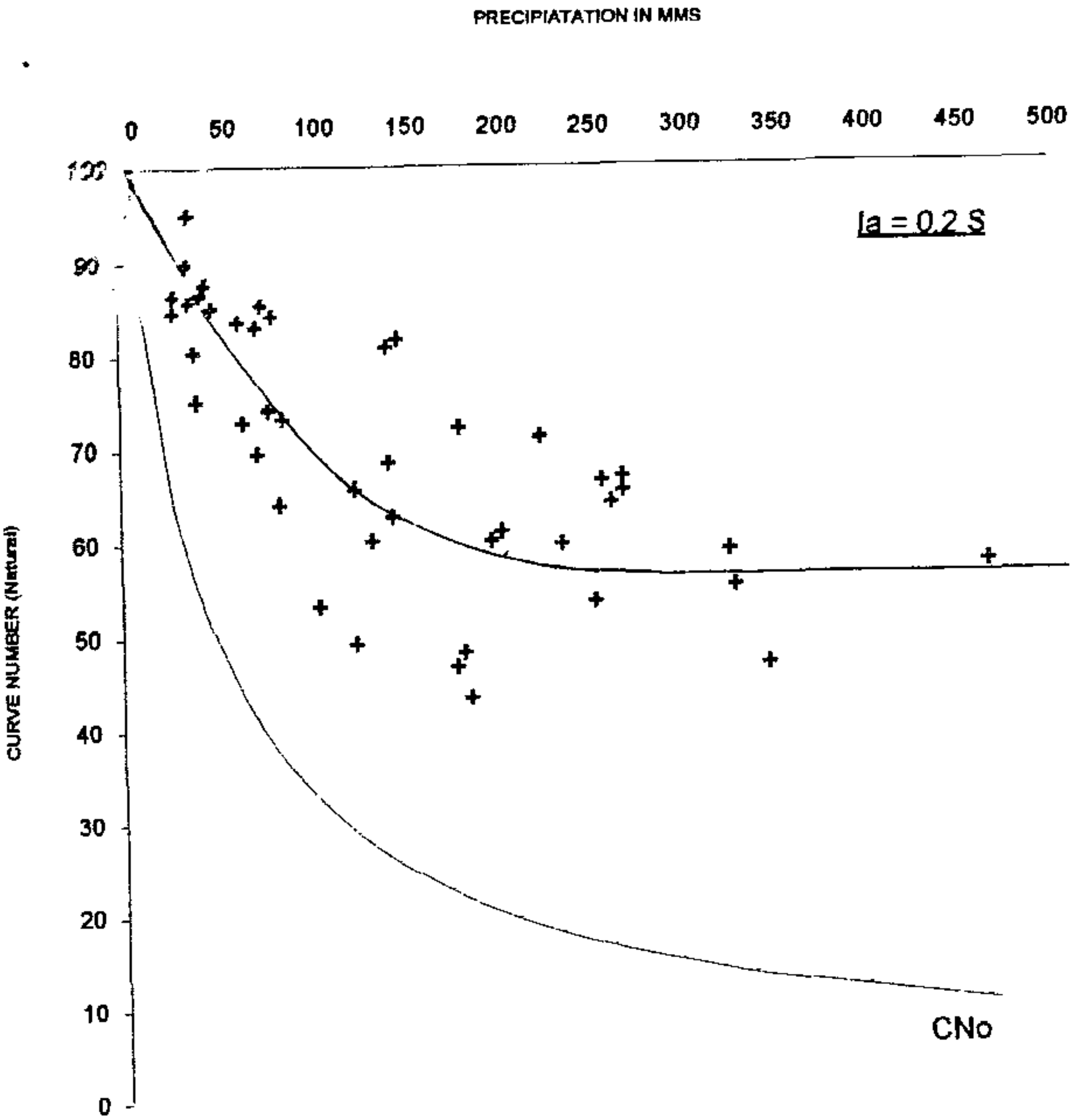


Figure 7. Variation of Curve Number (Natural) with Rainfall (Dandavati Watershed)

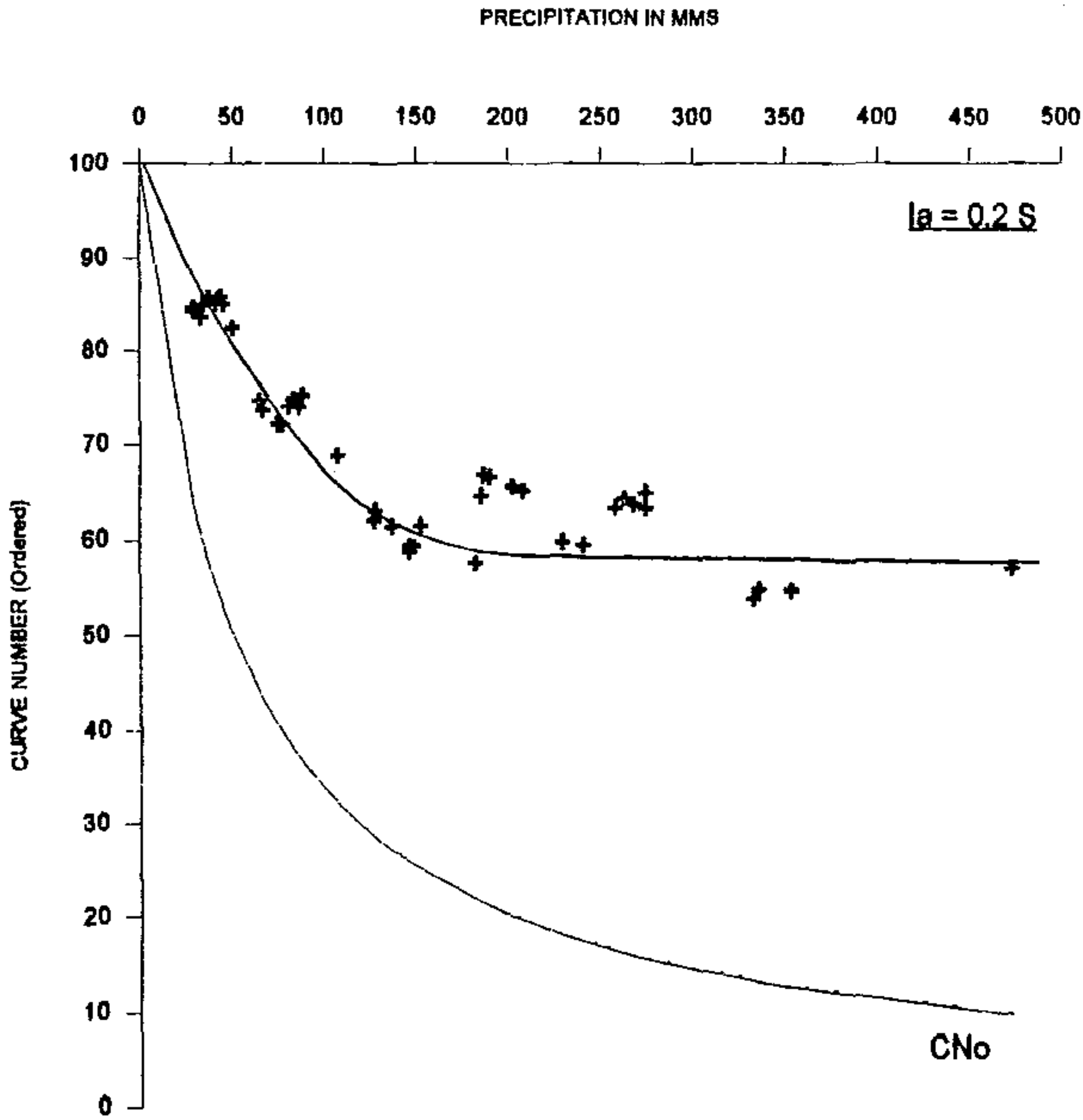


Figure 8. Variation ofCurve Number (Ordered) with Rainfall (Dandavati Watershed)

Table 2. a) Estimated Curve Numbers for the Watersheds for Different Ia Rates

Watersheds ---→	**Dandavati**		**Sagar**		**Honnammanahalla**	
Ia	Natural	Ordered	Natural	Ordered	Natural	Ordered
0.05 S	49.62	52.37	36.45	33.39	14.89	17.35
0.10 S	52.19	54.91	38.57	37.26	19.26	21.69
0.15 S	54.32	57.03	40.51	40.30	22.35	24.96
0.20 S	56.14	58.84	42.25	42.91	24.78	27.57
0.25 S	57.77	60.41	43.88	45.12	26.77	29.70
0.30 S	59.18	61.81	45.36	47.10	28.41	31.57
0.35 S	60.51	63.05	46.73	48.93	29.80	33.11
0.40 S	61.69	64.19	47.98	50.51	30.94	34.52
0.50 S	63.72	66.20	50.28	53.39	32.94	36.85
0.60 S	65.53	67.92	52.27	55.88	34.40	38.67

Table 2. b) Estimated Curve Numbers for the Watersheds for Different Ia Rates

Watersheds ---→	**Barchinala**		**Yettinahole**		**Jadkalhole**	
Ia	Natural	Ordered	Natural	Ordered	Natural	Ordered
0.05 S	26.87	33.40	17.61	21.02	42.22	42.57
0.10 S	31.29	36.79	20.92	23.33	47.33	47.42
0.15 S	34.89	39.67	23.18	25.19	51.04	51.14
0.20 S	37.90	42.20	25.01	26.81	53.95	54.12
0.25 S	40.48	44.45	26.45	28.28	56.33	56.61
0.30 S	42.81	46.38	27.83	29.48	58.35	58.72
0.35 S	44.81	48.18	30.02	31.78	60.09	60.55
0.40 S	46.72	49.76	28.92	30.65	61.63	62.17
0.50 S	49.92	52.66	31.81	33.72	64.23	64.94
0.60 S	52.65	55.09	33.50	35.32	66.36	67.22

Table 3. Results from Standard Asymptotic Fit for Natural and Ordered Data Set for Dandavati

Ia	Parameters of Standard Asymptotic Fit					
	CN∞	k (1/inch)	R-squared %	CNP (90)	Stability %	dQ/dP %
	Natural Data Set					
0.05 S	49.62	0.37	47.36	50.23	98.79	71.49
0.10 S	52.19	0.33	53.44	53.12	98.04	73.55
0.15 S	54.32	0.30	57.54	55.58	97.25	75.07
0.20 S	56.14	0.28	60.59	57.70	96.44	76.30
0.25 S	57.77	0.26	62.97	59.60	95.66	77.38
0.30 S	59.00	0.25	64.93	61.10	94.89	78.11
0.35 S	60.51	0.24	66.47	62.83	94.13	79.13
0.40 S	61.69	0.23	67.81	64.22	93.39	79.86
0.50 S	63.72	0.21	69.94	66.65	91.94	81.08
0.60 S	65.53	0.20	71.57	68.75	90.66	82.20
	Ordered Data Set					
0.05 S	52.37	0.45	91.69	52.59	99.54	76.24
0.10 S	54.91	0.40	92.63	55.31	99 13	78.25
0.15 S	57.03	0.36	93.24	57.61	98.65	79.71
0.20 S	58.84	0.34	93.68	59.61	98.14	80.83
0.25 S	60.41	0.31	94.00	61.36	97.59	81.71
0.30 S	61.63	0.30	94.27	62.76	97.06	82.33
0.35 S	63.05	0.28	94.47	64.35	96.46	83.09
0.40 S	64.19	0.27	94.65	65.65	95.90	83.66
0.50 S	66.20	0.25	94.92	67.95	94.82	84.64
0.60 S	67.92	0.23	95.14	69.92	93.77	85.47

Sagar

For the analysis, 117 rainfall-runoff combinations were selected from the daily rainfall-runoff data series of the year 1985-1995. Variation of CN with the rainfall values is a standard variation, as found earlier. The result from the asymptotic fit is given in table 4.

Table 4. Results from Standard Asymptotic Fit for Natural and Ordered Data Set for Sagar

Ia	Parameters of Standard Asymptotic Fit					
	CN∞	k (1/inch)	R-squared %	CNP (90)	Stability %	dQ/dP %
	Natural Data Set					
0.05 S	36.45	0.44	68.62	36.68	99.63	55.89
0.10 S	38.57	0.35	73.35	39.31	98.79	57.60
0.15 S	40.51	0.30	75.78	41.89	97.69	59.02
0.20 S	42.25	0.26	77.25	44.29	96.47	60.29
0.25 S	43.88	0.24	78.22	46.55	95.24	61.61
0.30 S	45.36	0.22	78.90	48.63	94.02	62.87
0.35 S	46.73	0.21	79.40	50.55	92.84	64.09
0.40 S	47.98	0.20	79.77	52.31	91.68	65.23
0.50 S	50.28	0.18	80.28	55.48	89.55	67.41
0.60 S	52.27	0.16	80.60	58.20	87.58	69.33
	Ordered Data Set					
0.05 S	33.39	0.39	93.13	33.86	99.29	49.35
0.10 S	37.26	0.33	93.48	38.20	98.49	54.82
0.15 S	40.30	0.29	93.54	41.72	97.62	58.58
0.20 S	42.91	0.27	93.51	44.76	96.76	61.60
0.25 S	45.12	0.25	93.46	47.37	95.90	63.96
0.30 S	47.10	0.24	93.39	49.70	95.09	66.02

0.35 S	48.93	0.26	93.32	51.82	94.34	67.89
0.40 S	50.51	0.22	93.26	53.69	93.58	69.40
0.50 S	53.39	0.20	93.14	57.00	92.25	72.13
0.60 S	55.88	0.19	93.03	59.82	91.07	74.38

Honnammanahalla

For the analysis, 241 rainfall-runoff combinations were selected from the daily rainfall-runoff data series of the year 1985-1995. The same variation is found in this watershed also with the CN and rainfall values. The result from the asymptotic fit is given in table 5.

Table 5. Results from Standard Asymptotic Fit for Natural and Ordered Data Set for Honnammanahalla

Ia	Parameters of Standard Asymptotic Fit					
	CN∞	k (1/inch)	R-squared %	CNP (90)	Stability %	dQ/dP %
	Natural Data Set					
0.05 S	14.89	1.05	96.61	16.87	97.67	0.00
0.10 S	19.26	0.70	98.13	25.69	92.04	0.00
0.15 S	22.35	0.55	98.71	33.20	86.02	0.00
0.20 S	24.78	0.46	99.01	39.45	80.50	0.45
0.25 S	26.77	0.39	99.19	44.64	75.60	2.28
0.30 S	28.41	0.35	99.30	48.99	71.25	4.84
0.35 S	29.80	0.31	99.39	52.70	67.38	7.70
0.40 S	30.94	0.28	99.45	55.89	63.88	10.63
0.50 S	32.94	0.24	99.54	61.10	58.00	16.42
0.60 S	34.40	0.21	99.60	65.19	53.07	21.73
	Ordered Data Set					

0.05 S	17.35	1.13	99.33	18.78	98.27	0.00
0.10 S	21.69	0.75	99.66	26.95	93.29	0.00
0.15 S	24.96	0.55	99.80	34.15	87.76	0.00
0.20 S	27.57	0.49	99.86	40.18	82.58	1.27
0.25 S	29.70	0.42	99.90	45.23	77.92	3.62
0.30 S	31.57	0.37	99.93	49.49	73.81	6.44
0.35 S	33.1!	0.34	99.94	53.12	70.08	9.41
0.40 S	34.52	0.31	99.95	56.26	66.80	12.43
0.50 S	36.85	0.26	99.96	61.40	61.13	18.22
0.60 S	38.67	0.23	99.97	65.42	56.38	23.477

Barchinala

For the analysis, 32 rainfall-runoff combinations were selected from the daily rainfall-runoff data series of the year 1988-1997. Variation of CN with the rainfall values is a standard variation. From the relationship between curve number and rainfall, it can be seen that there is a gap between rainfall data set between 200-350 (figure 9 and figure 10). The result from the asymptotic fit is given in table 6.

Table 6. Results from Standard Asymptotic Fit for Natural and Ordered Data Set for Barchinala

Ia	Parameters of Standard Asymptotic Fit					
	CN∞	k (1/inch)	R-squared %	CNP (90)	Stability %	dQ/dP %
	Natural Data Set					
0.05 S	26.87	0.44	72.91	31.09	94.22	8.85
0.10 S	31.29	0.37	79.31	37.38	91.14	15.80
0.15 S	34.89	0.33	82.75	42.39	88.48	21.66
0.20 S	37.90	0.30	84.92	46.52	86.13	26.69

0.25 S	40.48	0.28	86.42	49.99	84.02	31.05
0.30 S	42.59	0.26	87.55	52.78	82.25	34.62
0.35 S	44.81	0.25	88.39	55.60	80.44	38.34
0.40 S	46.72	0.24	89.08	57.92	78.97	41.49
0.50 S	49.92	0.22	90.12	61.81	76.26	46.73
0.60 S	52.65	0.21	90.88	64.98	73.95	51.06
	Ordered Data Set					
0.05 S	33.40	0.54	95.03	35.34	97.09	19.55
0.10 S	36.79	0.44	96.78	40.33	94.41	24.80
0.15 S	39.67	0.38	97.53	44.59	91.86	29.24
0.20 S	42.20	0.35	97.92	48.24	89.54	33.19
0.25 S	44.45	0.32	98.16	51.41	87.46	36.77
0.30 S	46.23	0.30	98.31	53.97	85.61	39.62
0.35 S	48.18	0.28	98.41	56.60	83.76	42.75
0.40 S	49.76	0.26	98.49	58.75	82.11	45.28
0.50 S	52.66	0.24	98.59	62.46	79.31	49.86
0.60 S	55.09	0.22	98.66	65.49	76.83	53.64

Yettinahole

For the analysis, 115 rainfall-runoff combinations were selected from the daily rainfall-runoff data series of the year 1989-1995. Variation of CN with the rainfall values is a standard variation. The result from the asymptotic fit is given in table 7.

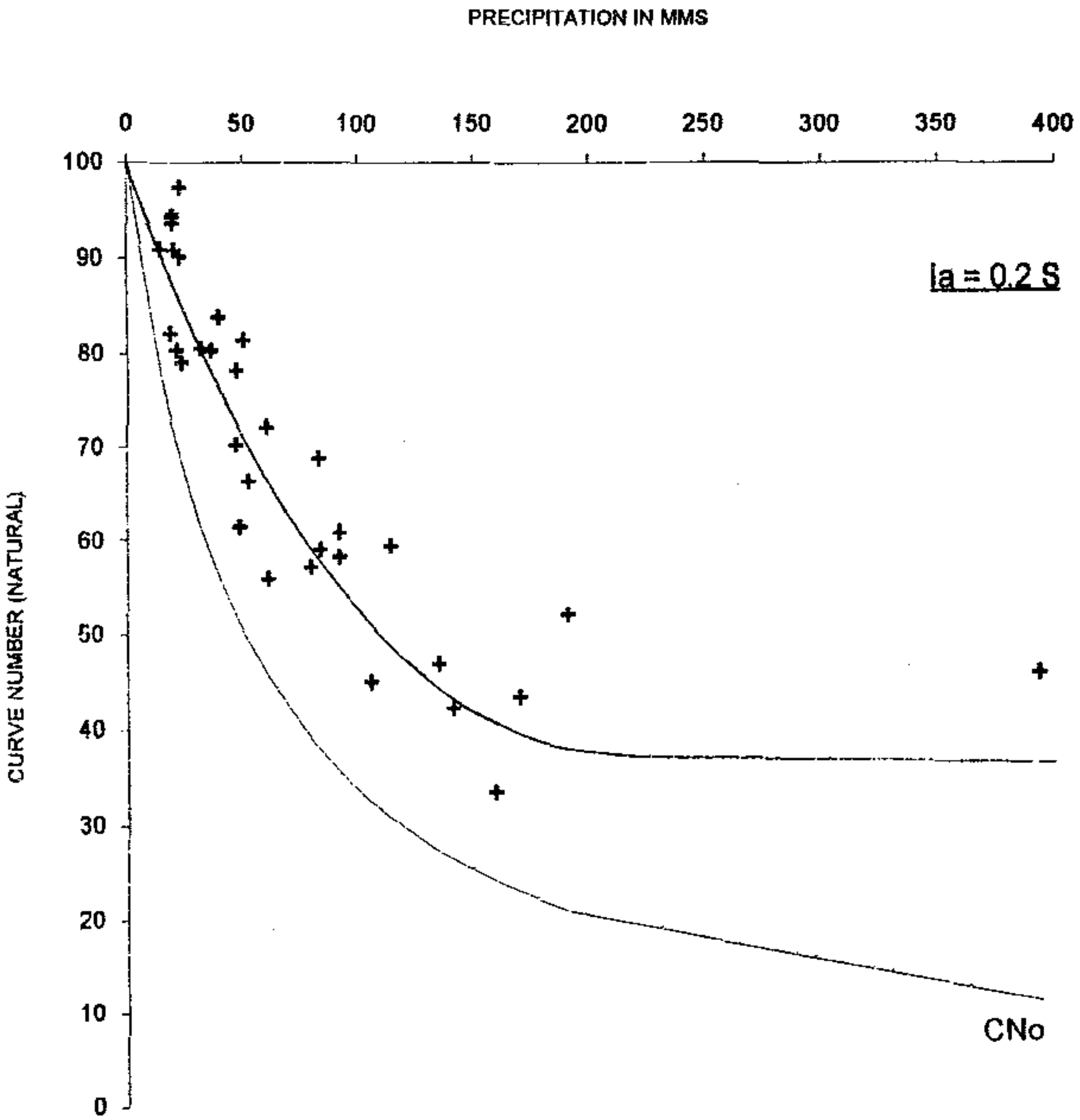


Figure 9. Variation of Curve Number (Natural) with Rainfall (Barchinala Watershed)

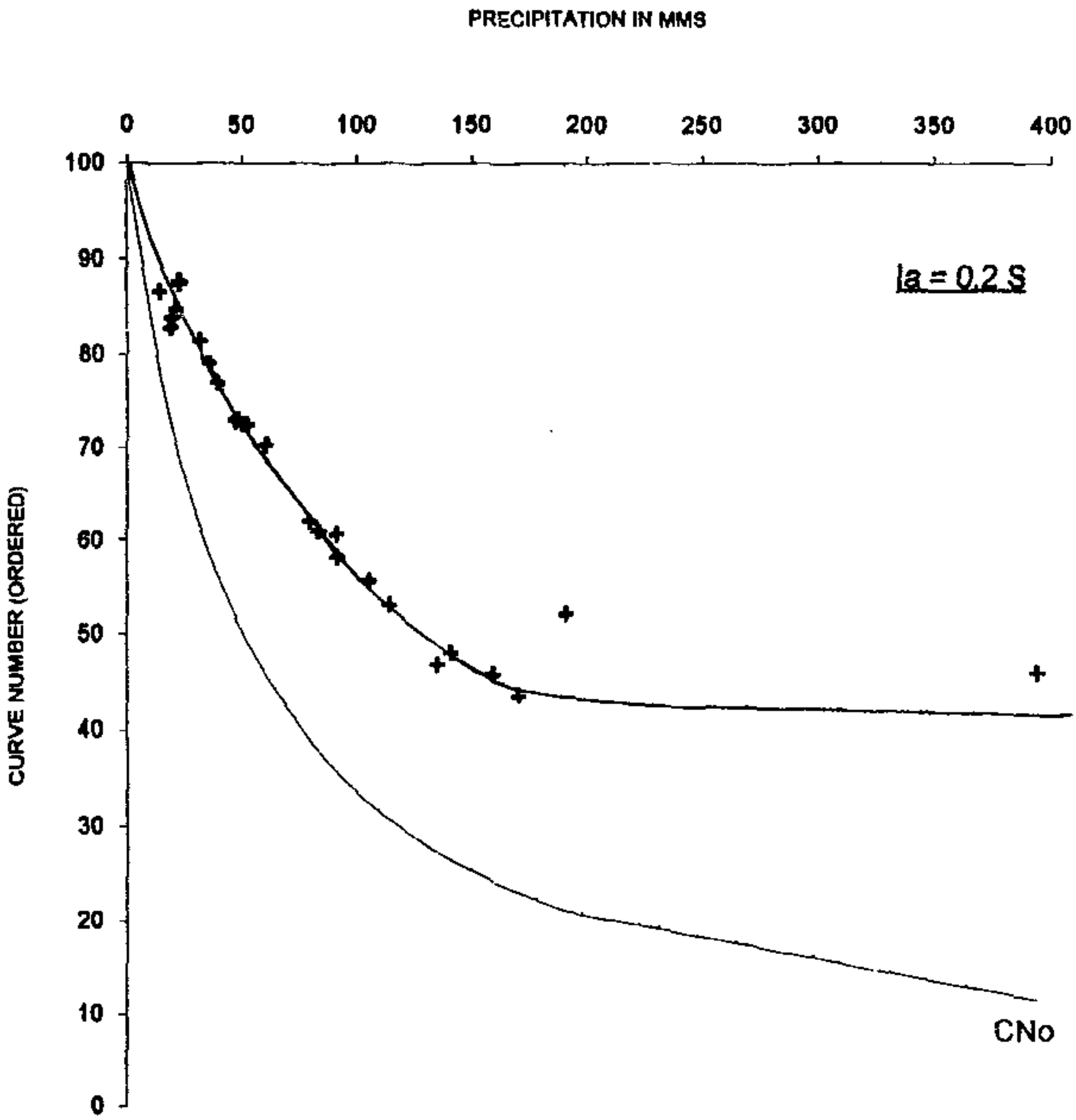


Figure 10. Variation ofCurve Number (Ordered) with Rainfall (Barchinala Watershed)

Table 7. Results from Standard Asymptotic Fit for Natural and Ordered Data Set for Yettinahole

Ia	Parameters of Standard Asymptotic Fit					
	CN∞	k (1/inch)	R-squared %	CNP (90)	Stability %	dQ/dP %
	Natural Data Set					
0.05 S	17.61	0.61	85.87	19.97	97.14	0.00
0.10 S	20.92	0.46	90.50	26.54	92.89	0.47
0.15 S	23.18	0.37	92.74	32.12	88.36	3.23
0.20 S	25.01	0.32	94.07	36.97	84.05	6.09
0.25 S	26.45	0.28	94.96	41.15	80.02	9.14
0.30 S	27.83	0.25	95.59	44.83	76.45	12.42
0.35 S	30.02	0.21	96.43	50.80	70.18	18.76
0.40 S	28.92	0.23	96.06	48.03	73.11	15.59
0.50 S	31.81	0.18	96.96	55.70	64.97	24.60
0.60 S	33.50	0.16	97.32	59.62	60.72	29.89
	Ordered Data Set					
0.05 S	21.02	0.67	98.15	22.60	97.99	0.00
0.10 S	23.33	0.49	98.66	27.92	94.02	1.86
0.15 S	25.19	0.39	98.95	32.99	89.58	4.93
0.20 S	26.81	0.33	99.13	37.59	85.31	7.77
0.25 S	28.28	0.29	99.26	41.62	81.40	10.82
0.30 S	29.48	0.26	99.36	45.16	77.76	13.86
0.35 S	31.78	0.22	99.51	51.13	71.63	20.09
0.40 S	30.65	0.24	99.44	48.32	74.52	16.99
0.50 S	33.72	0.19	99.60	55.88	66.56	25.82
0.60 S	35.32	0.17	99.66	59.75	62.23	30.89

Jadkalhole

For the analysis, 110 rainfall-runoff combinations were selected from the daily rainfall-runoff data series of the year 1986-1995. The result from the asymptotic fit is given in table 8.

Table 8. Results from Standard Asymptotic Fit for Natural and Ordered Data Set for Jadkalhole

Ia	Parameters of Standard Asymptotic Fit					
	CN∞	k (1/inch)	R-squared %	CNP (90)	Stability %	dQ/dP %
	Natural Data Set					
0.05 S	42.22	0.97	60.12	42.23	99.98	51.02
0.10 S	47.33	0.77	67.12	47.40	99.87	59.24
0.15 S	51.04	0.66	70.78	51.20	99.67	64.40
0.20 S	53.95	0.59	73.08	54.23	99.39	67.95
0.25 S	56.33	0.54	74.69	56.76	99.03	70.54
0.30 S	58.35	0.50	75.89	58.93	98.61	72.53
0.35 S	60.09	0.46	76.82	60.83	98.14	74.10
0.40 S	61.63	0.43	77.57	62.53	97.65	75.40
0.50 S	64.23	0.39	78.71	65.44	96.61	77.42
0.60 S	66.36	0.03	79.54	67.86	95.53	78.94
	Ordered Data Set					
0.05 S	42.57	1.00	95.65	42.58	99.98	51.65
0.10 S	47.42	0.78	96.94	47.48	99.88	59.40
0.15 S	51.14	0.67	97.47	51.29	99.69	64.57
0.20 S	54.12	0.60	97.76	54.39	99.42	68.26
0.25 S	56.61	0.55	97.95	57.00	99.10	71.03
0.30 S	58.72	0.51	98.07	59.75	98.75	73.19
0.35 S	60.55	0.48	98.17	61.20	98.37	74.93

0.40 S	62.17	0.45	98.24	62.94	97.97	76.38
0.50 S	64.94	0.41	98.34	65.94	97.16	78.68
0.60 S	67.22	0.38	98.40	68.42	96.35	80.45

5.2 Stability and Sensitivity Analysis

i) Stability Analysis

Using CN_∞ as the curve number of reference in design work assumes that the constant CN (= CN_∞) is approached closely for the large extreme events. Since most data sets cover periods of record much less than design return periods, safe extrapolation of the fitted P-CN relations must be a concern. This is a general problem in extending model results beyond measured data. However, stability criteria can be used as a measure of confidence. There are two methods to check the stability of the asymptotic fit; (i) using curve number for 90th percentile rainfall depth, and (ii) slope of the P:Q line. These are described below.

The degree of closeness of the upper range of the sample data to the CN_∞ index defines the stability of the fit. The relative closeness of fitted CN to the 90th percentile sampled rainfall depth is used to indicate the stability of the CN_∞ estimate. Here, the 90th percentile was determined by, rank ordering and interpolation with the rainfall data. Stability analysis is to check the extend of flattening of CN curve, and is defined as,

$$\text{Stability} = (100 - CN90) / (100 - CN_\infty)$$

The slope of the P: Q line is also a measure of hydrologically defined stability of the fit. The idea here is that the ultimate possible slope is 1:1 or 100 %. The fitted slope dQ/dP is calculated for the 90th percentile rainfall point and used as a measure of the relative development of the watersheds' hydrologic process for the upper ranges of the data set. This will vary from 0 to 100 %, with 100 % indicating a completely defined event hydrology, where the process of conversion of rainfall to runoff is completely explained by the asymptotic fit or the calculated CN value completely satisfies the SCS rainfall-runoff relation.

Stability of the asymptotic fit for the three watersheds was checked using the above mentioned criteria. The results are listed below.

Dandavati

Dandavati falls in high rainfall region of western ghat and the 90th percentile rainfall value is 30.28 cm. The curve number corresponding to this rainfall is 59.61, which is very close to the asymptotic curve number 58.84. This results in a high stability of 98.14%, which shows a high confidence level of the data set. This is further proved from the second stability criteria in which the slope of the P-Q line is found to be 80.83%.

Sagar

For Sagar watershed, the 90th percentile rainfall is 32.36 cm. The curve number corresponding to this rainfall is 44.76, which is close to the asymptotic curve number 42.9. This results in a high stability of 96.76%, which also shows the high confidence level of the data set.

Honnammanahalla

The 90th percentile rainfall for the Honnammanahalla watershed is 9.12 cm. The curve number corresponding to this rainfall is 40.18, which is significant with the asymptotic curve number. This result in a poor stability of 82.58%, which also shows the poor confidence level of the data set and need to be revised the data set further.

Barchinala

The 90th percentile rainfall for the watershed is 16.61 cm and the corresponding curve number is found to be 48.24. The CN_∞ for the area obtained from the fit is 42.20.

This gives a stability of 89.54%, which shows that the data set is poorly responding to the fit, as compared to other watersheds, and the use of calculated CN_{∞} in further applications may result in some degree of errors. This is further shown in the second stability criteria where the slope of the P-Q line is 33.19%, which shows that only about 33% of the path taken by rainfall to runoff is known.

Yettinahole

The 90th percentile rainfall for the Yettinahole watershed is 14.72 cm and the corresponding curve number is 37.56. The CN_{∞} for the area obtained from the fit is 26.81. This gives a stability of 85.31%, which shows that the data set is poorly responding to the fit, as compared to other watersheds, and the use of calculated CN_{∞} in further applications may result in some degree of errors.

Jadkalhole

The 90th percentile rainfall for this watershed is 21.92 cm and the corresponding curve number is 54.39, which is very close to the asymptotic curve number 54.12. This results in a high stability of 99.42%, which shows a high confidence level of the data set. This is further proved from the second stability criteria in which the slope of the P-Q line is found to be 68.26%.

ii) Sensitivity analysis

Storm runoff, as calculated by the SCS runoff curve number method is shown to be varying sensitivity to both input rainfall and curve number. Although, it is possible to calculate curve number from field data, such practice is not widespread since even when rainfall data are available, gauged small watersheds are rare. Clearly, an accurate estimate of curve number is the weak input link for this method.

The poor matching of curve number value estimated from the standard tables and using P-Q data could arise from a number of sources i.e., (i) inability of the users to apply the estimation technique correctly, (ii) poor input soils and vegetation data, (iii) incorrect hydrologic analysis of field data to calculate CN, and (iv) basic error inherent in the methodology in either runoff model or the estimation procedure.

Hawkins (1975) studied the effect of fractional errors in the precipitation data and estimation of CN on the calculated Q values. He found that errors from curve number sources are more serious than precipitation source errors. It implies that the runoff calculation efforts should devote attention to accurate and representative curve number estimation.

To study the effect of errors in the values of measured P and Q on CN values, a ±10 percent error was forced on the rainfall-runoff data set and CN_{∞} was estimated for different combinations of P-Q for all the watersheds under study. The values were used to plot isolines for different percentage errors in P and Q. The result shows that the curve number values are more sensitive to errors in runoff and rainfall. It shows the importance of accurate estimation of CN_{∞} and good quality of rainfall-runoff data.

5.3 Estimation of Initial Abstraction Co-effiecient

The asymptotically estimated values of the curve number for the various values of initial abstraction coefficient were considered as a representative values of the curve number for all the watersheds. The values of the observed rainfall and representative values of the curve number were further used for calculation of the direct runoff in the SCS model. Thus the data set obtained for the observed values of the rainfail-runoff and calculated runoff were used for the assessment of initial abstraction coefficients. The linear relationship was developed for the data set of observed rainfall-runoff values and compared with calculated runoff values. It is found that the relationship between observed values is very close to the line drawn between the data set of calculated runoff values for the initial abstraction coefficient values of 0.15 to 0.30. The values of the initial abstraction for all the watersheds are tabulated as in the table 9.

Table 9. Estimated Value of Initial Abstraction Coefficient for the Various Watersheds under Study

SR. No.	Name of the Watersheds	Initial Abstraction Coefficient
1.	Dandavati	0.15
2.	Sagar	0.25
3.	Honnammanahalla	0.25
4.	Barchinala	0.30
5.	Yettinahole	0.25
6.	Jadkalhole	0.15

From the table, it is noticed that, the initial abstraction coefficient values for most of the watershed is ranging between 0.15 to 0.30. The same may be considered as the representative value for this climatic zone. The more accurate values are obtained by considering the hourly rainfall-runoff events. However, the present study considers the daily rainfall-runoff events with the catchment area varying from few kilometers to few hundred square kilometers, whereas the basic values derived for the smaller watershed, which have lower time of concentration. Since, the present study involves the larger catchments with the higher time of concentration, it is difficult to segregate the rainfall-runoff events. Thus, to obtain the effect of the rainfall events and its transformation into runoff, the overlapping events add to the error in estimating the initial abstraction coefficient.

6.0 CONCLUSIONS

The advantages of the SCS curve number method are its simplicity, reliance on only one parameter, and responsiveness to major runoff producing watershed properties. However, it does have some major disadvantages like, its sensitivity to the choice of curve number, fixing the level of antecedent moisture condition, and the selection of initial abstraction ratio.

In the absence of an appropriate CN table for Indian conditions, it is desirable to estimate curve numbers from available P-Q data set or to use P-Q data set of homogeneous basins. This method also can be used as a check on the values estimated using the conventional SCS method and in a broader sense, can be used to revise the standard CN tables for land use conditions and soil characteristics which are not covered by the tables. But the consistency of the data set used is an important factor, which controls the accurate estimation of curve number.

Rainfall-runoff data can effectively be used for the estimation of runoff curve number. Since actual field data are involved, this method is more reliable. This method does not require information on the three levels of antecedent moisture condition. But, the selected data set should cover a wide range of AMC conditions, from dry to wet, in order to have reasonable results. However, this method is also not free from assuming suitable initial abstraction parameter, which affects the output (curve number/runoff). So, further research effort should be applied to provide some guidelines for selecting initial abstraction coefficient for different agro-climatic regions and soil types.

In the present study, event rainfall-runoff data are used to estimate curve number for six watersheds of various agro-climatic zones of hard rock region and average curve number value has been determined for each catchment by asymptotic fitting of the estimated curve number values for different rainfall-runoff events. This study is a primary attempt to establish the initial abstraction coefficient for different agro-climatic zones in Karnataka state. The values obtained as initial abstraction coefficient is ranging between 0.15 to 0.30. This value may be used as a representative value for the watersheds in this agro-climatic zone and made used for the further studies.

Also, it is recommended for the more in depth study using the hourly rainfall and runoff events to establish an accurate initial abstraction coefficient for different climatic zones in the Karnataka state.

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