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EXPERIMENTAL STUDY OF SEDIMENT TRANSPORT IN IRRIGATED CHANNEL CONSIDERING THE EFFECT OF INFILTRATION ON DEGRADATION

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Abstract

Sediment transport in the channel is of practical importance in agricultural practice as it provides an opportunity to optimize the nutrient delivery to crops and optimization of water to be supplied to the field. Irrigation channel bed degradation occurs, when the delicate balance among the channel discharge, sediment inflow, and channel slope is disturbed by natural or manmade factors. The primary objective of the present study is to provide an experimental procedure for the prediction of transient bed profiles and the effect of infiltration on degradation. For this purpose, here two types of study are performed. In the first case, the degradation is done without considering the infiltration (under saturated conditions); on the other hand, degradation is done unsaturated condition for considering the effect of infiltration. The results show that more degradation was occurring in the case of saturated condition as compared to unsaturated condition. The infiltration of channel bed was found to be the main factors affecting the depth of degradation of channel bed of sand.

Key words*: Sediment transport, Infiltration, Irrigation channel, degradation, soil water tension*

Introduction

Irrigation channel bed degradation occurs, when the delicate balance among the channel discharge, sediment inflow, and channel slope is disturbed by natural or manmade factors like; sediment coming from main canal, change of sediment supply rate, etc. When sediment load coming to a reach of the irrigation channel is less than its carrying capacity, the water in flow then picks up the sediments from channel bed and banks to maintain its transport equilibrium, thereby causing lowering of channel bed which is known as degradation (Garde and Ranga Raju,2006). Brown et al. (1988) proposed that sediment deposition along the furrow perimeter creates a low-permeability seal that increases the soil water tension at the furrow perimeter. The stress, in act, increases deposition and stabilizes the seal. This self-perpetuating process stabilizes the furrow perimeter and decreases the erodibility of the soil with time. The kinematic-wave model and zero-inertia model was commonly used for flow routing in early studies. Such models are stable and efficient for prismatic channels. These studies showed that the zero-inertia model is applicable with negligible errors for surface irrigation flow of small Reynolds numbers, and the kinematic-wave model is more applicable to channels of steeper slopes. However, these models neglected fluid acceleration, and thus, their accuracy are limited for unsteady flows.

Several sediment transport models have been developed for channel irrigation flows (Lu et al. 1987; Strelkoff and Bjorneberg 2001;Bjorneberg et al. 2006).Trout (1996) showed that Greater than 50% of the detached sediment can be deposited on the lower end of a field. Trout(1996) Studied the soil erosion and deposition distribution within furrow irrigated fields. It found that over half of the soil that eroded from the head end of the furrows deposited on the lower portions of the field as furrow flow rates decreased. Erosion rates on the upper quarter of uniformly-sloped furrows were 6-20 times greater than average rates from the airfield. Nevertheless, the erosion theory predicts that the erosion rate should diminish with distance from the head (inflow) end of the furrow. Zhang et al. (2012) developed a numerical model to simulate unsteady flow, sediment transport, and infiltration in irrigation furrows using the modified St. Venant equations. They considered the density of sediment-laden flow as a spatial variable. Two types of flume experiments were performed in the laboratory. The first series of experimental runs has a clear-water condition without feeding sediment at the flume entrance and another was with feeding sediments. The transport capacity for fine-grained sediment was determined by the modified Laursen formula. The correlation coefficient between the sediment discharge per unit width and the tractive shear stress found to be 0.883, without sediment feeding and in case of volumetric sediment concentration and the tractive shear stress was less than 0.707. This indicates that the volumetric sediment concentration is less correlated with the tractive shear stress than the sediment discharge per unit width. The present model well simulated the advance time and flow hydrograph as compare to sediment discharge. For the sediment discharge study more refined formula should be practiced. Several studies have been carried out by various authors and nobody has ben focused on effect of infiltration on sediment transport (degradation).

2. Experimental Set-up

The experiments were conducted in a 46cm wide, 100cm deep and 15 m long recirculatory tilting flume located in the hydraulics laboratory of Indian institute of technology, Roorkee. The flume was provided with glass side wall. The recirculatory system consisted of a rectangular tank sloped bottom to collect the sediment laden flow from the downstream end of the flume. A 25-H.P.pump was connected to the tank and a supply pipe for maintaining the recirculation. The discharge was controlled by a valve. A floating wooden wave suppressor provided at the entrance of the flume for damping the disturbances at the free surface. Rails made from metallic tube provided on the top offside walls. A movable carriage with a pointer gauge having at least count of 0.01 cm was mounted on a carriage which could move on the rails. This was applied for recording water surface and bed profiles. An adjustable gate at the downstream end of the flume was used to control the depth of flow in the flume.

Figure 1. A view of the experimental flume.

2.1 Sediment Gradation: Sieve analysis test is performed to determine the characteristics of the sediment used

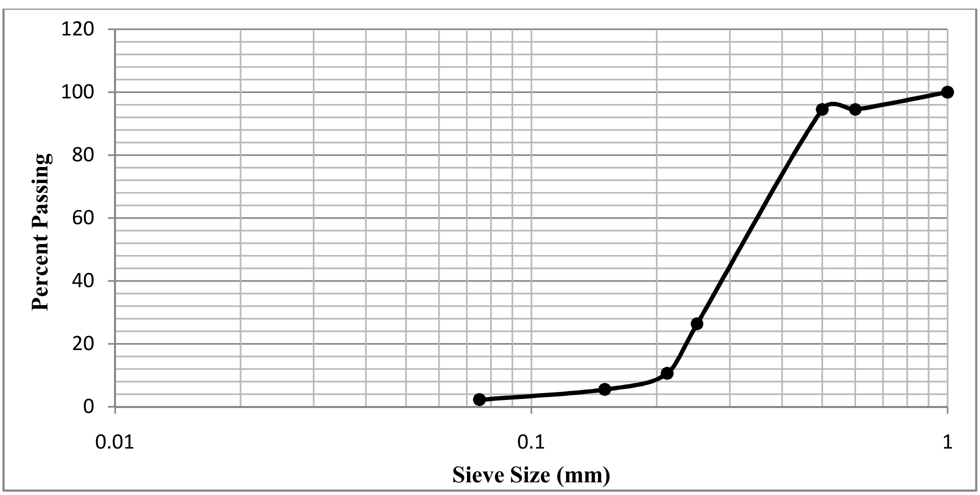

Figure 2. Sieve Analysis

The sediment used in this work is the sand from Ganga River. The size of the sediment used to obtain from the sieve analysis is found to be d_{50}=0. 32 mm. The sand was filled in the flume up to a depth of 35 cm and leveled parallel to the rails. The sand forming the bed and injected material had a median sieve diameter of 0.32 mm and geometric standard deviation of 1.39. The grain size distribution curve of the sand is shown in Fig.1. The specific gravity of the sand was 2.65.

3. Experimental Program

3.1 Experimental Procedure: In this section, a brief explanation of the procedure followed is given. Experiments were conducted in which the flow was injected at the upstream end and the degradation studied. Detailed measurement of the bed and water surface profiles at various times was taken; these were useful in the study of sediment transport and resistance to flow under non-uniform flow condition, apart from providing the basic data on degradation.

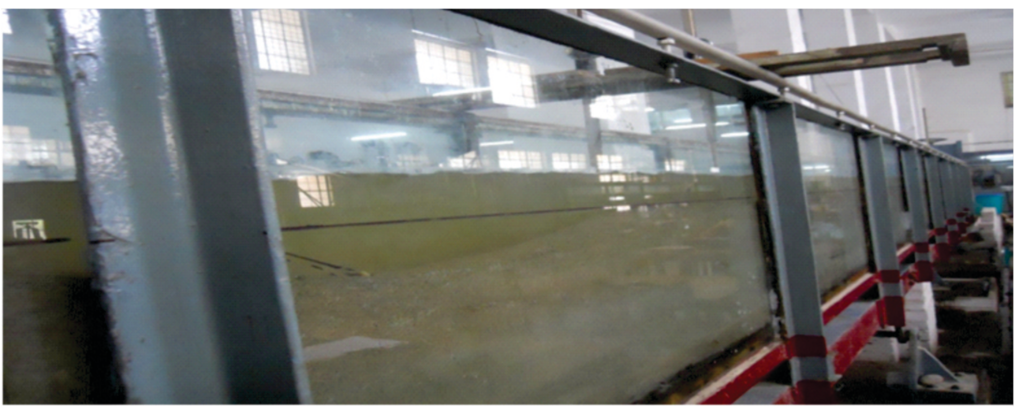

Figure 3. Transient bed and water surfaces, profiles in sand bed

In these experiments the flume was filled with sediment as mentioned earlier and then was given the desired slope. The recirculatory system was then filled with water and pumps started. The valve was slowly adjusted to give specified discharge and uniform flow was obtained by adjusting the tailgate at the downstream end of the flume and allowing the bed to adjust. Because of the effect of entrance and exit conditions on the flow, about 3 m length of the flume at the upstream and downstream ends was not considered in assessing the uniformity of the flow. After maintaining the flow, the required discharge was increased with the valve. The carrying capacity of irrigatd channel was increased. Consequently degradation took place along the length of irrigated channel.

Here two types of study were performed. In the first case, degradation was done without considering the infiltration (under saturated conditions), on the other hand, degradation was done unsaturated (drybed) condition for considering the effect of infiltration.

Figure 4. A view of degradation channel

The flow depth was measured with the help of pointer gauge having a least count of 0.1 mm whereas the bed profile was measured by using the gauge having a flat bottom (diameter = 10 mm) which also had the least count of 0.1 mm. The pointer gauge and the flat bottom gauge intruded into the flow only for very short time durations while taking the observations so as not to adversely disturb the flow and bed conditions. The flow depth and bed surface profiles were recorded for various time interval of about 30 min while the bed level changes were rapid, and subsequently at an interval of about 60 min during later part of the runs when the bed transients became more gradual. The point gauge readings for both flow depth and channel bed elevations were made at longitudinal spacing of 0.3 m along the centerline of the working section of the flume. First the bed elevations were recorded at each section along the channel centerline followed by the recording of flow depth at the same sections.

4.1 Time of Experiment

The degradation is measured along the length of flume at regular time interval t = 60, 75, 120 minutes.

5. Results and Discussion

5.1. Effect of infiltration on Degradation: The effect of infiltration on degradation is investigated with flow conditions (Q = 9.6 l/sec, y = 5.0 cm, d_{50}= 0.32 mm). The degradation is measured along the length of the flume at regular time interval t = 60, 75 and 120 minutes respectively. Maximum depth of erosion was occurred in the upstream of the irrigated channel. Transient bed and flow depth in irrigated channel are shown in figures (5).

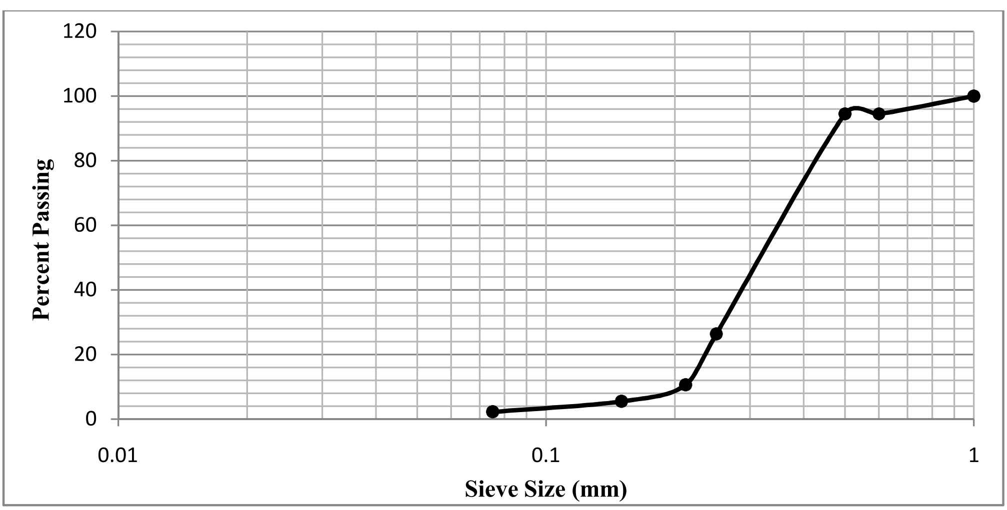

Figure 5. Transient bed profiles in the sand bed for 60 minutes.

Degradation without infiltration resulted in decreased bed elevation as compared to bed elevation measured by with infiltration. Also, infiltration is found to be the primary parameter which affecting both bed elevation and water elevation.

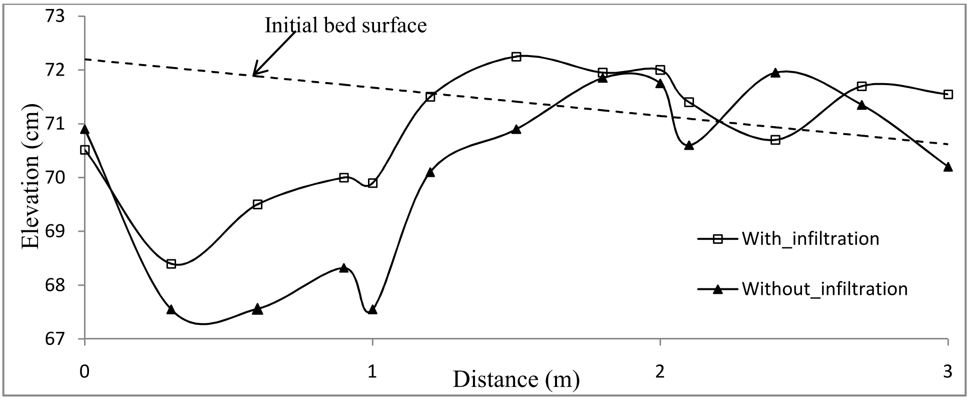

Figure 6. Transient bed profiles in the sand bed for 75 minutes.

When the duration was 60 minutes the corresponding bed and water surface elevation with infiltration was found to be 0.56m and 0.60m. However, in cases without infiltration values of bed and water surface elevation were 0.53m and 0.57m respectively.

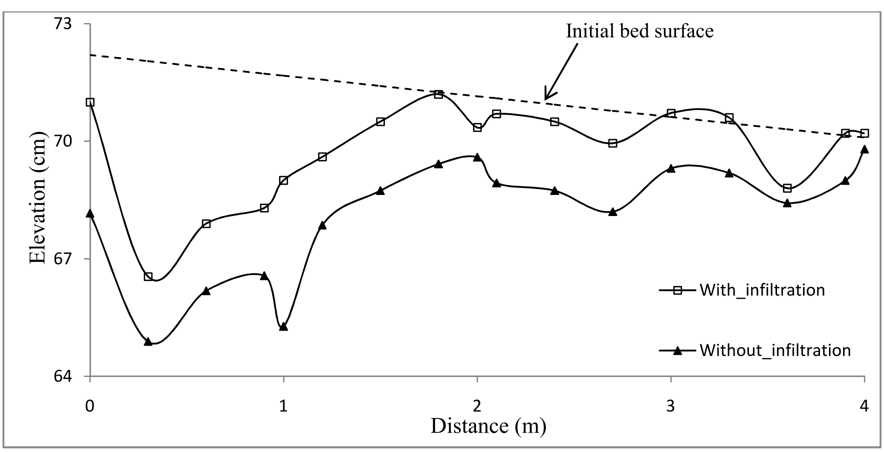

Figure 7. Transient bed profiles in the sand bed for 120 minutes.

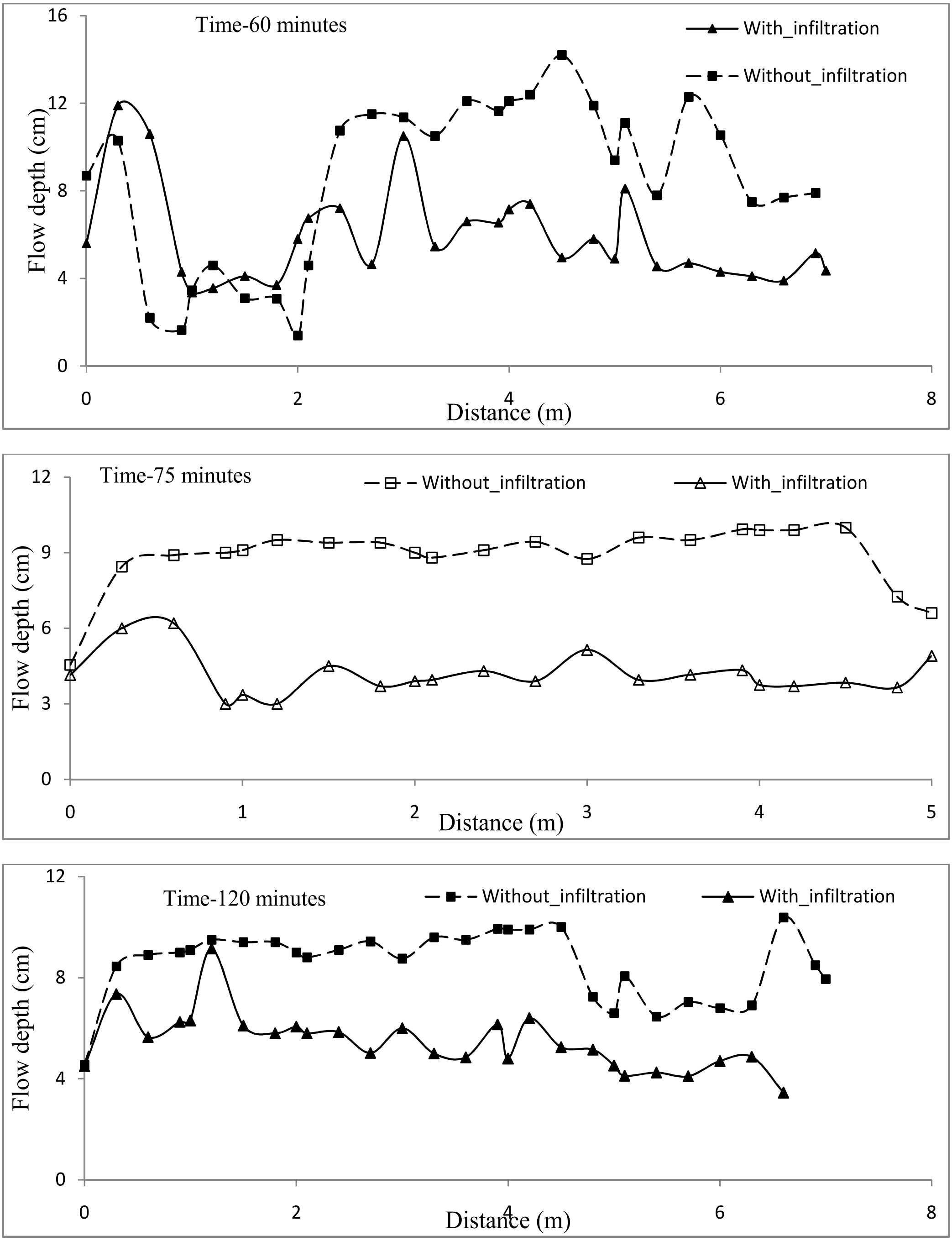

Figure 7. Variation of flow depth with time

Conclusions

1. Infiltration influenced the bed elevation and water elevation during degradation effectively.
2. However, bed and water elevation were increased during the infiltration. Compared to the without infiltration case (saturated condition for 60 minutes), Maximum bed degradation was found to be 9.73 cm. However, when the infiltration case (unsaturated condition for 60 minutes), corresponding maximum bed degradation was found to be 6.38 cm. Similar pattern were followed by other duration of transient bed and water surfaces, profiles eq. 75, 120 minutes.
3. Degradation without infiltration resulted in decreased bed elevation as compared to bed elevation measured by with infiltration. Also, infiltration is found to be the primary parameter which affecting both bed elevation and water elevation.
4. Due to infiltration (during unsaturated condition) tractive force is reduced, which is the primary force caused increased bed and water elevation. However, in the case of saturated condition tractive force may be greater than unsaturated condition.

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RUNOFF ESTIMATION WITH MODIFIED ASYMPTOTIC CURVE NUMBER IN OZAT WATERSHED OF GUJARAT (INDIA)

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Abstract:
According to National Resources Conservation Service (NRCS), standard asymptotic fit method (AFM) is the preferred technique for (Curve Number) CN determination. The AFM is based on ordered data and frequency matching approach method. Effect of the cumulative data has been ignored in AFM method. We investigated the impacts of cumulative data on CN estimation. In the present study modified asymptotic CNs were obtained by using cumulative data of different daily time period. Impact of modified CNs on performance of Soil Conservation Service Curve Number (SCS-CN) model was evaluated using data of the Ozat Watershed of Gujarat (India).
The two quantitative standard statistical performance evaluation measures, refined Willmott's index (d_r) and mean absolute error (MAE) are employed in comparing and evaluating the performance of the SCS-CN model with different curve numbers. For the study region, the proposed method was judged to be more consistent for 5 days cumulative data with d_r=0.55 and MAE=0.20 mm for λ=0.05, λ=0.10 and λ=0.20.Findings indicate that the modified asymptotic CNs produced the most statistically significant comparison between observed and estimated runoff in Ozat watershed.

Keywords: *Cumulative data; curve number; SCS-CN model; asymptotic fit method; Ozat watershed*

Introduction

The Soil Conservation Service Curve Number (SCS-CN) (now called National Resources Conservation Service Curve Number (NRCS-CN)) method is simple and widely used method for watershed modelling based on the main parameter curve number (*CN). CN* represents physical characteristics, recharge capacity and the antecedent moisture conditions of a watershed. Since its inception the SCS Method has grown in prominence and it continues to be updated and amended with increasing data and research (Mishra and Singh 1999; Jain et al. 2006). Despite its popularity, realistic estimation of the *CN* has been widely discussed among researches (Hawkins 1978; McCuen 2002; Simanton et al. 1996; Steenhuis et al. 1995; Bonta 1997; Mishra and Singh 2006). Usually, the *CN* is estimated based on handbook *CN* tables. Estimation of *CN* from Table becomes difficult where the validity of the hand book tables was not verified. However, when rainfall-runoff data are available for watershed, it is preferable to estimate the *CN* value from recorded rainfall-runoff data. *P* and *Q* pairs are used directly to determine the potential retention *S* characterizing the watershed (Chen 1982). (Hawkins 1993) determined asymptotic *CN*s using frequency matching approach and concluded that a secondary systematic correlation almost always emerges in watersheds between the calculated *CN* value and the rainfall depth. He gives hydrological definition of the watershed and some measures of asymptotic attainment of the fitting equations. (Sneller 1985) and (Hawkins 1993) identified three types of watershed responses (standard, violent, and complacent). The standard and violent responses lead to a constant *CN* with increasing rainfall depth, but the complacent response does not lead to a stable *CN*. Beside the standard function proposed by Hawkins, (Tomasz Kowalik and Andrzej Walega 2015) describes *P–CN* relationship by using kinetics equation and complementary error function peak. They found that asymptotic equation based on a kinetics equation, most effectively described the *P–CN* relationship in the watersheds of southern Poland. Further, (Bonta 1997) made improvement in the asymptotic *CN*s determination from measured data in "violent" and "standard" watersheds using derived distributions.

The asymptotic *CN* approach fails to describe the watershed response in small and medium rainfall events as temporal variability is not essentially taken into account. Due to spatial and temporal variability of rainfall, and the variability of antecedent rainfall and the associated soil moisture amount, the *CN* has sufficient room for variability. The antecedent condition is taken to vary from previous 5 days to 30 days, NEH-4 (SCS 1971) uses the antecedent 5 days rainfall for AMC, and it is usually practiced. (Hope and Schulze 1982) used a 15-day antecedent period in an application of the SCS procedure in the humid east of South Africa, and (Schulze 1982) found a 30-day antecedent period to yield better simulation of direct runoff in humid areas of the USA, but a 5-day period to be applicable in arid zones. However, there is no explicit guideline for soil moisture fluctuation with the antecedent rainfall of certain duration and the possible long-term cumulative effect of certain parameters. There is no known statistical method to model these effects. To fill this gap, we propose a hypothesis to determine asymptotic *CN* by using cumulative rainfall-runoff ordered data of different day durations. The objective of this study is to investigate the impact of cumulative P_n–Q_n order data in determination of the *CN* for Ozat watershed.

2. Theoretical Development

The SCS-CN method is based on the principle of the water balance and expressed by its governing equation as:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \; for P > I_a, Otherwise = 0, Where\ I_a = \lambda S \qquad (1)$$

Where *P* is the total precipitation (mm), I_a is the initial abstraction before runoff (mm), *Q* is direct runoff (mm), *λ* is the initial abstraction (ratio) coefficient, and *S* is the potential maximum retention (mm) which can vary in the range of $0 \leqslant S \leqslant \infty$, and it directly linked to *CN*. Parameter *S* is mapped to the *CN* using **Eq. (2)** as:

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

The CN depends on land use, hydrologic soil group, hydrologic condition, antecedent moisture condition (AMC) and it can vary from 0 to 100. (Mishra and Singh 2003) categorize AMCs as dry (AMC I) (lower limit of moisture or upper limit of S), moderate (AMC II) (normal or average soil moisture condition), and wet (AMC III) (upper limit of moisture or lower limit of *S*). Higher amount of antecedent moisture and *CN* value would indicate the more runoff generation and vice versa, therefore, median *CN* determined from array of *CN* values was commonly adopted for the watershed (Hjelmfelt 1991 and Schneider and McCuen 2005). *CN*I, *CN*II and *CN*III values for Ozat watershed were computed 64.46, 81.20 and 90.85 respectively based on land used, soil characteristics and previous 5 days rainfall. *CN*s from handbook table useful in the absence of better information, but incorporate only limited land uses and conditions and are often untested.

The potential retention *S* characterizing the watershed can be determined from *P—Q* pairs and λ when rainfall-runoff data are available for a watershed (Chen 1982) as:

$$S = \frac{P}{\lambda} + \frac{(1-\lambda)Q - \sqrt{(1-\lambda)^2 Q^2 + 4\lambda PQ}}{2\lambda^2} \qquad (3)$$

CN value can be directly calculated from rainfall-runoff data by substituting value of *S* in **Eq. (3)** and rearranging it as:

$$CN = \frac{25400}{\frac{P}{\lambda} + \frac{(1-\lambda)Q - \sqrt{(1-\lambda)^2 Q^2 + 4\lambda PQ}}{2\lambda^2} + 254}$$

(4)

2.1 *Asymptotic fit method (AFM)*

This 'frequency matching' based approach uses an 'Ordered' data (*P* and *Q* data are arranged in descending order) in which a *Q*-value corresponding to a particular *P* may not necessarily represent the actual runoff due to this rainfall. The 'Natural' data, however, retain the actual *P–Q* dataset. Therefore, this approach preserves the return-period matching between rainfall and runoff. It is found that a secondary relationship almost emerges between the *CN* and the *P* from ordered *P–Q* dataset. In standard AFM, *P* and *Q* data are re-aligned on rank-order basis using the rainfalls and runoff separately, and reassembling them as rank-ordered pairs (ordered *P-–Q* data). Out of three typical responses of watersheds, the standard behavior justifies the usage of the *CN* method and is often treated as a calibration (Hawkins et al. 2009) method. The Standard response was observed in Ozat watershed and to be described by the following equation:

$$CN(P) = CN_{\alpha} + (100 - CN_{\alpha})e^{-kp} \quad (5)$$

Eq. (5) has the algebraic structure of the Horton infiltration equation. In the standard response, the *CN* as a function of rainfall *P* (*CN* [*P*]) decreases to an asymptotic constant *CN*∞ *with k* (the fitting coefficient or rate constant in the units of 1/*P*) that describes the *CN* approach to the asymptotic constant *CN*∞. Optimized values of *CN*∞ and *k* are obtained by fitting **Eq. (5)** using least-squares procedure. The recent report to NRCS (Woodward 2010) recommends this procedure as the preferred technique for *CN* determination.

2.2 Modified *asymptotic fit method (MAFM)*

Precise determination of *CN* is crucial in the prediction of surface runoff. The antecedent precipitation index plays significant influences in *CN* determination. Daily *P–Q* data set not have much explanatory power to describe complex hydro meteorological characteristics of watershed, therefore, it might be failed to capture the cumulative effect. Long-term cumulative effects have not been adequately modelled by existing methodologies. The 5-day is used as an antecedent precipitation index in the original *CN* method to classify AMC conditions. Beside the antecedent period (5, 15 and 30 days); the use of AMC classes in 5-day period is also under discussion: Some researchers claimed that AMC classes should be considered (Boonstra, 1994) while the rest reported that it had no effect. The soils in the watershed are practically saturated from antecedent rainfalls (i.e. the soil moisture content is at field capacity). Cumulative rainfall-runoff data provides information about the maximum amount of water that can be stored in the watershed. Based on the soil characteristics, every watershed has different storage capacity. In order to incorporate effect of storage for cumulative rainfall-runoff data of different daily duration, we used cumulative rainfall (P_n) and runoff (Q_n) as:

$$P_n = \sum_{I=1}^{N} p_I \quad (6)$$

$$Q_n = \sum_{I=1}^{N} Q_I \quad (7)$$

Where, N is number of cumulative days. In this study, we used the standard asymptote model, based on the algebraic structure of the Horton infiltration equation proposed by Hawkins to describe *CN* parameter as a function of rainfall amount *P* (**Eq. (5)**). The best fitted *P–CN* relationship of 5 days (R^2=0.93, SE=3.60) cumulative dataset is presented in **Figure 3.** R^2 and SE indicate that the standard asymptotic function described by Hawkins (**Eq. (5)**) effectively described the *P-CN* relationship in Ozat watershed. Therefore, it would be more appropriate function for this study.

The parameters *CN*∞ and *k* are computed using P_n–Q_n ordered data set of calibration period and least-squares procedure. Daily *CN* values are then determined by incorporating daily mean rainfall amount in mm along with calibrated model parameters values in **Eq. (5)**. Maximum 35 days continuous daily storm is recorded from calibration period of Ozat watershed, therefore, in this study, up to 35 days cumulative data set are used to determine modified asymptotic *CN.* Surface runoff of Ozat watershed is then calculated by SCS-CN method with this modified *CNs.* The agreement between the computed and observed runoff values was the criteria to evaluate performance of SCS-CN method with different *Cns*.

3. Study Area

Ozat is a river flowing in western India in Gujarat state whose origin is near Visavadar and meets in Arebian Sea. Ozat catchment considered in this study geographically locates within the latitudes 21°19'N to 21°33'N and the longitudes 70°39'E to 70°56'E respectively as can be seen from toposheet no 41 K (10-11-14 and 15) of scale 1:50000. Gauge discharge (GDS) site is located near Khambhaliya village at bridge of Junagadh to Visavadar Road 33 km away from Junagadh. Information about soil and land use have been gathered from maps of National Bureau of Soil Survey and Land use Planning (ICAR) (1994). Study area (sub-watershed) has been delineated from Survey of India (SOI) topographic sheet using AutoCAD (2010) Software and presented in **Figure 1**. The land use map of the Ozat watershed is prepared based on Junagadh district map obtained from district planning map series (SOI) using AutoCAD (2010) Software and presented in **Figure 2**. The major portion of the precipitation occurs during the four months of June to September by south-west monsoon. The area is situated in semi-arid region with average annual rainfall of the area is 786 mm (1980-2010), mean maximum temperature 33.34℃ and mean minimum temperature 24.30℃. The total geographical area 358.8357 km^2 comprises of about 20.08% (72.0542 km^2) grass and open scrub land and remaining 79.92% area under arable land irrigated (286.7815 km^3) **Figure 2**. The major crops grown in the catchment are Ground nut, wheat and Cotton.

The hydrological data daily rainfall (mm) and runoff (m^3/s) (1980 to 2010) of Ozat catchment were collected from the State Water Data Centre, Gandhinagar. The information related to watershed characteristics, namely, physiography, number of streams of different orders, their length, slope and area contributing runoff to these streams were obtained from the topographic maps of the watershed.

Continuous storms of ⩾10 days were selected from calibration period (1980-1995) to calculate model parameters. In this study, to minimize uncertainty in the runoff estimation, *P* ⩾ 5 mm have been considered to determine *CN* values. Performance of SCS-CN method has been evaluated by using continuous storms of ⩾10 days from remaining dataset from validation period (1996 to 2010).

Periodic insufficient rainfall pattern, limited water storage capacity of aquifer and natural water conservation are vital issues for this region. Water availability is a critical factor in this area and therefore accurate estimation of runoff is needed for water resources management, crop water use, farm irrigation scheduling, and environmental assessment.

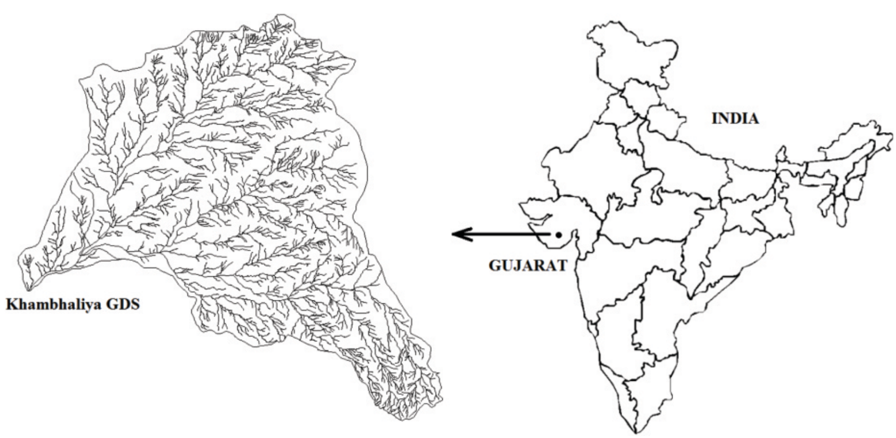

Figure 1 Digitized 6th order drainage network map of Ozat catchment

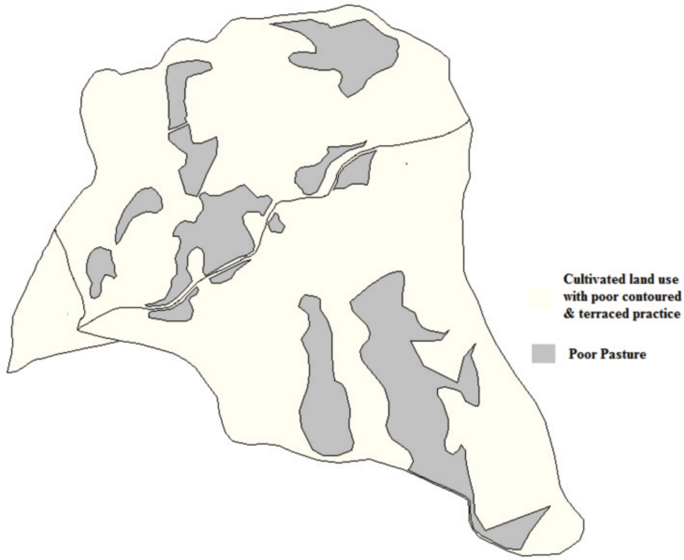

Figure 2 Land Use Map of Ozat Watershed

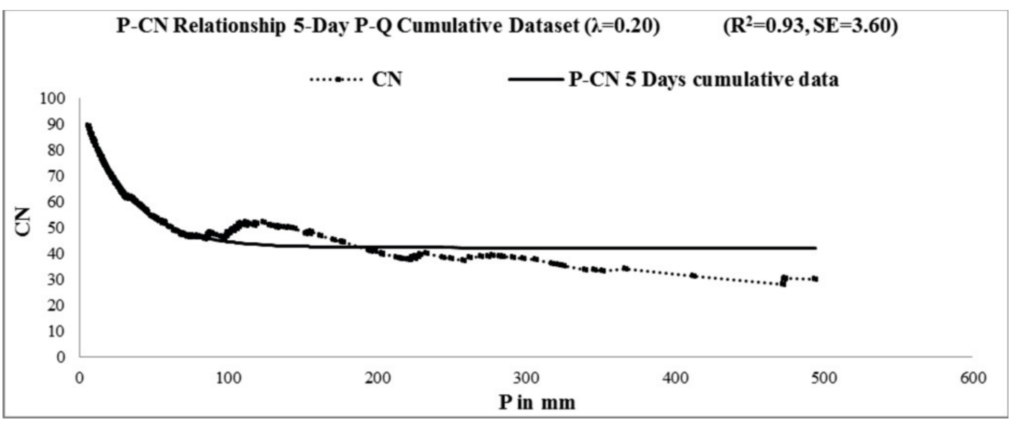

Figure 3 Comparison of *P-CN* relationship, with approximation of asymptotic functions *CN* (P) by Equations (7) and (8) for 5 days cumulative *P-Q* dataset of Ozat watershed (λ=0.20)

4. Statistical Criteria

In this study, the performance of the SCS-CN model using different *CN* are evaluated using two popular statistical criteria refined Willmott's index (d) (Willmott 2012) (Dimensionless statistic) and mean absolute error (MAE) (error index statistic).

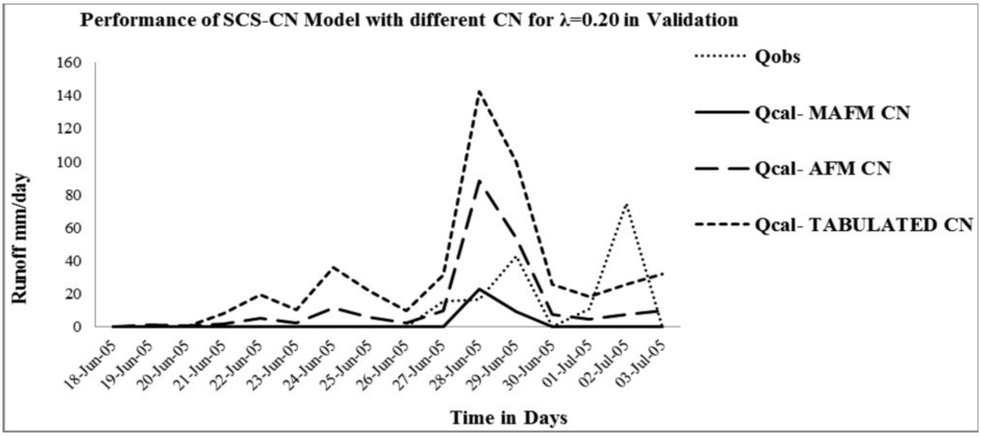

Figure 4 Performance of SCS-CN Model with Tabulated *CN*, AFM *CN* and MAFM *CN* at daily time scale in validation period (June-July, 2005) for Ozat watershed (λ=0.20)

Dimensionless techniques provide a relative model evaluation assessment, and error indices quantify the deviation in the units of the data of interest. These statistical criteria are used to measure the agreement between predicted and observed values of event runoff in validation period (1996-2010). To check precision and correctness of the methods, (d_r) is applied. The MAE does not tell about degree of error but it is used for the quantitative analysis of residuals.

The d_r is applied to quantify the degree to which values of observed runoff are captured by the models. The range of d_r is from -1.0 to 1.0. A d_r of 1.0 indicates perfect agreement between model and observation, and a d_r of -1.0 indicates either lacks of agreement between the model and observation or insufficient variation in observations to adequately test the model. MAE is error measure used to represent the average difference between model predicted and observed values. It is important to include absolute error measures MAE in a model evaluation because it provides an estimate of model error in the units of the variable. The MAE provides a more robust measure of average model error than the root mean square error (RMSE), since it is not influenced by extreme outliers (Legates 1999). A higher MAE value indicates poor model performance and vice versa. MAE=0 indicates a perfect fit. MAE is the most natural and unambiguous measure of average error magnitude.

5. Results and Discussion

In this study, we investigate the impact of cumulative rainfall –runoff data in determination of asymptotic *CN*. Cumulative P_n–Q_n ordered data are used in place of ordinary *P*–*Q* ordered data to determine asymptotic *CN* for Ozat watershed. The applicability of these modified asymptotic *CN* in runoff prediction then assessed by evaluating performance of the SCS-CN model using modified *CN*. Parameters $CN\infty$ and *k* of MAFM for λ=0.05, λ=0.10 and λ=0.20 are calibrated by using selected continuous storm rainfall-runoff dataset from calibration period (1980-1995). The best fit calibrated values of Parameters $CN\infty$ and *k* of MAFM model along with R^2 and SE are presented in Table 1 to 3. The performance of the SCS-CN model with different *CN*s (Tabulated *CN*, AFM *CN* and MAFM *CN*) then evaluated by using dataset of validation period (1996-2010). Data set of three continuous storms having maximum rainfall (421 mm in July-August, 2004; 791 mm in June-July, 2005 and 474 mm in July-August, 2006) from validation period are selected for comparison of performance of SCS-CN model with tabulated *CN*, AFM *CN* and MAFM *CN* for λ=0.05, λ=0.10 and λ=0.20 at daily time scale. d_r and MAE are used to evaluate the performance of SCS-CN model.

Presented results in Table 1 to 3 indicate that performance of SCS-CN model with *CN* computed by daily *P*–*Q* data set were found to be quite different from those under determined by cumulative P_n–Q_n data set. This means that cumulative P_n–Q_n data set play significant role in *CN* determination. Tabulated *CN* produced comparatively better results (d_r=-0.32 and MAE=0.66 mm) for λ=0.20 than for λ=0.05 and λ=0.10 while AFM *CN* produced marginally good results (d_r=-0.06 and MAE=0.48 mm) for λ=0.20 than for λ=0.05 and λ=0.10. No significant difference has been found when the results of MAFM *CN* are compared for λ=0.05, λ=0.10 and λ=0.20 which indicate that MAFM *CN* is less sensitive to changes in λ. Performance of SCS-CN model with MAFM *CN* gradually improved with increment in accumulation of data. However, no significant improvement has been found after attaining 5 days cumulative data (for λ=0.05, λ=0.10 and λ=0.20). This implies that the 5 days period may be more significant when taking AMC into account. These outcomes are in good agreement to the previous studies (Schulze 1982). Calibrated parameter $CN\infty$ of AFM was found in ranged from 65.99-71.17 while parameter k in ranged from 0.05 mm^{-1}-0.26 mm^{-1}. Calibrated vales of $CN\infty$ *and* k of MAFM were found in ranged from 11.51-71.17 and 0.02 mm^{-1}-0.26 mm^{-1} respectively for λ=0.05, λ=0.10 and λ=0.20. No significant improvement in performance of SCS-CN model has been found after 5 days cumulative data set in MAFM method. Figure 4 shows the performance of SCS-CN model with Tabulated *CN*, AFM *CN* and MAFM *CN* (June-July, 2005) at daily time scale for λ=0.20 in validation period.

It is evident from Table 1 to 3 that performance of SCS-CN model was improved up to 5 days cumulative days, after that slight decrement has been found in performance during prolonged cumulative days. The optimised values of parameters $CN\infty$ and k decrease gradually with increment in cumulative days. However parameter $CN\infty$ values decreases gradually with steeper slopes than parameter k with cumulative days.

It is observed from Figure 4 that SCS-CN model with Tabulated *CN* overestimate the runoff. Negative d_r and larger MAE values (d_r=-0.41 and MAE=0.76 mm, for λ=0.05, d_r=-0.38 and MAE=0.72 mm, for λ=0.10 and d_r=-0.32 and MAE=0.66 mm, for λ=0.20) indicate the poor performance of SCS-CN model with Tabulated *CN*. This shows that the reliability of SCS-CN method using constant *CN* is questionable. The SCS-CN model with AFM *CN* provides more reliable and consistent results (d_r=0.27 and MAE=0.33 mm, for λ=0.05, d_r=0.29 and MAE=0.32 mm, for λ=0.10 and d_r=0.33 and MAE=0.30 mm, for λ=0.20) than Tabulated *CN*. MAFM *CN* reduced the overestimation of runoff and improved the performance of SCS-CN model. Substantial improvement in error estimate is noticed while using MAFM *CN* values replacing AFM *CN* values. The best performance of the SCS-CN model has been found with MAFM *CN* (d_r=0.55 and MAE=0.20 mm) in this study for Ozat watershed. Antecedent moisture conditions of watershed exhibit long memory characteristics and which reflect in cumulative dataset. MAFM *CN* gradually improve the performance of the SCS-CN model with increment in cumulative days, however, after 5 days cumulative data

Table 1 Performance of the SCS-CN model with different *CN* in runoff prediction for Ozat watershed in validation period (λ=0.05)

Cumulative data	Optimized Parameters of Eq. (8)				MAFM *CN*		AFM *CN*		Tabulated *CN*	
P_n-Q_n	CN_∞	*K* *(mm^{-1})*	R^2	*SE*	d_r	MAE (mm)	d_r	MAE (mm)	d_r	MAE (mm)
1	65.99	0.26	0.28	4.40	0.27	0.33	0.27	0.33	-0.41	0.76
2	45.05	0.05	0.58	13.93	0.50	0.23	(AFM) Optimized parameters of Eq. (8) CN_∞=65.99 K=0.26 *mm^{-1}*			
3	33.83	0.05	0.73	14.12	0.54	0.21				
4	27.54	0.05	0.81	13.87	0.55	0.21				
5	26.78	0.09	0.88	3.31	0.55	0.20				
6	20.33	0.04	0.88	12.80	0.54	0.21				
7	18.21	0.04	0.90	12.36	0.53	0.21				
8	16.46	0.04	0.91	11.96	0.52	0.22				
9	15.11	0.03	0.92	11.65	0.52	0.22				
10	17.36	0.07	0.97	1.91	0.53	0.21				
11	16.61	0.07	0.97	1.97	0.52	0.21				
12	16.04	0.06	0.96	2.11	0.52	0.22				
13	15.53	0.06	0.96	2.18	0.52	0.22				
14	15.08	0.06	0.96	2.23	0.51	0.22				
15	14.58	0.06	0.96	2.25	0.51	0.22				
20	13.11	0.06	0.97	2.09	0.51	0.22				
25	12.38	0.06	0.97	2.12	0.50	0.22				
30	11.66	0.06	0.97	2.08	0.50	0.22				
35	11.51	0.06	0.97	2.07	0.50	0.22				

Table 2 Performance of the SCS-CN model with different *CN* in runoff prediction for Ozat watershed in validation period (λ=0.10)

Cumulative data	Optimized Parameters of Eq. (8)				MAFM *CN*		AFM *CN*		Tabulated *CN*	
P_n-Q_n	CN_∞	*K* *(mm^{-1})*	R^2	*SE*	d_r	MAE (mm)	d_r	MAE (mm)	d_r	MAE (mm)
1	69.37	0.11	0.61	4.23	0.29	0.32	0.29	0.32	-0.38	0.72
2	50.66	0.04	0.74	8.80	0.50	0.23	(AFM) Optimized parameters of Eq. (8) CN_∞=69.37 K=0.11 *mm^{-1}*			
3	41.45	0.04	0.84	9.13	0.54	0.21				
4	35.51	0.04	0.88	9.24	0.55	0.21				
5	34.24	0.06	0.93	3.26	0.55	0.20				
6	27.96	0.03	0.93	8.77	0.55	0.21				
7	25.57	0.03	0.94	8.56	0.54	0.21				
8	23.53	0.03	0.95	8.30	0.53	0.21				
9	21.91	0.03	0.96	8.11	0.52	0.22				
10	23.37	0.04	0.98	1.93	0.52	0.22				
11	22.41	0.04	0.98	2.03	0.52	0.22				
12	21.68	0.04	0.98	2.18	0.51	0.22				
13	21.02	0.04	0.97	2.28	0.51	0.22				
14	20.45	0.04	0.97	2.35	0.51	0.22				
15	19.81	0.04	0.97	2.38	0.51	0.22				
20	17.94	0.03	0.98	2.29	0.50	0.22				
25	17.14	0.03	0.98	2.26	0.50	0.22				
30	16.15	0.03	0.98	2.21	0.50	0.23				
35	16.02	0.03	0.98	2.31	0.50	0.23				

Table 3 Performance of the SCS-CN model with different *CN* in runoff prediction for Ozat watershed in validation period (λ=0.20)

<table>
<tr><td>Cumulative data</td><td colspan="4">Optimized Parameters of Eq. (8)</td><td colspan="2">MAFM CN</td><td colspan="2">AFM CN</td><td colspan="2">Tabulated CN</td></tr>
<tr><td>P_n-Q_n</td><td>CN_∞</td><td>K (mm^{-1})</td><td>R^2</td><td>SE</td><td>d_r</td><td>MAE (mm)</td><td>d_r</td><td>MAE (mm)</td><td>d_r</td><td>MAE (mm)</td></tr>
<tr><td>1</td><td>71.17</td><td>0.05</td><td>0.82</td><td>3.19</td><td>0.33</td><td>0.30</td><td>0.33</td><td>0.30</td><td>-0.32</td><td>0.66</td></tr>
<tr><td>2</td><td>56.15</td><td>0.03</td><td>0.85</td><td>5.12</td><td>0.50</td><td>0.23</td><td colspan="2" rowspan="18">(AFM) Optimized parameters of Eq. (8) CN_∞=71.17 K=0.05 mm^{-1}</td><td colspan="2" rowspan="18"></td></tr>
<tr><td>3</td><td>49.17</td><td>0.03</td><td>0.91</td><td>5.45</td><td>0.54</td><td>0.21</td></tr>
<tr><td>4</td><td>43.93</td><td>0.03</td><td>0.93</td><td>5.71</td><td>0.55</td><td>0.21</td></tr>
<tr><td>5</td><td>42.20</td><td>0.03</td><td>0.93</td><td>3.60</td><td>0.55</td><td>0.20</td></tr>
<tr><td>6</td><td>36.68</td><td>0.02</td><td>0.96</td><td>5.51</td><td>0.55</td><td>0.21</td></tr>
<tr><td>7</td><td>34.16</td><td>0.02</td><td>0.97</td><td>5.44</td><td>0.54</td><td>0.21</td></tr>
<tr><td>8</td><td>32.01</td><td>0.02</td><td>0.97</td><td>5.27</td><td>0.53</td><td>0.21</td></tr>
<tr><td>9</td><td>30.23</td><td>0.02</td><td>0.98</td><td>5.16</td><td>0.52</td><td>0.22</td></tr>
<tr><td>10</td><td>30.62</td><td>0.02</td><td>0.97</td><td>2.54</td><td>0.52</td><td>0.22</td></tr>
<tr><td>11</td><td>29.49</td><td>0.02</td><td>0.97</td><td>2.63</td><td>0.51</td><td>0.22</td></tr>
<tr><td>12</td><td>28.65</td><td>0.02</td><td>0.97</td><td>2.76</td><td>0.51</td><td>0.22</td></tr>
<tr><td>13</td><td>27.88</td><td>0.02</td><td>0.97</td><td>2.86</td><td>0.51</td><td>0.22</td></tr>
<tr><td>14</td><td>27.20</td><td>0.02</td><td>0.97</td><td>2.93</td><td>0.51</td><td>0.22</td></tr>
<tr><td>15</td><td>26.45</td><td>0.02</td><td>0.97</td><td>2.93</td><td>0.51</td><td>0.22</td></tr>
<tr><td>20</td><td>24.08</td><td>0.02</td><td>0.98</td><td>2.75</td><td>0.50</td><td>0.23</td></tr>
<tr><td>25</td><td>23.29</td><td>0.02</td><td>0.98</td><td>2.77</td><td>0.50</td><td>0.23</td></tr>
<tr><td>30</td><td>21.98</td><td>0.02</td><td>0.98</td><td>2.59</td><td>0.50</td><td>0.23</td></tr>
<tr><td>35</td><td>21.72</td><td>0.02</td><td>0.97</td><td>2.86</td><td>0.50</td><td>0.23</td></tr>
</table>

no further significant improvement has been found. This indicates that cumulative data set eliminates long memory characteristics and variance heterogeneity of watershed. This means that 5-day antecedent moisture condition influences the surface runoff rates remarkably for Ozat watershed.

Conclusions

The AFM is recommended and well known method to determine *CN* from rainfall-runoff data. However, in AFM, impact of cumulative data set is not being taken in to account in determining asymptotic *CN*. In the present study, a method for computing the modified *CN* is proposed to investigate the impact of cumulative P_n–Q_n order data in determination of the *CN*. The proposed improved method (MAFM) is built based on the cumulative P_n–Q_n ordered data and it eliminates long memory characteristics and variance heterogeneity of watershed. The results indicate that the SCS-CN method using the modified *CN* values obtained by the proposed MAFM *CN* determination methodology provides superior runoff predictions in Ozat watershed. The performance of SCS-CN model using Tabulated *CN*, AFM *CN* and MAFM *CN* for λ=0.05, λ=0.10 and λ=0.20 at daily time scale was compared and evaluated by d_r and MAE.

The study found that the SCS-CN model with Tabulated *CN* overestimate the runoff. Statistical criteria (higher d_r values and lower MAE values) indicate that the SCS-CN model with MAFM *CN* is the best-performing model for Ozat watershed, and it performs consistently better than the SCS-CN with Tabulated *CN* and AFM *CN*. For the study region, the proposed method was judged to be more consistent for 5 days cumulative data set, with d_r=0.55 and MAE=0.20 mm for λ=0.05, λ=0.10 and λ=0.20.

The results indicate that the cumulative P_n–Q_n ordered data can influence the *CN* determination procedure and significantly improve the ability of SCS-CN model in predicting runoff. However, similar to the standard AFM, the proposed MAFM also does not suitable for watershed which shows complacent response for which a consistent *CN* cannot be adequately defined.

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ASSESSMENT OF RAINFALL RUNOFF USING SCS CN AND RRL AWBM MODEL

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Abstract

Rainfall-runoff models have been widely used through the last century all over the world. These models help to build a trustworthy relationship between the precipitation and runoff. The relationship between rainfall and runoff is essential in a catchment for hydrologic analysis and design. In the current paper, we have used two models for runoff estimation viz. SCS CN method and the RRL toolkit Australian Water Balance Model (AWBM). The SCS CN method is an empirical approach for estimation of Direct Runoff. The SCS CN method is highly trusted method and used by the hydrologists all over the globe for prediction of runoff. With SCS CN model, we have used Arc Map 10.2 GIS tool to generate the soil map, the land use map and ultimately the composite curve number of the watershed is calculated. In the second model, RRL toolkit software is used in which the AWBM is selected for assessing the runoff. The AWBM is a catchment water balance model that relates runoff to rainfall with daily or hourly data. We used the daily rainfall data, and daily evapotranspiration data as an input for the AWBM RRL toolkit. In total 5 years of daily data, first 3 years of data was taken for model calibration and the rest 2 years data was taken for model validation. The coefficient of determination for the models was obtained indicating good agreement between the observed and simulated runoff. The models were also evaluated based on Nash–Sutcliffe Efficiency Index (EI). The Nash Sutcliffe efficiency obtained for calibration and validation of AWBM was found to be 0.852 and 0.890 respectively.

Keywords: *SCS CN, RRL, AWBM, Evapotranspiration, Nash-Sutcliffe efficiency.*

Introduction

Water is the natural important resource which needs preservation, control and management. The water resources can be managed by implementing and improving the engineering practices. The hydrological behaviour of the any watershed is to be taken care of for the effective planning of the water resources available. A rainfall-runoff model is a mathematical model that describes catchment and gives relationship between precipitation and runoff. A rainfall runoff model is helpful in computation of discharge from a basin. In most of the locations we have the rainfall data but the discharge or the runoff data is not available or is available in gaps. Modelling gives information to hold up the decision making of water management policies.

The proper planning and management of the water resources in a location becomes a real big trouble for the hydrologists if discharge data is not available. Hence, engineers and hydrologists from all over the world have inclined towards the computer softwares for the estimation of runoff in any catchment or basin for handling any civil engineering project. These software models are more accurate and less time consuming than the physical method for the collection of data. They also have an advantage of extending the result and therefore future prediction is also possible.

In the present study, Bina basin, Madhya Pradesh, India is chosen for rainfall runoff modelling. For this study area, we have developed and applied two hydrological models viz. the SCS CN model and the AWBM RRL model. As the Bina city is well known because of the industrial activities going on over here and runoff estimation is very much necessary therefore we have selected this basin having Rahatgarh as the g/d site.

2. Review of Literature

2.1 *SCS CN Model*

Reddy (1994) worked to find the effect of land use on transportation network by employing the remote sensing techniques. In this study he used remote sensing data and found that these remote sensing data are more accurate and can be collected whenever required. Reddy (1997) worked on the improvement of image classifier for land-use and land cover. He found that described that integrated information is provided by the remote sensing satellites.

Yu (1998) took assumptions as the

spatial variability of infiltration capacities and the temporal variability in rainfall intensities. He came up with a SCS CN model based on the mentioned assumptions. He said that whenever the time varying rainfall rate surpasses the spatially variable, runoff will be produced.

Mishra and Singh (1999) also did their research in this field. In the study the two hydrologists came up with the result that the SCS-CN equation can be developed from the water balance equation. But they used an assumption that rate of change of retention with effective precipitation is a linear function of retention.

Pradhan et al (2010) used the remote sensing data and GIS tool to compute the rainfall runoff in Teesta river, east Singtam, Sikkim. The study was conducted for the year 2009. They believed that the conventional method of data collection is not accurate, so they used RS data and GIS tool. They found that this RS data is very useful in the rainfall runoff modelling and modelling can be done in remote areas also.

Somashekar et al. (2011) used the SCS CN method in their study on Hesaraghatta watershed. This research was conducted to obtain the runoff, They used the RS data in research. The IRS LISS III images in the form of False Colour Composites were used. They also concluded that the SCS method gives good results when accompanied with GIS and remote sensing data.

Latha (2012) developed SCS CN and Strange table models for Veernam tank, Tamil Nadu. The location of the catchment is latitude 11° 15'00” and longitude 79° 30'00' E in Cuddalore District of Tamil Nadu, India. The data used was of the period from 2000 to 2004. The analysis showed that SCS CN when used with GIS tool gives more accurate results.

Dhawale (2013) worked on Darewadi watershed of Maharashtra. In this study, he used the remote sensing data along with GIS tool for the computation of runoff. He employed the SCS CN method for the runoff estimation. He got 85 and 75 as curve number values using GIS tool. He concluded that the SCS CN method computes more precise surface runoff when RS and GIS tool is employed together.

Nagarajan et al. (2013) employed the SCS CN model in his study to find the impact of land use changes on surface runoff. He took a rural watershed of Tamil Nadu in this study. The result obtained implies that which month has more runoff and which month has lesser.

Viji et al. (2015) developed a SCS CN model using GIS tool for estimation of runoff in Kundahpalam Watershed, Nilgries District, Tamilnadu. The land use and composite CN (48, 68, 83) were found and the runoff was estimated. The estimated runoffs were found comparable to the observed data.

Joycee and Santhi (2015) used the CN method with GIS and remote sensing data for the estimation of runoff in the sub basin of Kodayar, Tamilnadu. The weighted curve number was found to be 75. The runoff computed by the NRCS CN technique obtained a very good R^2 value of 0.9939.

2.2 *AWBM RRL Model*

Boughon (2006) developed an AWBM model for the hydrologic rainfall runoff modelling. A set of 99 rainfall-runoff data sets of poor quality are used to test some methods. These rainfall runoff data were previously rejected. He concluded that this model gave more than two-third good calibrated values and scope of improvement of the data sets is present for further study.

Kumar (2013**)** developed two hydrological models named the SCS CN model and AWBM model in Tadepalli, Andhra Pradesh. The total catchment area was 61.5 sq km. Along with SCS CN, GIS was used for obtaining the composite curve number and getting the land use/ land cover pattern. The value of co-relation r2 =0.76 was obtained between observed and computed runoff.

Haque Et al. (2015) used the AWBM model for quantitative assessment of uncertainty. Both gauged and ungauged catchments were taken in the study. The main result obtained from this research work was that AWBM modeling outputs could vary from −1.3% to 70% with two different input rainfall data. The performance of the AWBM model was found to be dominated mainly by the selection of appropriate rainfall data followed by the selection of an appropriate calibration data length and optimization algorithm.

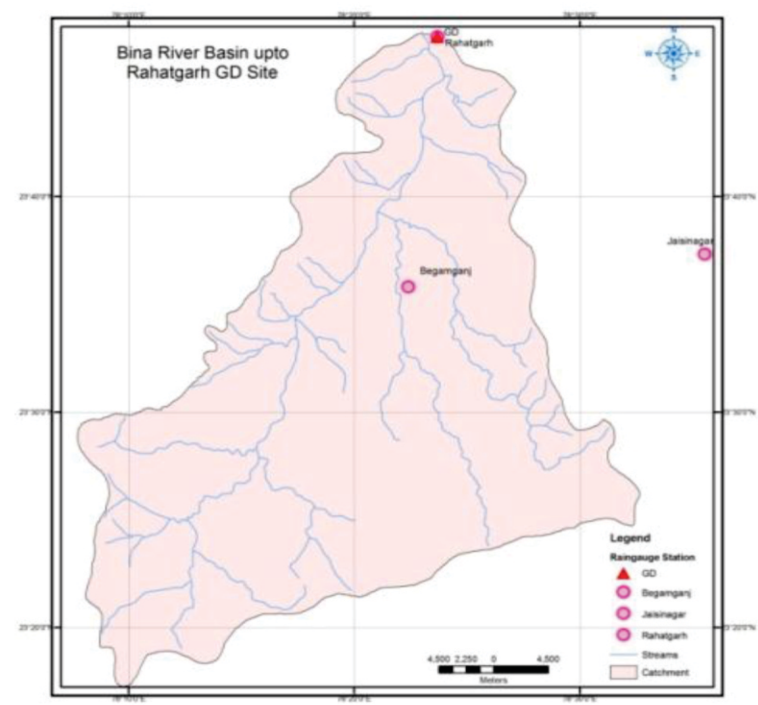
Yu (2015) used two models for rainfall runoff computation namely AWBM and SimHyd for river Rambeod, French Alps. The Nash Sutcliffe efficiency for both AWBM and SimHyd models was around 0.71.

Balvanshi and Tiwari (2015) developed a Rainfall Runoff model using AWBM for runoff estimation. The coefficient of determinations for the model calibration and validation were 0.909 and 0.835 respectively. The model was also tested on Nash–Sutcliffe Efficiency Index (EI) and the calibration and validation values obtained were 0.824 and 0.618 respectively.

3. *Materials and Methods*

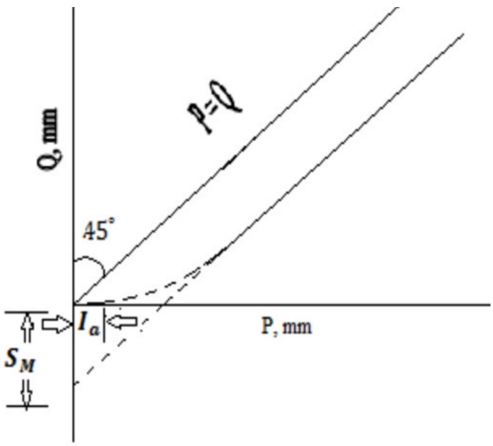
3.1 *Study Area*

Bina river begins from Raisen district near Bhopal, Madhya Pradesh. It then go through in Rahatgarh block and traverses through Khurai and Bina tehsils of Sagar district. The Bina river meets the Betwa near Khurwai. The Bina Basin has coordinates extending from 23.55407 North and 78.290580 East to 24.171972 North and 78.038877 East. In its path the river Bina passes through Rahatgarh, Eran, Bina, Belai, Jaisnagar and Begumganj. The total catchment area is 1180 km^2 with the g/d site located at Rahatgarh.



3.2 *SCS CN Model*

In 1933, the Soil Erosion Service was set up in United States. The main objective of SES was to perform experiments and produce new measures for soil conservation. In 1935, a law known as the “soil conservation act of 1935” changed the agency name to Soil Conservation Service. Later on in 1994, the name was again changed from soil conservation service to NRCS (Natural Resources Conservation Service).



$P = Q + F + I_a$ (1)

This is Water Balance Equation.

$$\frac{F}{S} = \frac{Q}{P - I_a} \quad (2)$$

This is proportionality equality hypothesis.

From eqs. (i) & (ii),

$$\frac{P - Ia - Q}{S} = \frac{Q}{P - I_a} \quad (3)$$

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (4)$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (I_a = 0.2\ S) \quad (5)$$

$$S = \frac{25400}{CN} - 254 \quad (6)$$

where S is in mm

The Arc Map 10.2 GIS tool was employed to develop the theissen map, soil map and the land use map of the basin. The input to GIS tool was LISS III image and the soil sheet published by ICAR, Nagpur. These soil and land use maps were the base for determining the composite curve number for the bina basin. The above formulaes were then applied in the programmed excel sheet so as to get the estimated direct runoff by the SCS CN method.

3.3 *AWBM RRL Model*

AWBM stands for Australian Water Balance Model. This model is a conceptual, lumped rainfall-runoff model. The basic data required for the set up of AWBM model is listed below:

- Area of catchment in km^2
- Rainfall data daily time series in dat format, mm/day
- Potential Evapotranspiration data daily time series in .dat format, mm/day
- Observed data daily time series in dat format, mm/day or m^3/s.

The water balance equation employed in this model is given below:

$Store_n$ = $store_n$ + rain - evap (7)

Here n value varies from 1to 3. If evapotranspiration is greater than the moisture content then value becomes negative and the value is set to zero. If moisture in the store becomes greater than its capacity then runoff is generated. When runoff occurs from any store, part of the runoff becomes recharge of the base flow store. The fraction of the runoff used to recharge the base flow store is BFI*runoff. BFI is the base flow index which is the ratio of base flow to total flow in the stream flow.

The remains of the runoff, i.e. (1.0 - BFI)*runoff, becomes the surface runoff. The base flow store runs down at the rate of (1.0 - K)*BS, where BS is the current moisture in the base flow store and K is the base flow recession constant. The surface store operates in the similar way as the base flow store, and runs down at the rate of (1.0 - KS)*SS, where SS is the current moisture in the surface runoff store and KS is the surface runoff recession constant.

3.4 *Model Evaluation*

.4.1 *Coefficient of Determination, r^2*

The squared value of the coefficient of correlation is termed as coefficient of determination. Mathematically it is expressed as follows:

$$r^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \bar{P})^2}} \right)^2$$

Where, O and P are observed and Predicted values respectively. The range of this evaluation parameter lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction.

3.4.2 *Nash Sutcliffe criteria, E*

The efficiency E or η was proposed by Nash and Sutcliffe in the year 1970. It is defined as 'one minus the sum of the absolute squared differences between the calculated and observed values normalized by the variance of the observed values' during the period of study.

Mathematically the formula is expressed as:

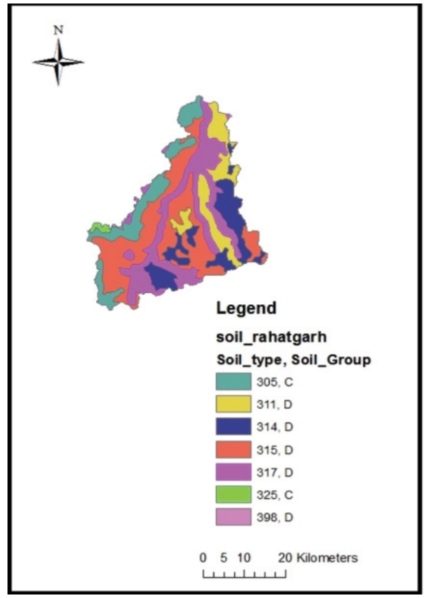
$$E = 1 - \frac{\sum_{1}^{n} (O_i - P_i)^2}{\sum_{1}^{n} (O_i - \bar{O})^2}$$

Results and Discussions

S.No	Rainfall Station	Percentage Weight (%) of station	Individual Weights
1	Begumganj	67	0.67
2	Gairatganj	22	0.22
3	Rahatgarh	9	0.09
4	Jaisnagar	2	0.02

Table 1 Theissen weights of raingauge stations

Figure 1 Theissen Map



re 1 Soil Map

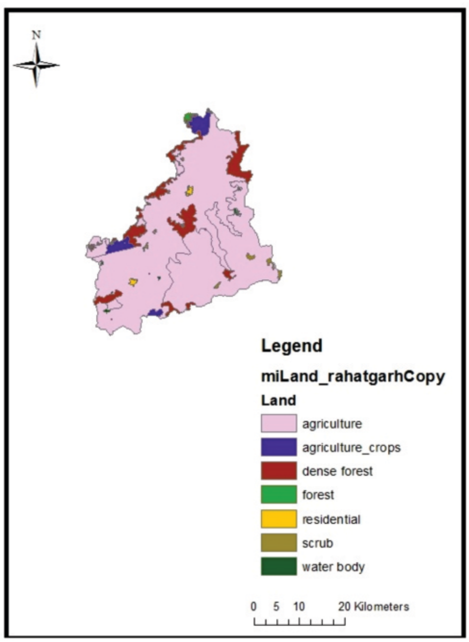
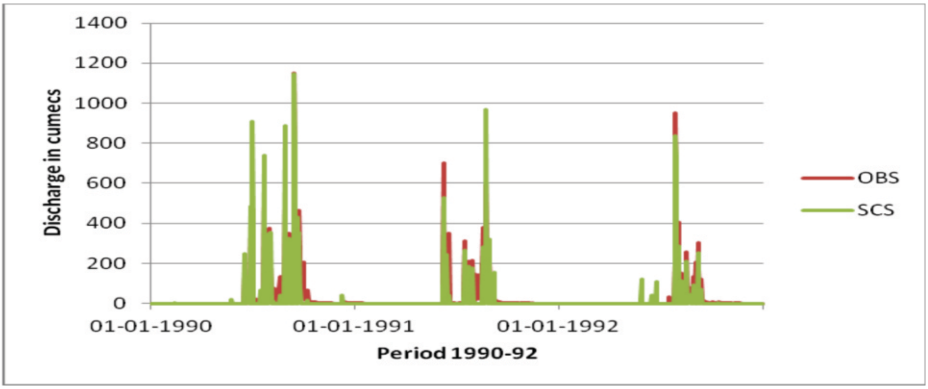
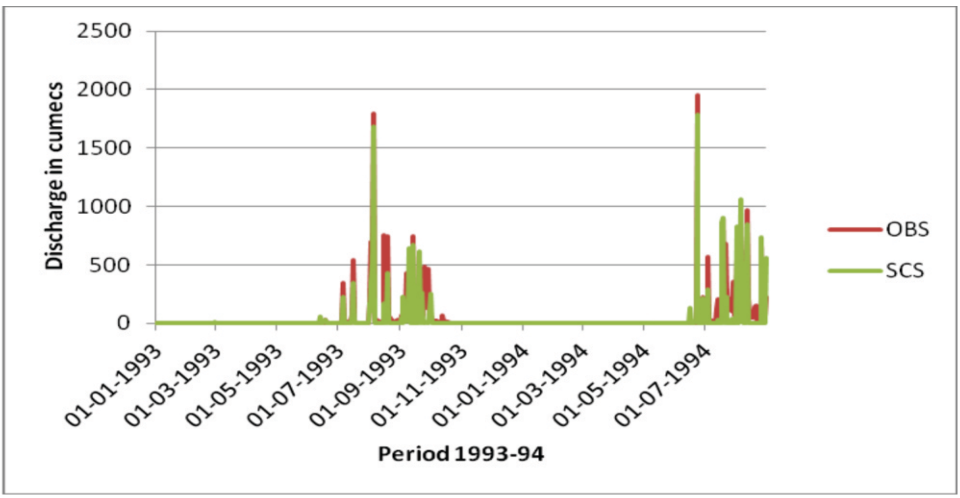


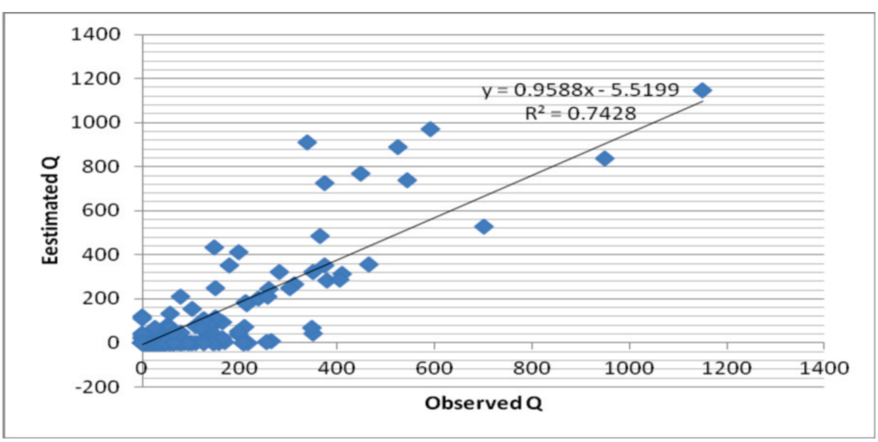
Figure 2 Land Use/ Cover Map

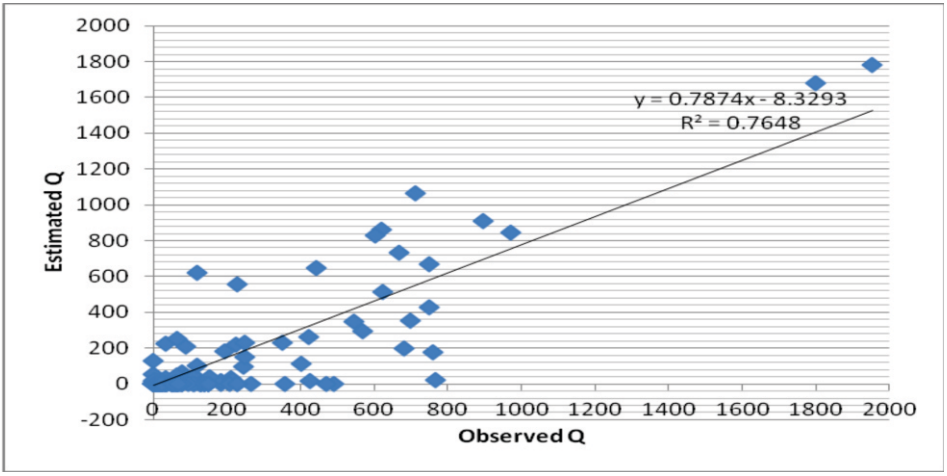
Using the attributes of the soil map and the land use/cover maps, the maps were merged and layered together so as to derive the composite curve number. The CCN was found out to be 77 for the bina basin.

Discharge graphs and Scatter plots of SCS CN model for the period 1990-92 & 1993-94

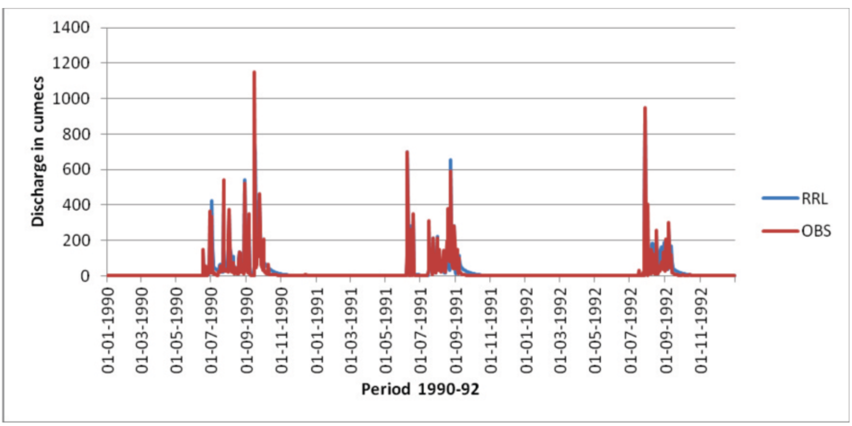


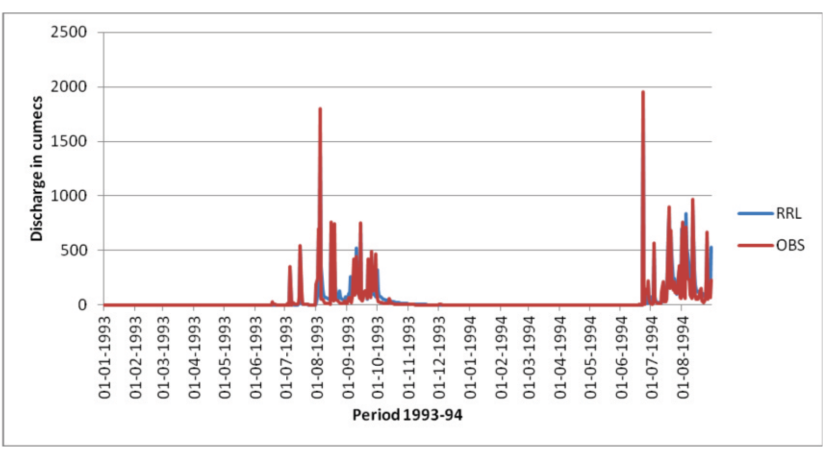


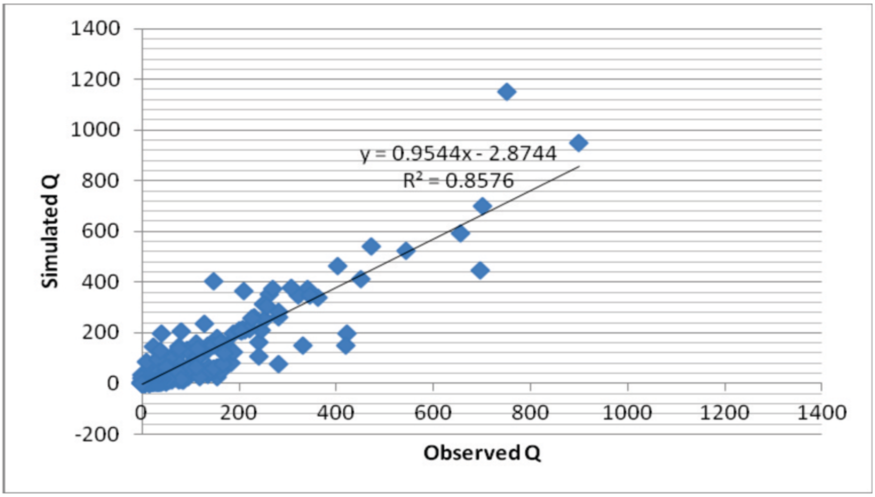


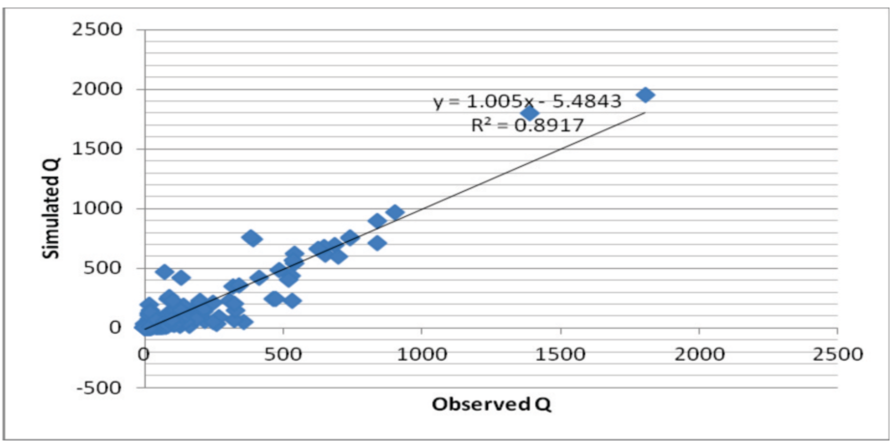


Discharge graphs and Scatter plots of AWBM model for the period 1990-92 & 1993-94

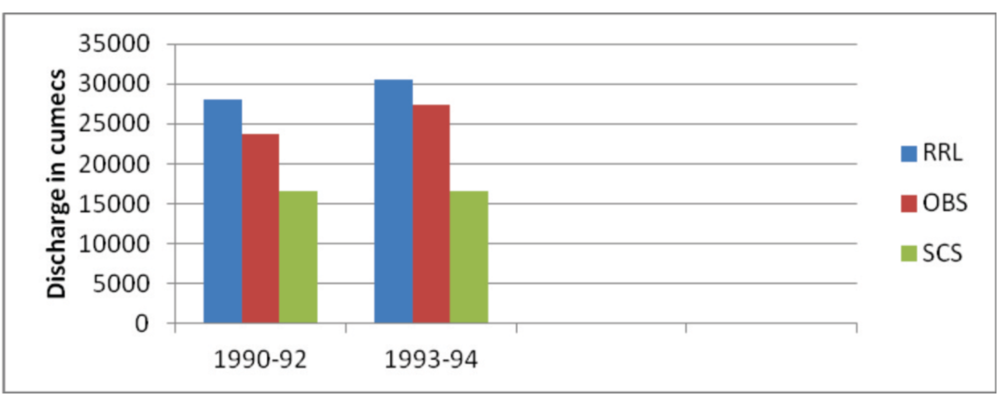








Comparative bar charts of AWBM RRL, SCS CN and Observed discharge



Clearly it can be seen that the AWBM model slightly over predicts the discharge and the SCS CN under-predicts. The AWBM also shows good match between the simulated and observed discharge.

Conclusions

The SCS CN model gave the NSE during 1990-92 as 0.673 and 0.752 for the years 1993-94. The coefficient of determination values were 0.742 and 0.764 for the respective periods. The AWBM RRL model gave the NSE during 1990-92 as 0.852 and 0.890 for the years 1993-94. The coefficient of determination values were 0.857 and 0.891 for the respective periods. We applied two models, out of which the AWBM is found to be more accurate and less time consuming in comparision with the SCS CN model. As the bina project is about to come so the AWBM model can be employed further in the bina basin for prediction of runoff and to get better understanding of the catchment.

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DEVELOPMENT OF CONCEPTUAL MODEL FOR GROUNDWATER FLOW IN NETHRAVATHI RIVER BASIN

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Abstract

Conceptual model for groundwater flow is a qualitative representation of the hydro-geological data. Conceptual modeling has been a crucial process while constructing a numerical model for the better understanding of complex groundwater systems. This helps in identifying gaps in the hydro-geological data that is required to be filled into the model to get better simulations for the groundwater flow.

In this study, Groundwater Modeling System 10.08 (GMS), a software package which uses MODFLOW for groundwater flow simulations, is used for the development of model for Nethravathi River Basin based on "Conceptual model approach-1". In this approach, the model is developed using GIS tools available in the Map module for the watershed basin. The source/sink of water, physical boundaries, distribution of hydraulic properties of the region and other necessary hydro-geological data are basic components needed to be defined for simulation. The conceptual model can be converted to the grid model for groundwater flow simulations using MODFLOW. Survey of India toposheets are used for delineation of watershed boundary and creating feature-objects. Groundwater level data of 15 open wells are collected from Department of Mines and Geology, Karnataka for the study. River-stage data is collected from Central Water Comission (CWC). Recharge rates are estimated as per the Groundwater resource Estimation Committee (GEC) guidelines. Aquifer parameter values are obtained based upon the field data.

The purpose of the present study is to build and visualize the existing hydrological data in the form of a conceptual model for groundwater flow in Nethravathi river basin.

Keywords: *Conceptual model, Hydro-geological data, Numerical model, MODFLOW.*

Introduction

Conceptual modeling has been a crucial process while constructing a numerical model for the better understanding of complex groundwater systems. Conceptual model for groundwater flow is a qualitative representation of the hydro-geological data for the regional setting. The basic components of a conceptual model are sources/sinks of water, physical boundaries and the distribution of hydraulic properties within the region. A conceptual model also allows for general conclusions regarding the impacts of aspects of the current hydrologic conditions on current groundwater flow directions (Leon and Ferre 2003). Thus, it has been a pre-requisite step to develop a conceptual model which is then converted into a numerical model for modeling the groundwater flow. It helps in identifying gaps in the hydro-geological data that is required to be filled into the model to get better simulations for the groundwater flow. The basic objective of building a conceptual model is to simplify the field problem and categorize the associated data so that the system can be analyzed more readily and easily (Anderson and Woessner 1992). Thus, the conceptual model should therefore be kept as simple as possible although retaining the adequate capacity to sufficiently represent the physical elements of the hydrological behavior (Singhal and Goyal 2011).

The purpose of the present study is to build and visualize the existing hydrological data in the form of a conceptual model for groundwater flow in Nethravathi river basin.

2. Present Study

In this study, Groundwater Modeling System 10.08 (GMS), a software package which uses MODFLOW for the groundwater flow simulations, is used for the development of the model for the Nethravathi River Basin based on "Conceptual model approach-1". In this approach, the model is developed using GIS tools available in the Map module for the watershed basin. The basic components of a conceptual model such as sources/sinks of water, physical boundaries and the distribution of hydraulic properties and all other necessary hydro-geological data within the region are integrated to form a conceptual model. The conceptual model can be converted to the grid model for groundwater flow simulations using MODFLOW.

3. Description of the Study Area

3.1 Nethravathi River Basin

Nethravathi river has its origins in the Western Ghats of Karnataka state in India. Some of the places on the banks of this river are Mangalore, Bantwal, Pane Mangalore, Dharmasthala and Ullal. Nethravathi basin spreads over a watershed boundary of 3314.43 km^2 area. The river originates at Bellalarayana durga in the Dakshina Kannada district at an altitude of 1 km and flows west up to its confluence with the Arabian Sea. The river basin consists of many sub-basins namely, Kumaradhara, Kallaji hole, Gowri hole, Belthangadi hole, Nethravathi Hole, Neriya hole, and Shisla hole. The location map of the Nethravathi basin is shown in Figure 1.

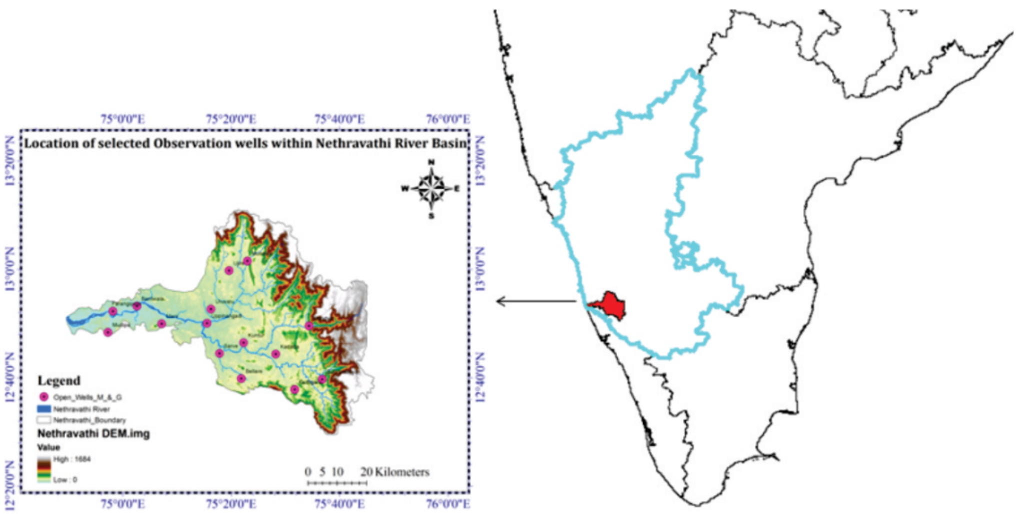

Figure 1 Geographic location of the Nethravathi basin

3.2 Hydrogeology

Weathered and fractured gneiss, granite and schist are the major water bearing formations. Alluvial formation of limited thickness and aerial extent is found along the courses of major rivers. Groundwater occurs under phreatic (water table) condition in weathered zones of gneiss, schist and granite and under semi-confined to confined conditions in joints and fractures of these rocks at deeper levels. Weathered and fractured gneiss is the predominant aquifer found in the district followed by schistose and granitic aquifers, which occur as isolated patches in some taluks.

The depth to water level during pre-monsoon (May 2011) ranges from 4.12 mbgl to 15.2 mbgl. During post-monsoon (Nov 2011) it ranges from 0.75 mbgl to 8.65 mbgl. The seasonal fluctuation data shows that 36.5% of the wells show rise while, 63.5% of the wells show a fall in water level. The rise in water level ranges from 0.15 m to 16.0 m while, the fall ranges from 0.65 m to 4.62 m. Analysis of the long-term water level trend in the last 10 years (2001-2010) reveals that 58% of the wells show a rise in water level ranging from 0.014 m to 0.12 m, whereas, the remaining wells (42%) show a fall in the range of 0.01m to 0.19 m (CGWB Report 2012).

3.3 Groundwater Status

According to the Central Groundwater Board (2012), the groundwater draft (exploitation) for domestic and industrial uses is set to increase sharply in Dakshina Kannada, and its availability for irrigation will decrease drastically by 2025.

4. Methodology

4.1 Development of conceptual model

For the present study, arcs and coverages are created for different hydro-geological layers such as watershed boundary, local sources/sinks including wells, drainages and Nethravathi river using Map module. Specific head and drain arcs are defined and then polygons are built for defining head values in the watershed. Well locations are created and defined as point objects. In order to accurately model the groundwater flow near wells, grid refinement is done by assigning refinement data directly to the wells in the conceptual model. Then, hydraulic properties such as recharge and hydraulic conductivity are defined for the polygons which is built for the watershed. After this, layer elevations are defined to complete the development of the feature-object based conceptual model. Subsequently, conceptual model so developed can be converted into a mathematical model such as 3D modular finite difference based MODFLOW model (McDonald and Harbaugh, 1988).

4.2 Data collection and preparation

Survey of India toposheets of scale 1:50000 are used for delineation of watershed boundary and creating feature-objects such as drainages and Nethravathi river. Groundwater level data of 15 open wells are collected from Department of Mines and Geology, Karnataka for the study. Lithology data is collected from CGWB. River-stage data is collected from Central Water Comission (CWC). Recharge rates are estimated as per the Groundwater resource Estimation Committee (GEC 1997) guidelines. Aquifer parameter values are obtained based upon the field work.

4.3 GIS Integration

Geographic Information System (GIS) has played a key role in the preparation of the datasets, which are used as an input for the desired model in this study. Different hydro-geological layers such as watershed boundary, local sources/sinks including wells, drainages and Nethravathi river are created by using ArcGIS software. Thus, GIS layers, created in the form of shapefiles are imported into GMS and then converted into coverages for building a conceptual model.

4.4 River Boundary

River-stage data of Nethravathi river and Kumaradhara river near Uppinangadi station was collected from Central Water Commission (CWC). Monthly river stage values are assigned at the start and end nodes of both the rivers. The river bed conductance is defined by the equation (1),

A/L *k C= (1)

Where, k is the hydraulic conductivity of the river bed material. Based on the field observations, river bed material was found to be fine to medium sand. The hydraulic conductivity for fine sand is 2.5 m/day and that of medium sand is 12 m/day (Todd and Mays 2005). Hence, a value of 10 m/day is assigned. L is the length of the reach in the cell. Fortunately, GMS can automatically calculate the lengths of arcs. Therefore, when a conductance is entered for an arc, it should be entered in terms of conductance per unit length. Therefore, river bed conductance per metre length are determined and assigned for both the rivers.

4.5 Flow rate of wells

Groundwater level data of 15 open wells of Dept. Of Mines & Geology, Karnataka are collected in the study area. Flow rate is calculated using groundwater draft values determined for those 15 wells.

4.6 Aquifer parameters

4.6.1 Recharge rate

Rainfall is the major source of recharge in the area. Recharge rate is assigned for the model boundary as recharge to the groundwater system. Hence, a recharge co-efficient of 10 % is adopted during pre-monsoon season for the entire study area (according to GEC 1997 guidelines).

4.6.2 Hydraulic Conductivity

The aquifer parameters required for the model are hydraulic conductivity and specific yield. These aquifer properties are often determined by pumping tests.

CGWB has carried out pumping tests in various locations in the area and estimated that the transmissivity values range between 3 to 20 m^2/day. Horizontal hydraulic conductivity is estimated by these pumping test values.

4.7 Layer Elevations

From the lithology data available for 6 different locations of bore log information from CGWB, it can observed in the Figure 2. that permeable layers from top soil to clay vary upto 20 - 40 m depths below the ground surface. Top and bottom elevations of model boundary define the aquifer thickness. Assuming the aquifer to be unconfined, top and bottom layer elevations of the single layer model are assumed as 30 m and 0 m respectively.

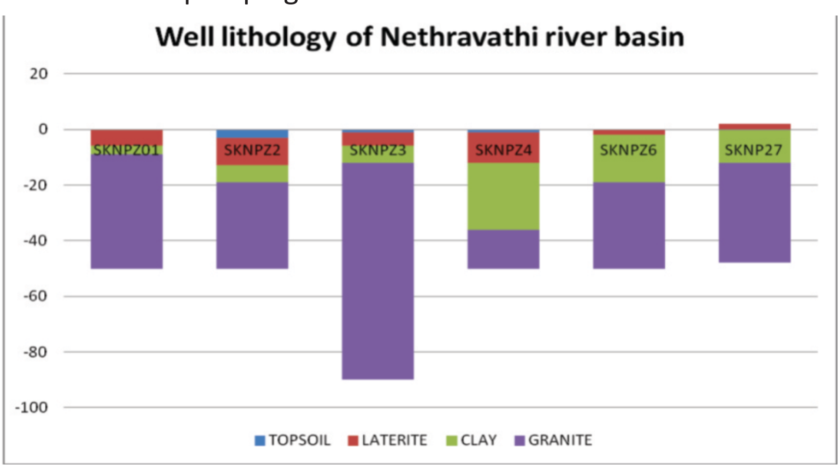

Figure 2 Well lithology of Nethravathi river basin

4.8 Building the model

In the present study, conceptual model approach-1 is adopted. In this approach, all input data are represented in terms of physical objects, such as wells, rivers, recharge zones, etc., which are then converted into a grid based mathematical model with the help of pre-processor software.

4.8.1 Importing the data

In the project explorer window of GMS user-interface, a new conceptual model is created to build the model and units are defined. Boundary and sources/sinks coverages are created in the conceptual model by importing different hydro-geological layers such as watershed boundary, local sources/sinks including wells, drainages and Nethravathi river, into the map module of GMS, created by using ArcGIS software.

4.8.2 Defining the coverages

Five coverages are built in the present model by selecting suitable MODFLOW packages such as well (WEL), specific head (CHD), river bed conductance (RIV), recharge (RCH) to define them. These following coverages contain information such as extent/boundary of the study area, flow rate of wells, recharge rate, horizontal hydraulic conductivity values and layer elevation values of the considered boundary of the river basin as shown in Figure 3:

Boundary coverage

Sources and sinks coverage

Recharge coverage

Hydraulic conductivity coverage

Layer elevations coverage

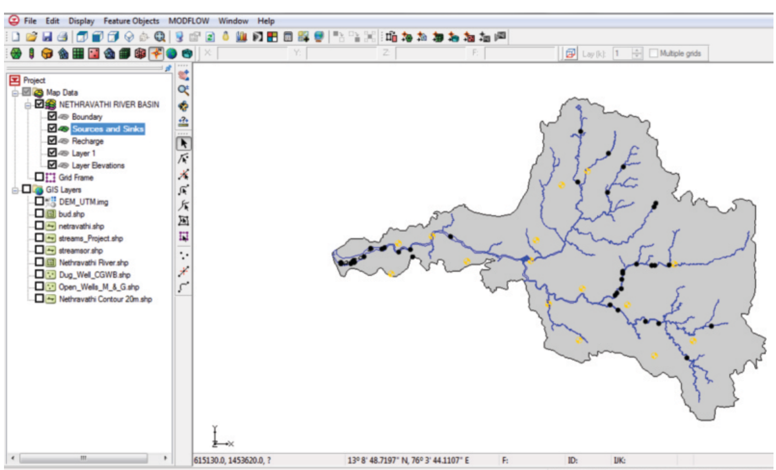

Figure 3 Coverages of Nethravathi river basin imported into GMS

4.8.3 Locating the grid frame to the model and creating the grid

Grid frame is defined for the model boundary by selecting the location and orientation of the model boundary inside the frame. The grid frame represents the outline of the grid. All the feature objects are converted into 3D grid.

4.8.4 Selecting the flow package

The MODFLOW/MODPATH package is selected to run the model for grid-wise groundwater flow calculations for all applicable coverages which are defined.

4.8.5 Initializing the MODFLOW data and defining active/inactive zones

Once the grid is constructed, MODFLOW data for the whole grid is initialized and then active/inactive zones of the model boundary are delineated. This is accomplished automatically using the information in the sources and sinks coverage. Each of the cells in the interior of any polygon in the local sources and sinks coverage is designated as active and each cell which is outside of all the polygons is designated as inactive.

4.8.6 Converting the conceptual model

The conceptual model is converted from the feature object-based definition to a grid-based MODFLOW numerical model as shown in Figure 4.

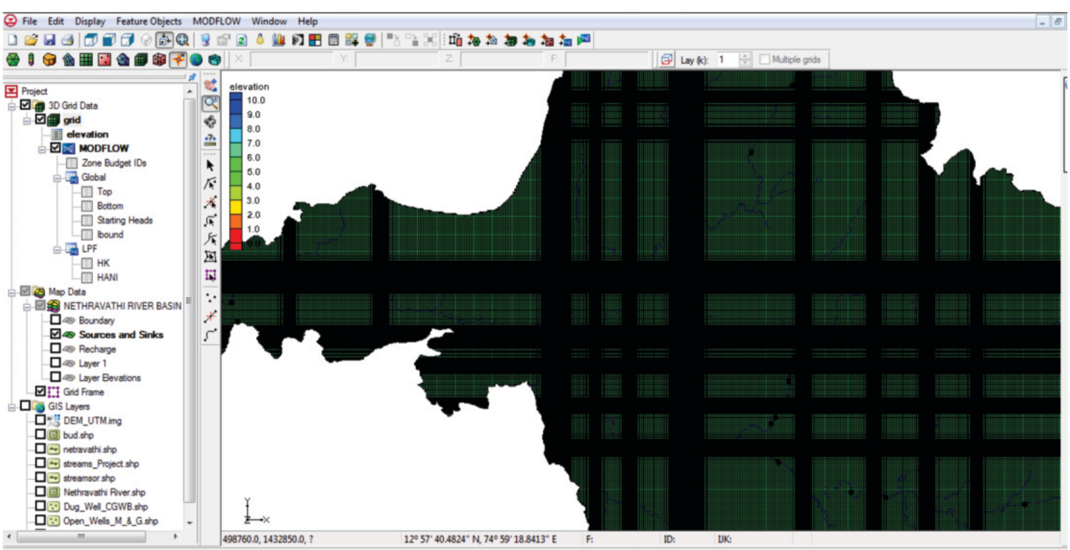

Figure 4 Grid-based MODFLOW numerical model

4.8.7 Checking and running the simulation

Before running the simulation, the Model Checker is run to identify and rectify the mistakes/errors if any are made during the preparation of the conceptual model. Gridded model is run for the simulation after removing all the errors and warnings and simulated model looks as shown in the Figure 5.

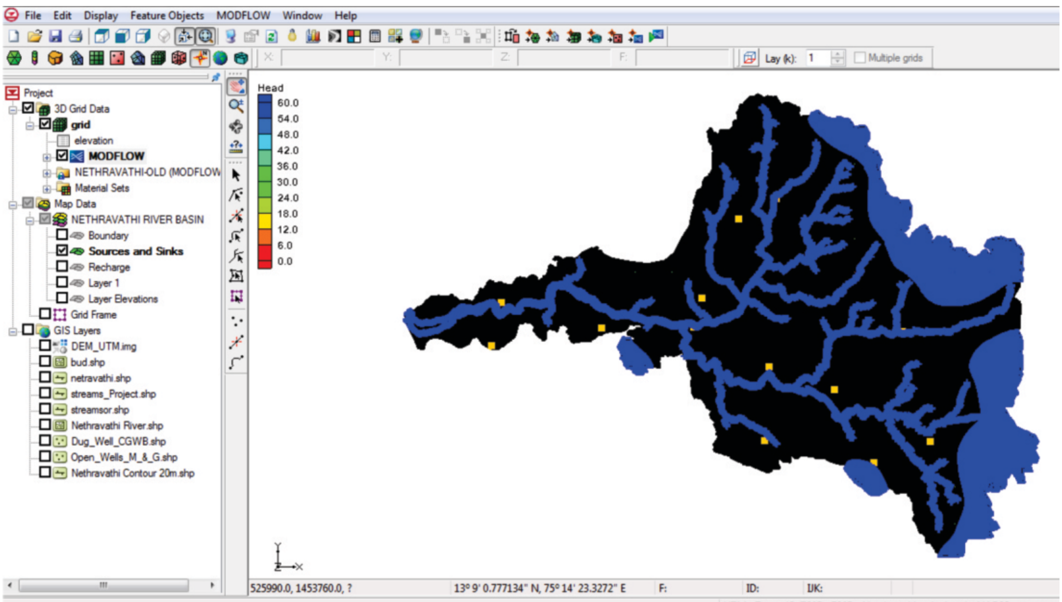

Figure 5 Simulated MODFLOW numerical model

4.8.8 Viewing the results

A set of contours representing the groundwater heads for all the time steps carried out by the model and flow budget values are the results available after the simulation as shown in Figure 6. The MODFLOW solution consists of both a head file and a cell-by-cell flow (CCF) file. GMS uses the CCF file to display flow budget values.

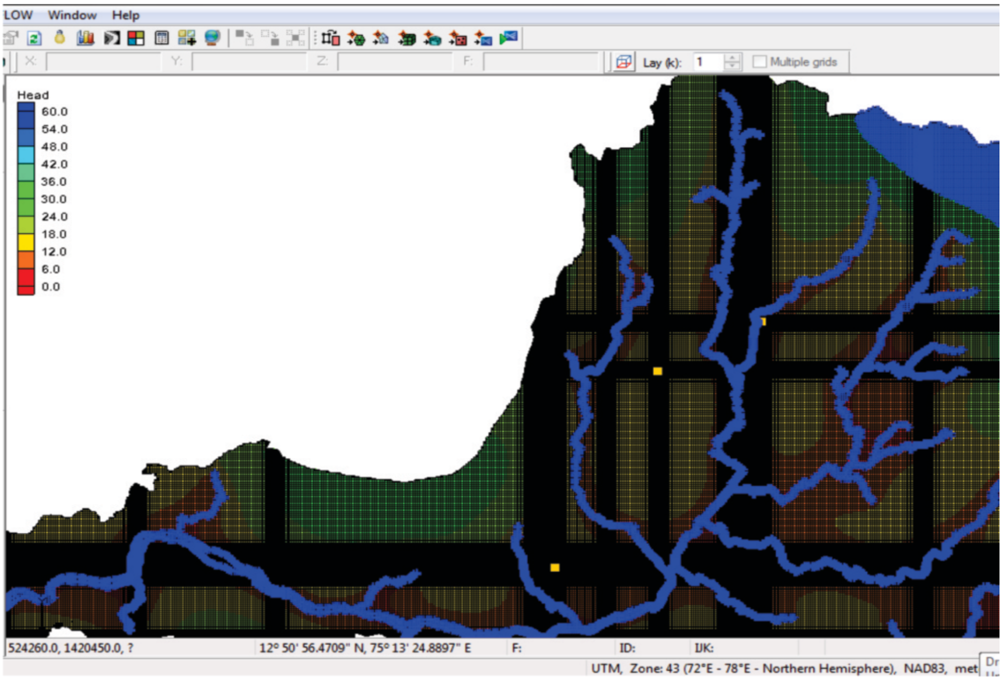

Figure 6 Groundwater head contours and flow budget of simulated MODFLOW numerical model

A conceptual model has been developed by using the minimum available hydrogelological data for the study area. A sample simulation has also been conducted for the developed conceptual model. The groundwater head contours give a generic idea about the groundwater water flow directions in the study area. A flow budget has also been prepared as a result of the simulation which clearly shows the behavior of wells, rivers and recharge conditions of the study area for the provided data. The simulation for wells was done on the basis of groundwater draft values, so flow out is more whereas flow-in is zero for wells. The bed conductance of river accounts for lesser leakage value of river compared to the river discharge values. Since 20% of average annual rainfall value was considered, recharge is more as flow-in and zero for flow-out.

The model can be improved by re-strengthening the conceptual model with more accurate data regarding river-bed conductance, recharge rate, hydraulic conductivity and many other hydro-geological and aquifer parameters by conducting field experiments. Further data collection should also be done considering more wells for aquifer head measurements and groundwater drafts.

Conclusion

The present study demonstrates the strength of conceptual model coupled with MODFLOW for groundwater flow simulation. The numerical model provides an insight to the complex groundwater flow systems by quantifying the groundwater budget and predicting groundwater flow directions. Conceptual modeling need not necessarily have to be followed by numerical modeling. But, it helps in identifying gaps in the hydro-geological data that is required to be filled into the model to get better simulations for the groundwater flow.

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