IJRD International Journal of Research & Development Organisation

ISSN: 2455-6653

Journal of Applied Science

AN INNOVATIVE APPROACH FOR ESTIMATION AND EVALUATION OF SPATIALLY DISTREIBUTED HYDROLOGICAL PARAMETERS WITH TEMPORAL RESOLUTION OF LAND USE-LAND COVER CLASSES USING REMOTE SENSING & GIS BASED 'RINSPE' MODEL

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Abstract:

The estimation of Hydrological parameters of a catchment is an important aspect in engineering planning, environmental impact assessment, flood forecasting and water balance calculations. There have been efforts to estimate, analysis and evaluate the Hydrological parameters to make stable water use and other Hydrological problems to solve. This study focuses on the rainfall-runoff and infiltration estimation and evaluation of results by considering temporal resolution of Land use-Land cover classes using'Runoff-Infiltartion and non-Point Source Pollution Estimation' (RINSPE) model. To proceed this study through the ArcView selecting study area and collecting data, basically, are needed. This study chosen karha basin which is a sub-basin of Bhima basin and gathered various raster and feature class data. These collected data were used in preprocessing in the ArcGIS 9.3 for computing Hydrologic parameters. As input data for the rainfall-runoff model, this study selected the total 8 number of gauge stations. To reflect spatial rainfall characteristics of precipitation data of specific hydrologic events IDW method was used. Finally, RINSPE Model run in which SCS-CN method adopted for calculating runoff. The model run in two differ scenarios by considering temporal resolution of 10 years (2004-2013) for land use-land cover maps. The estimated runoff depths and infiltration

were 268.63 mm, 281.02 mm and 315.65 mm, 316.88 mm from two differ years of 2004-05 and 2013-14 Land Use-Land Cover maps.

Key words: *RINSPE, SCS-CN, Runoff, GIS, Temporal Resolution*

1. INTRODUCTION

The uses of geographic information systems (GISs) to facilitate the estimation of runoff from watershed have gained increasing attention in recent years. This is mainly due to the fact that rainfall–runoff models include both spatial and geomorphologic variation [1]. Streamflow estimation requires Rainfall-Runoff modeling which need the precipitation data, land use data, soil data and topologic data. These required data are basis of computing hydrologic parameters of Rainfall-Runoff, infiltration, Initial Loss etc. Nonpoint source (NPS) pollution is an exceedingly complex phenomenon and may be defined as the introduction of impurities into surface or sub-surface water supplies, generally from indirect, intermittent or diffuse sources and often associated with storm, rainfall or snowmelt events [2]. Nonpoint source pollution results from a wide variety of human activities on the land. It represents the cumulative effects of all of the land uses in a watershed and associated human activity. Land use data from Bhuvan web site of National Remote Sensing Centre (NRSC), Soil data from Food And Agricultural Organisation (FAO) of USDA comprise the basic spatial geomorphologic data set. Using collected geospatial data and attribute data of CN values corresponding Initial abstraction values, this study conducted for computing runoff depths &infiltration with different Land use-Land cover classes. Several authors has been utilized SCS-CN model for different hydrological problems in estimation of rainfall-runoff. Mockus [3], Sherman [4 & 5] and Andrews [6] contributed to develop the unique procedures for estimating direct runoff from storm rainfall. Sherman [4 & 5] was one of the pioneers to suggest plotting direct runoff versus storm rainfall. Mockus [3] proposed that surface runoff of ungauged watersheds could be estimated by using information of soil, land use, antecedent rainfall, storm duration, and average annual temperature. The rainfall runoff relation of Mockus [3] and the soil, vegetation-land cover of Andrews became the building blocks of the SCS Curve Number method. Mishra and Singh [7], Andrews [6] developed a graphical procedure for estimating runoff from rainfall for combinations of soil texture and type, the amount of vegetative coverage, and conservation practices. R. Kumar *et al.* [8] estimated the runoff using SCS-CN method for an ungauged catchment using geomorphological instantaneous unit hydrograph (GIUH) models. Ramakrishnan *et al.* [9] used the SCS-CN based approach for identifying the potential water harvesting sites in the Kali Watershed, Mahi River Basin. V. Kumar *et al.* [10] did the analysis of the runoff for watershed using SCS-CN method and geographic information systems (GIS). Somashekar *et al*. [11] estimated surface runoff of Hesaraghatta watershed. The analysis was carried using IRS-1D, LISS III satellite images in the form of FCC using SCS curve number method and found that the runoff estimated by SCS method showed reasonable good result. N. Nagarajan *et al.* [12] found that from the runoff values estimated by the curve number technique, it is possible to assess which month has more runoff, which month has a moderate runoff and which month has a low runoff. With the help of these values, irrigation scheduling, rotation of cropping pattern and selection of suitable crops can be suggested. Pradhan, R. et al stated that, the use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall [13].

2. STUDY AREA

Karha river basin in Maharashtra State, is a part of Neera basin which is a sub-basin of Bhima river basin. Karha is the principal river of the Karha basin. The river originates in the hills of Sahyadri, upstream of village Garade and flows through Purandar hills, plateau region of Kade Pathar, plains of Baramati region of Pune District and then joins river Neera. The basin is landlocked between Upper Bhima basin and the remaining Neera basin. The river is seasonal in nature, flows in monsoon months only. The river is intermittent since i.e. stream flow falls to zero most of the time, especially during non-monsoon period. It is one of the driest watersheds of the Bhima basin classified under drought-prone zone. The area of Karha basin catchment extracted from RINSPE Model is 1334 km^2. The commencement of the hydrologic year for the Karha basin in the month of June, when groundwater is at its lowest water level. The location map of the Karha basin is shown in Fig. 1.

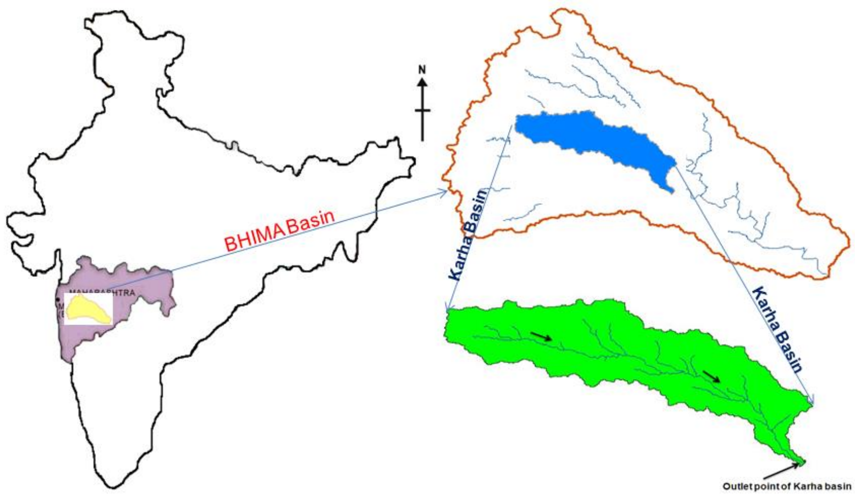

Figure 1 : Location Map of Karha Basin

3. MATERIALS REQUIRED

GIS based runoff and infiltration estimation from RINSPE Model using NRCS Curve Number (CN) method normally requires the following spatial and non-spatial inputs:

- ✓ Land use / Land cover Map
- ✓ Soil Type/Hydrologic Soil Group Map
- ✓ Rainfall Distribution Map
- ✓ Values of CN for each type of Land use / Land cover
- ✓ Values of Initial Abstraction or Initial Losses for each type of Land use / Land cover

3.1 Preparation of Input Data

3.1.1 Preparation of Land Use-Land Cover(LU/LC) Map

This study mainly dealt with estimation of runoff with different temporal resolution of the Land use/ Land cover maps. For this LU/LC data a request has been made for BHUVAN-ISRO web site [14] for the year 2004-05 and 2013-14. The required data has been supplied through the user email and was down loaded. The LU/LC map supplied having decimal degree coordinate system. It was clipped/sub-set in ArcGIS environment using the Water Management Area (WMA) boundary of the Karha catchment (Figure 1) and later it was projected to UTM projection by specifying a grid cell size of 24 m using 'Project Raster' command in ArcGIS environment for accurate volume calculations.

3.1.2 Land Use-Land Cover Map - 2004-05:

The Land use-Land cover map supplied by BHUVAN-NRSC classified into 13 types in karha basin. The maximum area of 557.53 sq. km covered under current fallow, which is 42 % of the total area. And the minimum and least area of Evergreen forest class covered with 0.003 sq. km area which is a very least percentage of the area covered in the Karha basin in the year 2004-05. In Karha basin all types of crop fields having an area of 518.88 km^2 and all Forest types having an area of 0.623 km^2. The Land use-Land cover map of 2004-05 is shown in Fig. 2

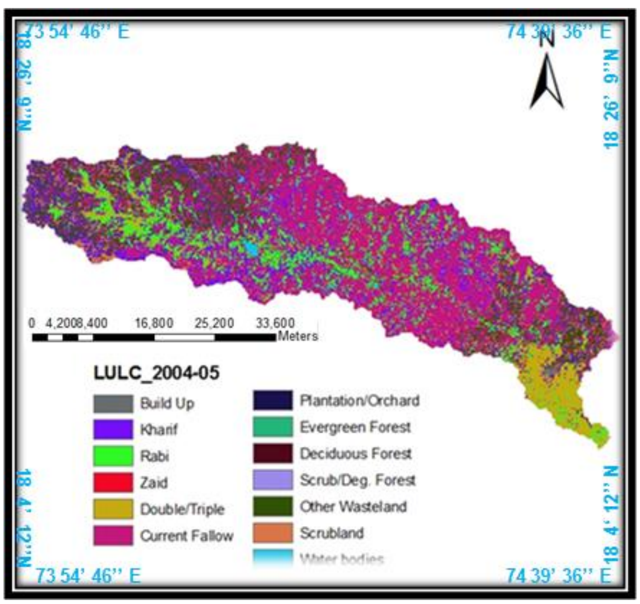

Figure 2: Land Use-Land Cover Map of 2004-05

3.1.3 Land Use/Land Cover Map - 2013-14:

The BHUVAN-NRSC classified map covered under 13 types similar to the 2004-05 classified map in karha basin. The maximum area of 590.64 sq. km covered under current Fallow, which is 44% of the total area. And the minimum and least area of 0.003 km^2 covered which is similar to 2004-05 Land use-Land cover map. The Land use-Land cover map of 2013-14 is shown in Fig. 3.

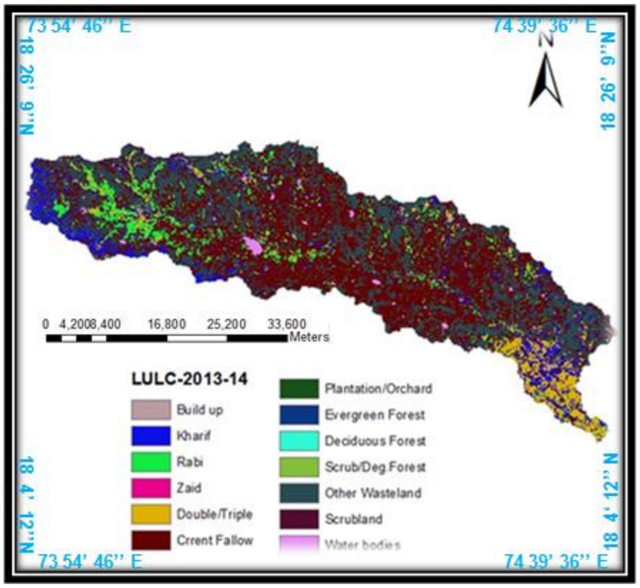

Figure 3: Land Use-Land Cover Map of 2013-14

3.1.4 Comparison of Land Use- Land Cover Maps - 2004-05 & 2013-14:

From the analysis of both Land use-Land cover maps, it is evident that all forest types identified in smaller quantity. Also there is nil variation of area in Deciduous forest and Evergreen forest after a 10 years period of gap (2004-2013) between both LU/LC maps and remaining all types of classes are varied in small to larger in quantity. A huge variation in areas is identified between both LC/LC maps from Kharif, Rabi & Other Wasteland type of land cover classes. In 2004-05, higher area of 230.26 km^2 of Kharif crop and in 2013-14, Other Wasteland has highest area of 419.09 km^2 are identified. The lowest areas of 0.003 km^2 evergreen forest identified from both the years. The discrimination of areas between 2004-05 & 2013-14 Land use-Land cover maps shown in Fig.4.

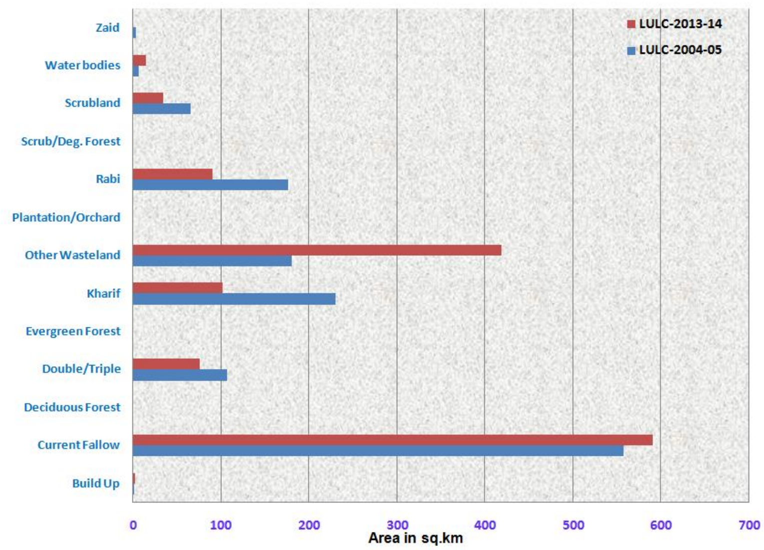

Figure 4: Area comparison graph of LU/LC classes between 2004-05&2013-14

3.2 Preparation of Soil Map:

The soils data used to run RINSPE Model was downloaded from the U.S. Department of Agriculture"s (USDA) Food and Agricultural Organization (FAO) database [15] and specifications are necessary before the data can be loaded into RINSPE Model. After writing the correct soil texture descriptions from the Land Type data attribute table, the sub menu "Assign Hydrologic Soil Group (HSG) Types (A, B, C, and D" was run to assign the HSG types to different textures and later sub menu called Assign Hydrologic Soil Group Codes (A, B, C, and D) was run to assign the HSG code values of 1 to 4 to HSG types A, B, C and D. The karha basin has 854 km^2 area covered under Hydrologic Soil Group (HSG) of C, HSG of B covered an area of 268 km^2, and 175 km^2, 9.14 km^2 area under A and D. The study area of Karah basin covered a highest percentage of 65% contains HSG of C and least percentage of 0.7% contains HSG of D type. After assigning the HSG code values, the vector data was converted to a grid of HSG types by running the sub menu called "Hydrologic Soil Group Code Grid Map Preparation". The model predicted HSG grid map is shown in Fig. 5.

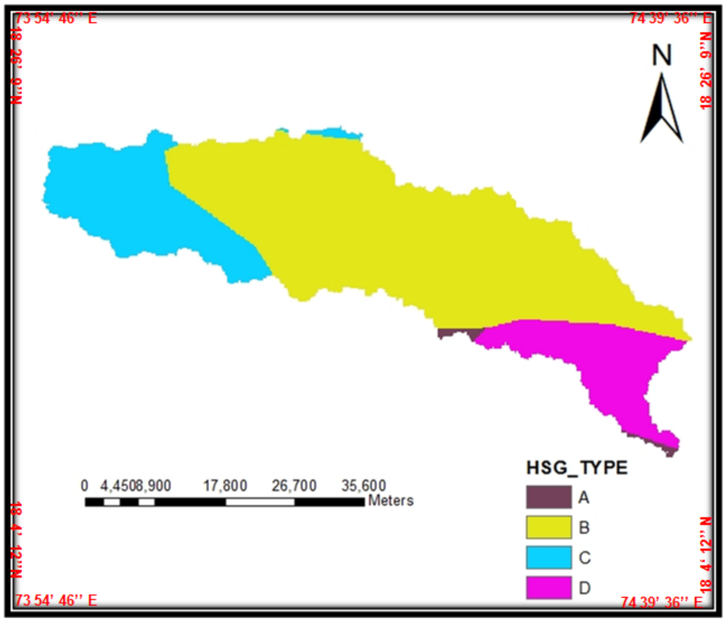

Figure 5: Soil Map of Karha Basin

3.3 Preparation of Rainfall Map:

There are 8 rain gauge stations identified in Karha basin, and prepared shape file by indicating each gauge location in the basin. After preparation of a rainfall data for each station, the shape file is converted in to a raster map using raster calculator in spatial analyst tools. This point map of rainfall is interpolate to raster map using Inverse Distance Weighted (IDW) method and converted into a grid map. The prepared grid map of Rainfall distribution is shown in Fig.6.

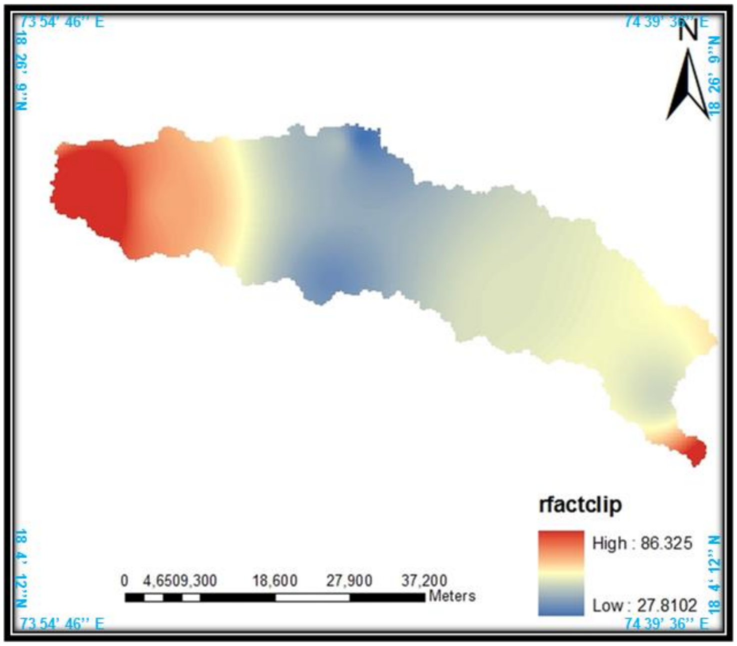

Figure 6: Rainfall Distribution Map of Karha Basin

3.4 Values of Curve Number (CN) and Initial Abstraction or Loss (Ia)

The input values of CN and Ia were identified for the different Land use - Land cover types and HSG combinations through a literature search done on the Internet and from other means/sources [16]. The Curve-Number (CN) values and its corresponding Initial Abstraction (Ia) values are entered in excel sheet with specified names. The excel file is saved as 'Text (Tab Limited)' format to get a text file. These text files are given as input when ever required in the process of RINSPE model run.

4.0 METHGODOLOGY

In this study, GIS based model for estimating runoff and infiltration from two different years Land Use/ Land Cover types was developed using 'Runoff, Infiltration and Non-Point Source Pollution Estimation' so called 'RINSPE' model. The model was developed taking into consideration that the model needed to be sophisticated enough to account for the routing of all precipitation in the form of surface runoff, infiltration and pollution loading. In order to estimate these parameters, some suitable method for estimating the areal distribution of rainfall losses through infiltration and runoff had to be chosen first in designing the model. In many runoff–infiltration assessment studies, the methods commonly used are the rational method, Curve Number (CN) method, Horton's model for infiltration capacity and the Green Ampt infiltration model [17].

It was decided to use the NRCS-Curve Number (CN) method for a quick estimation of runoff and infiltration taking place in the identified study area. The NRCS curve number method is an empirical description of infiltration. It combines infiltration with initial losses (interception and detention storage) to estimate the rainfall excess, which would appear as runoff. It is important to note that surface runoff and infiltration in any location can be estimated through the following equation:

$$\text{Surface Runoff} = \text{Rainfall} - \text{Initial abstraction} - \text{Infiltration}$$

This model is relatively simple requiring few input parameters, and has been widely applied in the fields of soil physics and hydrology [18]. The method is an empirically based one, and is applicable to the situation in which amounts of rainfall, runoff, and infiltration are of interest [19]. According to the Soil Conservation Service National Engineering Handbook Section 4 [20] (Chapter 10-Estimation of Direct Runoff from Storm Rainfall) the curve number is based on water balance equation and two assumptions. The water balance equation is:

$$P = Q + F + Ia \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (I)$$

Where,

P is rainfall depth;

Q is direct runoff depth;

F is actual retention after runoff begins

Ia is initial abstraction.

First hypothesis states that the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual retention to the amount of the maximum potential retention. Mathematically, the above can be written as follows:

$$F/S = Q/ P-Ia \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (II)$$

ISSN: 2455-6653
Journal of Applied Science

Now comparing eqs I & II we see two parameters S & Ia which are unknown. To remove the necessity for estimating both these parameters, the US Soil Conservation Service suggested a linear relation. It is written as follows:

$$Ia = \lambda * S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(III)}$$

Where, λ is the initial abstraction ratio & S is soil storage index or maximum soil potential retention. The NRCS suggested a standard value of $\lambda = 0.2$. and the NRCS - Curve Number basic equation is as follows:

$$Q = (P-0.2S)^2 / P+0.8S \qquad \text{For } P \geq 0.2S\ldots\ldots\ldots \text{(IV)}$$

$$Q = 0 \qquad \text{For } P \leq 0.2S\ldots\ldots\ldots \text{(V)}$$

For the ease, S is mapped into a dimensionless parameter Curve Number (CN). CN varies in the range of 0 to 100. If S is in inches, the equation is written as follows:

$$CN = 1000 / 10+S\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots \text{(VI)}$$

The runoff derived by SCS-CN method is a function of runoff potential which can be expressed in terms of the runoff coefficient (ratio between the runoff and rainfall) which can be classified into three classes, viz., high (>40%), moderate (20–40%) and low (<20%). The watershed curve number serves as a substitute for soil storage index S. The CN method of estimating runoff volumes from rainfall is simple and easy to use. It is being used in a wide range of design situations by the practicing engineers and hydrologists. There appears to be no regional variation in CN for the same cover type. However, the lack of data may be influencing this conclusion. There appears to be seasonal variation in certain forested CN, which may reflect either seasonal moisture or leafing stages in hardwood [21]. The whole methodology applied in RINSPE model is given in the form of flow chart as shown in Fig.7

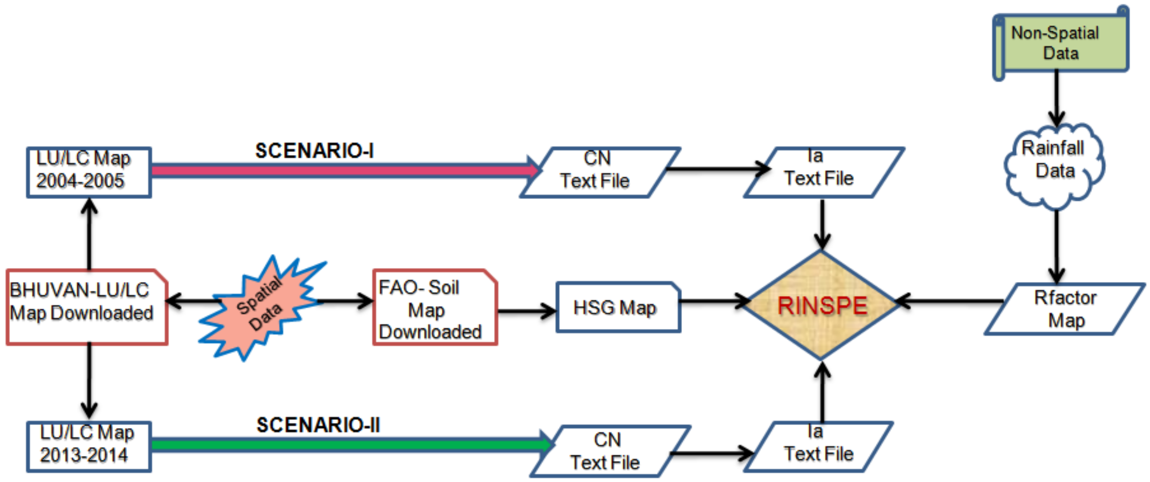

Figure 7: Flow chart of Methodology

4.1 Over View and Working with RINSPE Model

Using ArcView GIS version 3.2 and its extension Spatial Analyst a 'Runoff, Infiltration and Nonpoint Source Pollution Estimation'(RINSPE) Model (Fig.8) was developed for estimating runoff, infiltration and nonpoint source pollution in the Kuils Eerste river catchment [22]. With this model, using digital elevation data, land use/ land cover type grid data and rainfall data together with attribute tables covering chemical characteristics, surface water runoff and pollutant loading in surface runoff waters was calculated and various maps displaying the distribution of these parameters were generated. Due to the paucity of data regarding the controlling parameters and because of the complexities involved in assessing surface water bodies, a pragmatic approach was adopted for the estimation of runoff volume for a catchment scale assessment. In this model, the runoff volume from different land cover types is estimated and the important factors that can control surface runoff within the catchment are identified as: i) hydrologic soil group type; ii) land use / land cover type, iii) antecedent moisture conditions and iv) initial loss or initial abstraction. Each factor is accounted for in the model. The first three factors have a direct relationship with the surface runoff.

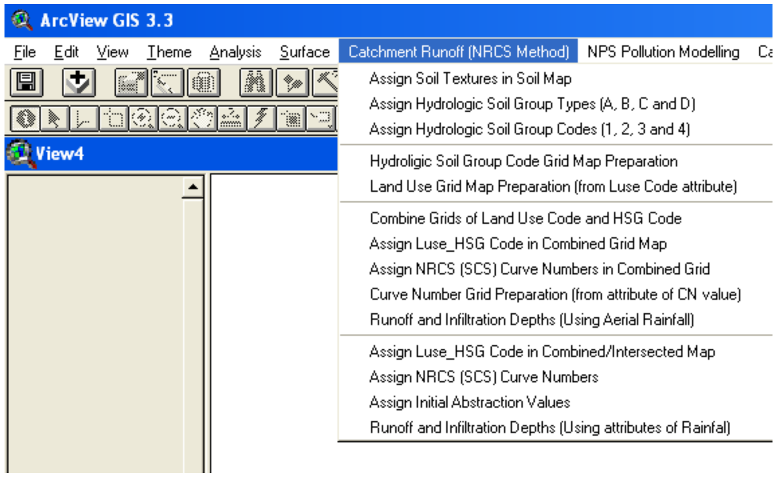

Figure 8: Over view of RINSPE Model

Using land use and soil hydrologic group themes, a map showing the area under various land uses on different hydrologic soil groups is generated by intersecting/combining these two maps with the GIS. A curve number value is assigned for each unit of this map, which leads to the preparation a runoff curve number map. The hydrologic soil group map can be generated by reclassifying the various soil units or lithological units (as defined by geological map) based on their drainage potential (textures of the sediments). The runoff and infiltration depths are calculated from the rainfall grid using the assigned CN values and initial abstraction values. RINSPE has been developed with land use data specific to the Western Cape Province of South Africa, and very little user interaction is required to run a basic analysis for this area. However, applying the tool in other regions may require the preparation of land use input data in the required format.

5.0 MODEL RESULTS AND DISCUSSIONS

The temporal resolution of Land use-Land cover map as the basis for this studies and prepared all the necessary input data to perform 'RINSPE' model in 2 scenarios.

Scenario-I: A land use-land cover map for 2004-05 was consider as one of the input data along with other data, the model was run and the spatial distribution of runoff volume obtained as shown in Fig: 9.

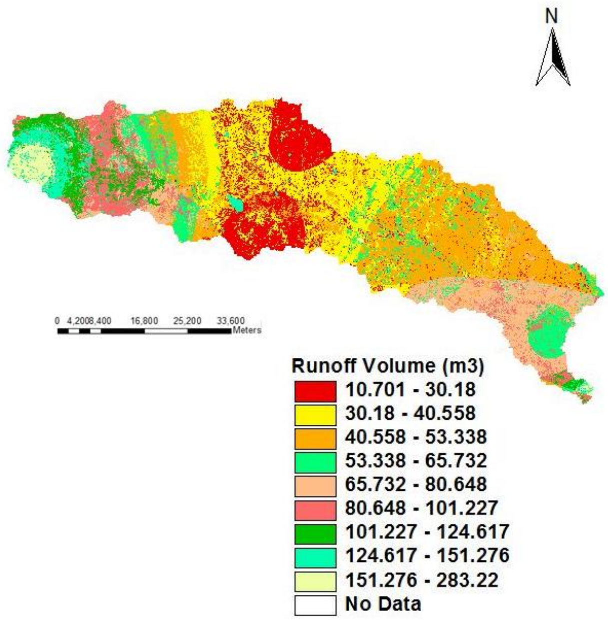

Figure 9: RINSPE Model results for Scenario-I

The results reveals that the highest runoff depth obtained 32.59 mm from Evergreen Forest, and the least runoff depth of 12.28.mm obtained from Current Fallow. The Land use–Land cover class of Build Up is the 2nd highest runoff depth of 28.38 mm and the 2nd lowest runoff depth of 13.20 mm obtained for Scrubland. The lowest area of Evergreen forest, highest area of Current Fallow has delivered 44.66 % and 29.14 % runoff. The RINSPE model predicted Hydrological components of Rain, Infiltration loss, Initial loss and Runoff for Scenario-I are shown in graphical form in Fig.10

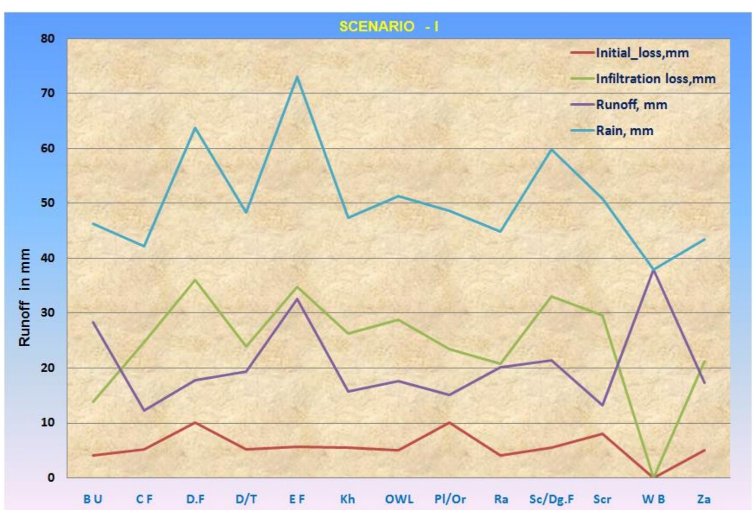

Figure 10: RINSPE Model Results–Scenario-I

Scenario-II: Similarly, a land use-land cover map for 2013-14 was consider as another input data along with soil, rainfall and attribute data of 'CN' value and 'Ia' value data, the model was run and the output graphical representation of results obtained was shown in Fig: 11

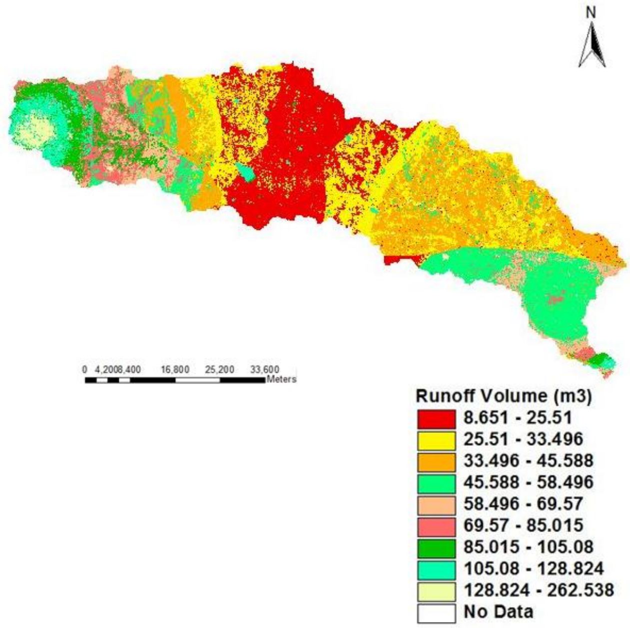

Figure 11: RINSPE Model results for Scenario-II

From scenario-II, the highest runoff depth occurred from Evergreen forest as the case of scenario-I of 32.59 mm. The minimum runoff depth of 12.80 mm occurred from Current Fallow land similar to scenario-I. Build Up land is the second highest runoff depth given of 28.54 mm and Other Waste land is the second lowest runoff delivered of 13.42 mm. The RINSPE Model results by using 2013-14 Land use-Land cover map for Scenario-II is prepared in graphical form and shown in Fig.12.

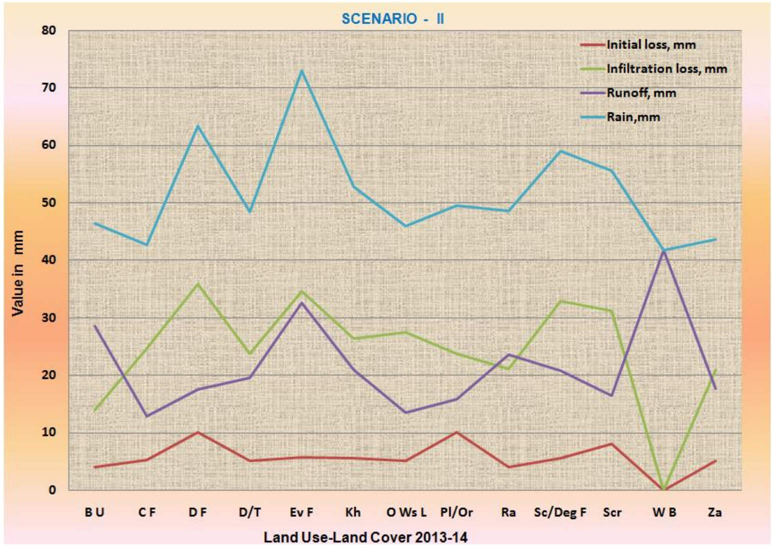

Figure 12: RINSPE Model Results –Scenario-II

The over-all results obtained at temporal resolution of 10 years of Land use-Land cover maps from both scenarios are compiled and tabulated in the form of Table 1as given below.

Table 1: RINSPE Model Results of Scenario-I & II

LULC_TYPE	AREA, sq.km		RAIN, mm		Initial Loss, mm		Infiltration loss, mm		Runoff, mm	
	2004-05	2013-14	2004-05	2013-14	2004-05	2013-14	2004-05	2013-14	2004-05	2013-14
Build up	2.56	2.61	46.22	46.5	4	4	13.83	13.95	28.38	28.54
Fallow	557.53	590.64	42.15	42.72	5.2	5.2	24.67	24.72	12.28	12.80
Deciduous Forest	0.39	0.39	63.7	63.38	10	10	35.96	35.88	17.73	17.49
Double/Triple	107.2	76.22	48.35	48.4	5.1	5.1	23.86	23.79	19.38	19.51
Evergreen Forest	0.003	0.003	73.0	73.0	5.7	5.7	34.7	34.70	32.59	32.59
Kharif	230.26	102.0	47.36	52.74	5.5	5.5	26.15	26.33	15.71	20.90
Other Wasteland	180.54	419.09	51.35	45.96	5	5	28.75	27.54	17.60	13.42
Plant/Orchard	0.7	0.61	48.55	49.52	10	10	23.41	23.78	15.14	15.73
Rabi	177.10	90.74	44.84	48.64	4	4	20.71	21.09	20.13	23.54
Scrub/Deg.Forest	0.22	0.17	59.74	59.07	5.5	5.5	32.9	32.87	21.34	20.69
Scrubland	66.14	35.2	50.75	55.56	8	8	29.55	31.22	13.20	16.33
Water bodies	7.5	15.56	37.93	41.78	0	0	0.0	0.0	37.93	41.78
Zaid	4.32	1.49	43.42	43.72	5	5	21.16	21.01	17.25	17.70

The total runoff depth from Scenario-I & Scenario-II observed as 268.63 mm and 281.02 mm and the corresponding Infiltration was 315.65.mm, 316.88 mm and initial loss was 73 mm. The rainfall varies from scenario-I to scenario-II. Because of its corresponding areas occupied by land-cover classes are different from 2004-05 to 2013-14. The table result reveals that the runoff depth is inversely proportional to its corresponding areas occupied by each LU/LC types. The runoff depths for different land use-land cover classes are shown in Fig. 13. It is observed that, there are four verities of crops covered in 2004-05 & 2013-14 land use–land cover map. The larger area of 518.88 km^2 area from 2004-05 LU/LC map and the lower area of 270.45 Km^2 from 2013-14 LU/LC map and its corresponding total runoff depth of 72.47 mm & 81.65 mm from RINSPE model results. As stated earlier, Forest types are the lowest areas covered for both 2004-05&2013-14 land use-land cover classes. The total areas and its corresponding runoff depths are 0.613 km^2 & 71.66 mm for 2004-05 LU/LC map and 0.563 km^2 & 70.77 mm for 2013-14 LU/LC map.

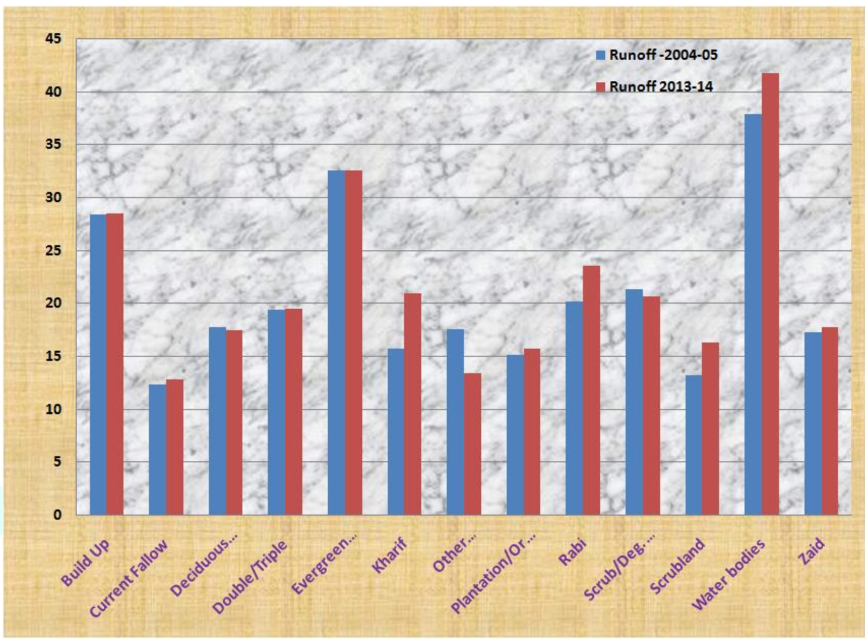

Figure 13: Runoff Depths for 2004-05 & 2013-14

6.0 CONCLUSIONS

The RINSPE Model run with two different spatiotemporal land use-land cover maps at 10 year variation of 2004-05&2013-14. The total runoff of 268.63 mm by running RINSPE model with 2004-05 land use-land cover map. After 10 years 0f 2013-14 land use-land cover maps results a total runoff of 281.02 mm obtained from the model. A slight variation in infiltration loss from both years of land use-land cover maps. A higher percentage of 61.4% runoff obtained from Build Up land and a lowest percentage of 26.01% obtained from

Scrubland using 204-05 land use-land cover map. A lowest percentage of 29.94% and a highest percentage of 58.3% of infiltration occurred from Build-up and scrubland.

In case of 2013-14 land use-land cover map, Build up land deliver a higher percentage of 61.39% runoff, a lowest percentage of 27.64% from Deciduous Forest. The average percentage of all forest types deliver 35.76% of runoff and 42.21% of runoff from all types of crop fields. A lowest percentage of 30.01% and a highest percentage of 59.92% of infiltration occurred from Build up land and other waste land types from 2013-14 land cover classes. A higher percentage of runoff obtained from Forest categories of 2004-05 land cover class, and highest percentage of runoff obtained from all crop land types from 2013-14 land cover classes. Though, there is abrupt increase in area of 238.55 km^2 of Other Wasteland type from 2004-05(180.54 km^2) to 2013-14 (419.09 km^2) land cover maps, there is no proportionate increase in runoff for a period of 10 years. Similarly a decrease in area of Kharif crop from 2004-05 (230.26 km^2) to 2013-14 (102 km^2) by 128.26 km^2, there is a little variation of runoff occurred by 5.19 mm only. From both land use-land maps, current Fallow has the highest area (Table 1) in karha basin, which derives a low runoff depth from both years. Finally, with the spatial information and GIS technology enables to design RINSPE model and it is useful for estimation of hydrological parameters. The Temporal Resolution of Land Use-Land Cover maps utilized for evaluation of impact on hydrological components for design engineers and hydrologists.

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude to Dr. Abraham Thomas, South Africa, for make availability of software and clarification of doubts during the course of running the model and also I would to thank ISROs Geoportal gateway of India for in time supply of digital LU/LC maps by BHUVAN-NRSC to carry out this investigation successfully.

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