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Development of GIS based Decision Support System for Estimation of Watershed Surface Runoff

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SUMMARY

Runoff from rainfall is an important component of the hydrological cycle. Estimation of runoff is critical for the design of hydrological structures and drainage systems in watersheds. Different soils, land use and water management practices affect runoff differently. In real watersheds, land use, soils and weather conditions vary spatially over the geographical area of the watershed leading to spatial variations in runoff. Also, most watersheds form a part of larger drainage basin or a large watershed consisting of several such sub-watersheds. Each sub-watershed is hydrologically connected to the other sub-watersheds of the basin. A comprehensive Geographical Information System (GIS) based decision support system (DSS) for estimation of runoff that includes the spatial variations in rainfall and natural resources is presented. A DSS is a computer-based information system which serve the management, operations, and planning levels of an organization and help people make decisions about problems that may be rapidly changing and not easily specified in advance. The DSS is developed as a deployable application by integrating independent GIS layers of watershed features created in ArcGIS with MapObjects in Visual Basic software, as a case study for the KK3 watershed in Mahaboobnagar district of Telangana state, India. The DSS generates thematic maps of spatial variations in runoff on individual rainy days for the sub-watersheds.

Keywords: GIS based DSS, GUI, Land use, Rainfall, Remote sensing, Runoff, Soil, Sub-watershed, Watershed.

1. INTRODUCTION

A watershed is considered as an ideal unit for the management of natural resources in achieving sustainable development (Sarma and Saikia 2012). Many decisions associated with watershed management are based on controlling various hydrologic processes that occur over it, principally runoff. Different soil, land use, and water management practices affect runoff differently. Runoff is a complex, temporally and spatially variable process, and is influenced by many factors (Shah *et al*. 1996, Chaubey *et al*. 1999a, 1999b). In most real watersheds, land use, soils and weather conditions vary spatially over the geographical area of the watershed. Also, most watersheds form a part of larger drainage basin or a large watershed consisting of several such sub-watersheds. Each sub-watershed then drains to a single outlet on a stream, which is a part of the basin's drainage network and is hydrologically connected to the other sub-watersheds of the basin through this network (Moore and Hutchinson 1991). A comprehensive decision support framework that can assist in watershed management decision making must include these spatial variations in resources and hydrologic processes. In recent years GIS and remote sensing tools has facilitated the estimation of runoff from watershed and gained increasing attention among the researchers and policy makers. Hydrological modeling in GIS with the aid of remote sensing technology is a powerful tool of system investigation for run off generation in geo-hydrologic environment. Use of these advanced tools along with process based hydrologic models and empirical approaches have made the surface runoff estimation more accurate and less cumbersome (Thakuriah and Saikia 2014, Patil *et al*. 2008). By using these technologies, there are several models available for estimation of run off such as, Rangeland hydrology and erosion Model, NAM rainfall-runoff model, HECHMS etc., (Chakraborti 1991, Biswas *et al*. 1999, Shrestha 2003, De *et al*.

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2005, Martin *et al*. 2005, Nooka Ratnam *et al*. 2005, Arun *et al*. 2005, Hernandez *et al*. 2000, Jetten 2002, Zhang *et al*. 2011, Billa *et al*. 2011, Hegedus *et al*. 2013, Ghoneim and Foody 2013, Alfugura *et al*. 2011) which offer quantitative simulations of the surface runoff depth based on a certain amount of rainfall. However, these models are generally conceptual and complex in nature and difficult for an ordinary user to operate without specific skills or training. In this context, it is contemplated to develop a less complex and user friendly model with graphical user interface platform.

The objective of this study is to present the development of a GIS based DSS for the assessment of spatial distribution of surface runoff. The DSS is developed as a deployable application by integrating independent GIS layers of watershed features created in ArcGIS with MapObjects in Visual Basic (VB) software, for the study area.

2. STUDY AREA

The KK3 Macro watershed is located in Pedalakothapalle, Kodair and Gopalpet mandals of Mahaboobnagar district of Telangana State, India. The geographical extent of the watershed is covered in part by three Survey of India (SOI) top osheets numbers viz.,56 L-6, 56 L-7 and 56 L-11and were used as source data for various parameters of the watershed at 1:50,000 scale. The study area lies between 78º 15' E to 78º 35' E longitude and 16º 20' N to 16º 35' N latitude. The watershed has an aerial extent of 452 km^2 (Fig.1).

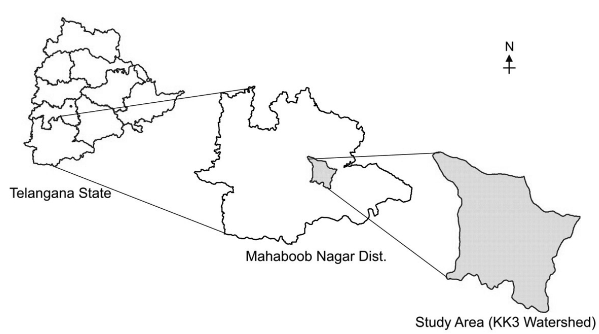

Fig. 1. Location map of the study area

The average annual rainfall of the watershed is 633 mm. The drainage pattern in the study area is dentritic to sub-dentritic at higher elevations and from parallel to sub-parallel at lower elevations. Based on the drainage orders, the KK3 watershed has been classified as fourth order basin and the runoff water is draining into the Dindi River (Fig.2).

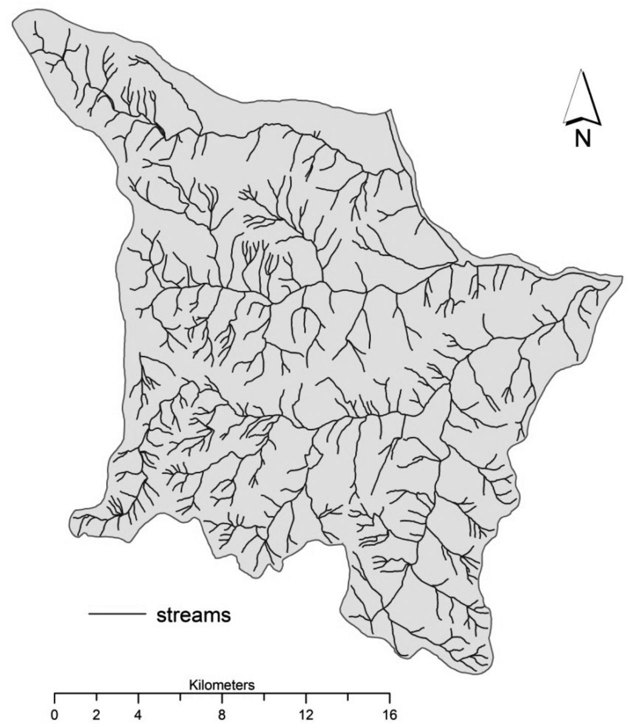

Fig.2. Study area stream network

Most of the study area is covered by Clayey and Clayey Calcareous soils. Granite and Granite- Gneiss rocks predominantly underlie the watershed area, which are medium to coarse in texture. These rocks are exposed as high hill ranges, linear ridges and domes in many places of the watershed.

Climate of the study area is characterized by hot summer and is generally dry except during Southwest monsoon season (June-September). From February, both day and night temperatures begin to increase steadily. May is the hottest month with mean maximum daily temperature of 40^{o}C. With the onset of South–West monsoon into the district early in June there is an appreciable drop in temperature and weather becomes pleasant. There is a considerable drop in temperature in the beginning of November with the mean daily temperature at 29^{o}C.

Main occupation of the people is Agriculture, which is dependent on the vagaries of monsoon. It is reported that three out of five monsoon years are subnormal with deficit ranging from 25-35 percent below normal rainfall. The rainfall is erratic and does not uniformly get distributed to suit crop growth period and crop water requirement. Long dry spells lasting 3-4 weeks are not uncommon. As a consequence, crops are subjected to severe moisture stress resulting in low and unpredictable yields.

3. MATERIALS AND METHODS

To begin with the DSS and making estimation of runoff, one needs some basic data as input. The flow chart for runoff computation and thematic mapping for a particular rainy day is given in Fig. 3a, 3b, 3c, 3d and 3e.

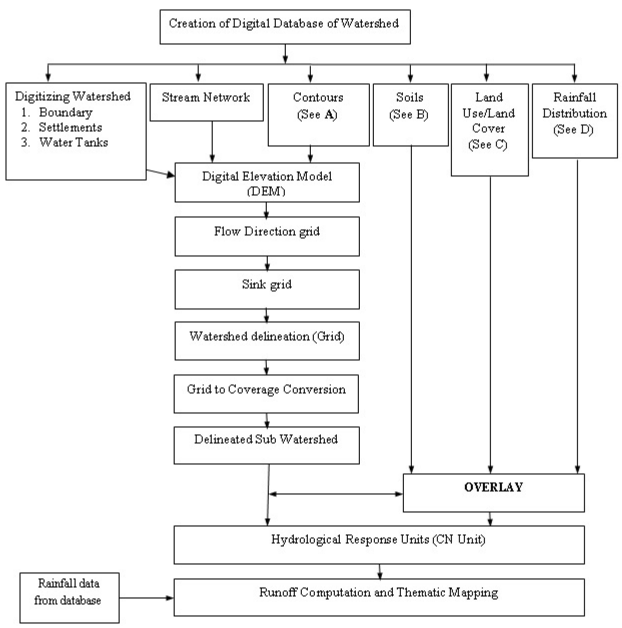

Fig. 3a. Project flow chart

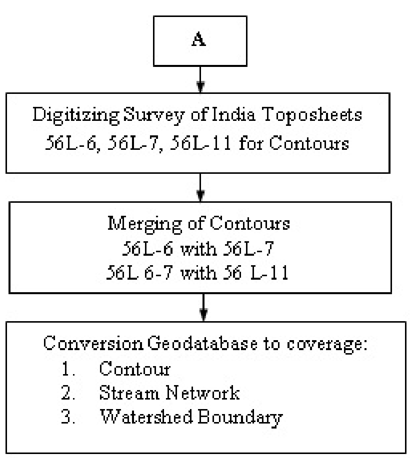

Fig. 3b. Project flow chart

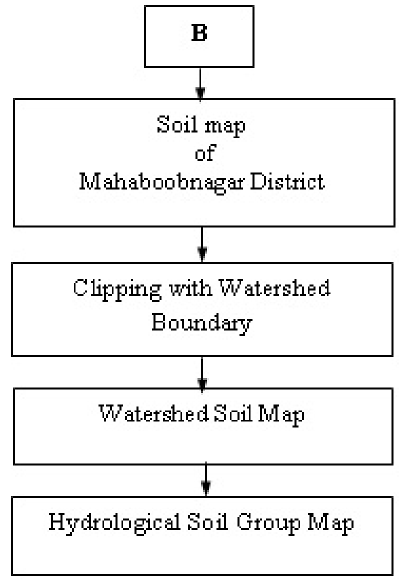

Fig. 3c. Project flow chart

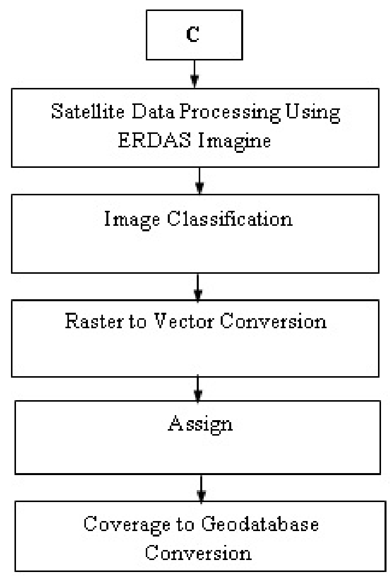

Fig. 3d. Project flow chart

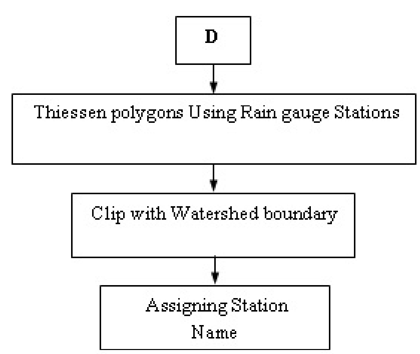

Fig. 3e. Project flow chart

The KK3 watershed has been delineated based on the water divide line concept. The stream network and contour layers were prepared based on the topographic maps on a 1:50,000 scale for the watershed study area. Since the KK3 watershed falls in three toposheets(1:50,000), the contour feature and boundary feature classes of above toposheets were merged using Edge Match method using Arc GIS.

Location	The KK3 Macro Watershed is in Pedalakothapalle, Kodair and Gopalpet mandals of Mahabubnagar district of Telangana, India.
Streams	The watershed has a well-defined stream network draining the precipitation into the Dindi River. These streams are digitized using SOI top sheet 56 L-6, 56 L-7 and 56 L-11
Soils	Clayey and Clayey Calcareous soils are predominant in the watershed. Source for Soils map of the Watershed is the Soil map of Mahabubnagar district. Granite and Granite-Gneiss rocks predominantly underlie the watershed area, which are medium to coarse in texture. These rocks are exposed as high hill ranges, linear ridges and domes in many places of the watershed. Data purchased from ICAR-NBSSLUP
Agriculture	Main occupation of the people is Agriculture, which is dependent on the vagaries of monsoon. It is reported that three out of five monsoon years are subnormal with deficit ranging from 25-35 percent below normal rainfall.
Climate	The rainfall is erratic and does not uniformly get distributed to suit crop growth period and crop water requirement. Long dry spells lasting 3-4 weeks are not uncommon. As a consequence, crops are subjected to severe moisture stress resulting in low and unpredictable yields. Climate of the study area is characterized by hot summer and is generally dry except during Southwest monsoon season (June-September). From February, both day and night temperatures begin to increase steadily. May is the hottest month with mean maximum daily temperature of 40 degrees. With the onset of South –West monsoon into the district early in June there is an appreciable drop in temperature and weather becomes pleasant. There is a considerable drop in temperature in the beginning of November with the mean daily temperature at 29º C. India Meteorological Department (IMD) Daily weather data from year 1960 to 2000 has been used in this study.

3.1 Weather Data

Rainfall data of the three rain gauge stations (Nagarkurnool, Tadur and Telkapalli) covering the Study area was assembled in an external database in MSAccess. Based on Rain gauge point feature class, rain gauge thiessen polygons feature class were generated using Spatial Analyst techniques in Arc GIS.

3.2 Digital Elevation Model (DEM)

In the process of delineating the watershed using ArcGIS Workstation, initially DEM (20-meter resolution) was generated using the Boundary of the watershed. The resultant watershed is in raster format, and the same was converted into vector format for computation of runoff assessment. The above defined watershed was further delineated as sub watershed with 500 ha as threshold value; and the study area was divided into 10 sub watersheds based on rain gauge stations (Fig. 4).

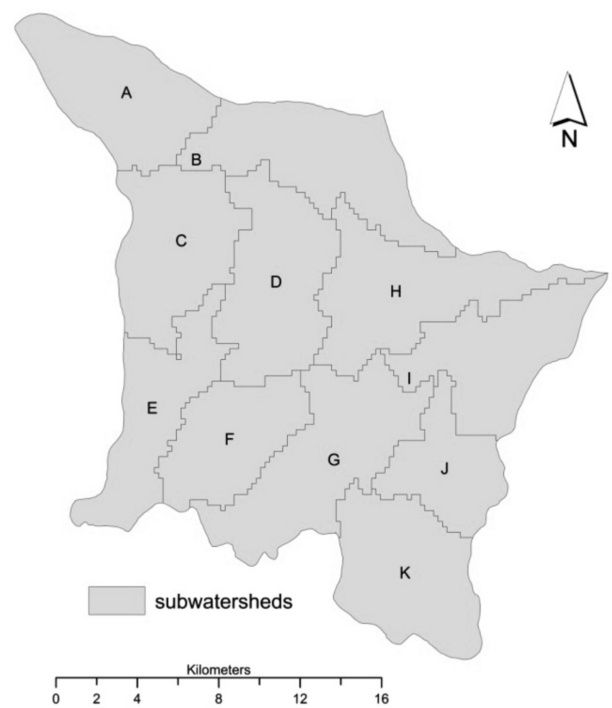

Fig. 4. Classified 10 sub watershed area map

3.3 Soil and Land Use Data

Soil map of watershed was extracted from soil map of Telangana State (Project Report 2006). Based on IRS LISS III Image, landuse and land cover (LULC) were prepared and classified into four classes viz., Dense Vegetation, Sparse Vegetation, Waste land and Water Bodies using ERDAS Imagine software. For this study, unsupervised classification with K-means algorithm has been used for better results. In the study area soils are classified into hydrologic soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The Curve Number Method (CN) for a drainage basin is estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC).

3.4 Estimation of Surface Runoff

The natural resources conservation services curve number method is one of the most widely used methods for quick and accurate estimation of surface runoff from ungauged watersheds (Patil *et al*. 2008). The interface for surface runoff estimation using curve number techniques was written in Visual Basic for Applications (VBA) programming language, which is the built-in macro programming language for ArcGIS. The runoff was calculated using the following formulas.

$$Q = \frac{(P - Ia)^2}{[(P - Ia) + S]}$$

Where

Q = runoff (mm)

P = rainfall (mm)

S = potential maximum retention after runoff begins (mm) and

Ia= initial abstraction (mm)

Initial abstraction (Ia) includes all water that is lost before runoff begins, and includes water that is retained on the surface in depressions and water that is held by vegetation. It also includes evaporation and infiltration. Studies of many small watersheds have shown that Ia can be approximated by $Ia = 0.2 * S$. The potential maximum retention storage S of watershed is related to a CN, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. The CN is dimensionless and its value varies from 0 to 100.

In the process of deriving curve number, initially hydrological response units are derived by applying spatial analysis techniques for the layers Soils, Land Use Land Cover and thiessen polygon of rainfall distribution. Finally, curve numbers derived for the available classes of the study area based on the Hydrological methods for runoff assessment as shown in the following table.

CN Value Table

	Soil Group			
Class Name	A	B	C	D
Dense Vegetation	65	75	82	86
Sparse Vegetation	70	79	84	88
Waste Land	71	80	85	88
Water Bodies	100	100	100	100

The S value in mm can be obtained from CN by using the relationship

$$S = \left(\frac{25400}{CN\_Value}\right) - 254$$

Calculating runoff volume in cubic meters

$$= (Q * (Shap\_Area)/1000)$$

3.5 Graphical User Interface (GUI)

The GUI for watershed surface runoff assessment was developed using VB as front end with MS Access database as backend. This GUI environment helps to enter, edit or update the rainfall database besides links to general information about the DSS. The GIS based Watershed runoff assessment GUI system is user friendly, and it further simplifies the user's interaction by using visual elements such as dropdown menus, buttons, scroll bars, windows and dialog boxes.

The DSS is made available as a deployable application so that users can dynamically update the rainfall data, and assess the variations in runoff and its spatial distribution over the past or current seasons. The present DSS framework can function as the starting point for design of soil and water conservation structures and evaluating the impact of alternate land use and watershed management decisions.

3.6 Main Functions of DSS

The main functions of DSS are given below:

1. Estimation of daily runoff depth for Hydrological Response Unit (HRU) based on user selected date.
2. Estimation of daily runoff volume for each sub watershed.

3. Estimation of monthly and seasonal runoff depth and weighted average rainfall for a selected year for each sub watershed.
4. Generation of monthly and seasonal time series for runoff and rainfall for the sub watershed.

4. RESULTS AND DISCUSSION

Area of watershed spread across the three mandals *viz.,*Pedalakothapalle, Kodair and Gopalpet of Mahaboobnagar district, Telangana state, India. The spread areas in these mandals are 15.38, 55.11 and 29.51% respectively. These mandals are classified into 10 sub watershed areas based on rain gauge stations and the area covered in these sub watersheds are given in Table 1. The previous five days' average rainfall data was collected from above mandals is 44.6mm, 66.0 mm and 40.0 mm respectively (Fig. 5). The study area soils are classified in to four categories *viz.,* Clayey, Clayey Calcareous, Cracking Clay Calcareous and Gravelly loam and constitutes 0.63, 0.28, 0.08 and 0.005% in watershed respectively (Fig. 6; Table 2).

Table 1. Sub-watershed wise occupied area in sq.km

Classified sub-watershed	Area in sq.km	Area in %
A	40.52	8.96
B	43.11	9.53
C	98.34	21.75
D	45.79	10.13
E	33.46	7.40
F	48.87	10.81
G	42.07	9.30
H	43.16	9.55
I	28.05	6.20
J	28.74	6.36

Table 2. Type of soils covered in the study area

Soil type	Area in sq.km	Area in %
Clayey	284.94	0.63
Clayey Calcareous	128.85	0.28
Cracking Clay Calareous	36.15	0.08
Gravelly loam	2.22	0.005

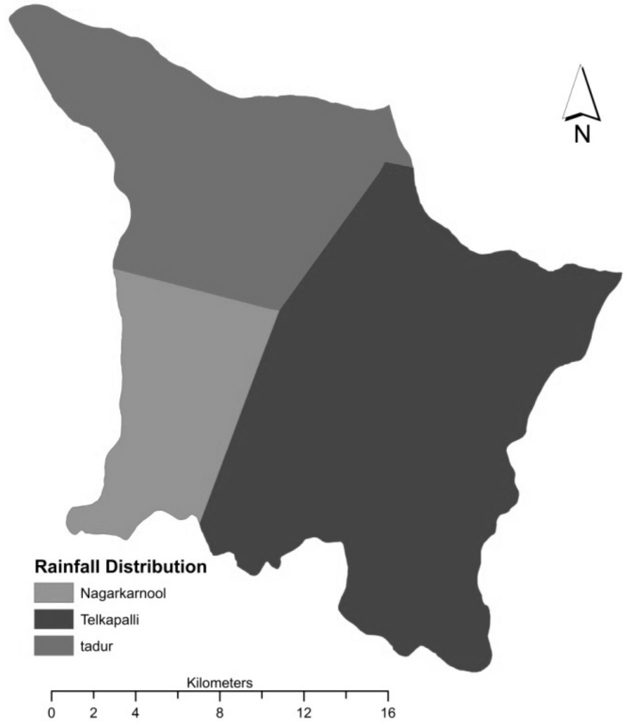

Fig.5. Study area rainfall distribution map

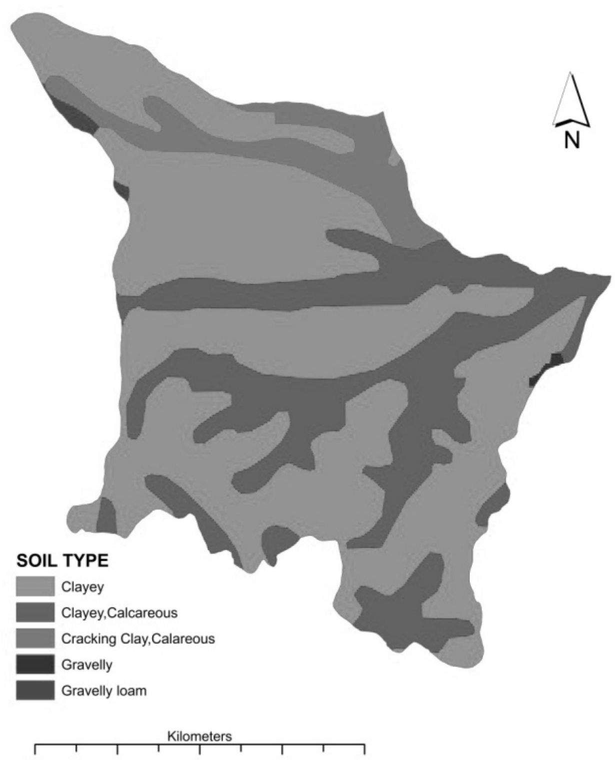

Fig.6. Classified soils in the study area

In watershed management, LULC analysis is being identified as an important parameter and it has been dealt with great emphasis in many recent works (Javed *et al*. 2009, Chauhan and Nayak 2005, Shetty *et al*. 2005). Sub watershed wise LULC mapping was carried out using IRS LISS III image and four broad classes were identified within the study area *viz.,* Dense Vegetation, Sparse Vegetation, Wastelands and Water bodies (Fig. 7). As per LULC analysis it has been observed that dense vegetation covered 11.97% and Sparse Vegetation, Wastelands and Water bodies covered 14.92, 71.50 and 1.61% respectively (Table 3).

Table 3. Area under various LULC classes

LULC classes	Area in sq.km	Area in %
Dense Vegetation	54.13	11.97
Sparse Vegetation	67.47	14.92
Wasteland	323.30	71.50
Water bodies	7.28	1.61

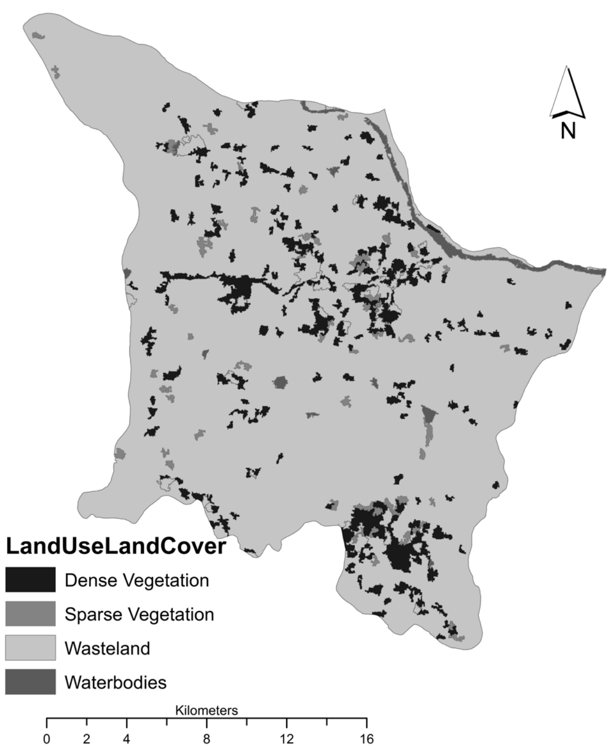

Fig. 7. Watershed study area LULC

To generate the slope map of the study area, DEM feature map was used. Finally, the watershed study area slopes are categorized into three types viz., gently sloping, very gently sloping, undulating sloping (Fig 8). Slope wise calculated runoff volume is given in Table 4 and sub watershed wise mandal wise calculated runoff volume is mentioned in Tables 5 and 6. The GUI based seasonal runoff as well as sub watershed runoff volume thematic maps generated based on the date selected from the daily runoff option (Fig. 9). A graphical user interface (GUI) has been developed and incorporated into comprehensive GIS process framework as shown in Fig. 10. The GUI based DSS is very user friendly and decision makers can take better decisions without much GIS and hydrological process knowledge.

Table 4. Slope wise runoff volume

Category	Runoff volume (m^3)
Gently sloping	6393091
Undulating lands	6684
Very Gently sloping	4325161
(blank)	25665

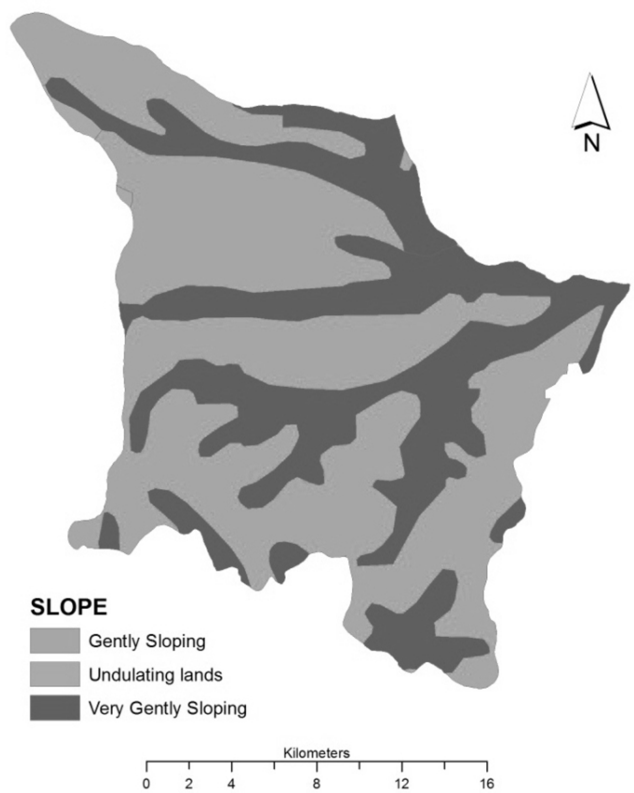

Fig 8. Classification of slope map

Table 5. Sub-watershed wise runoff volume

Sub watershed	Runoff volume (m^3)
A	494788
B	745116
C	1591173
D	1512887
E	1063682
F	1569630
G	1303384
H	1374221
I	646430
J	449287

Table 6. Mandal wise runoff volume

Mandal name	Runoff volume (m^3)
Nagarkarnool	1092446
Tadur	1677087
Telkapalli	7981068

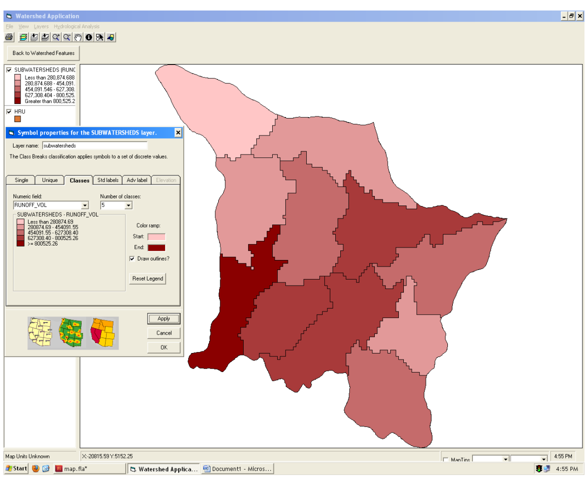

Fig. 9. Thematic map for sub watershed runoff volume

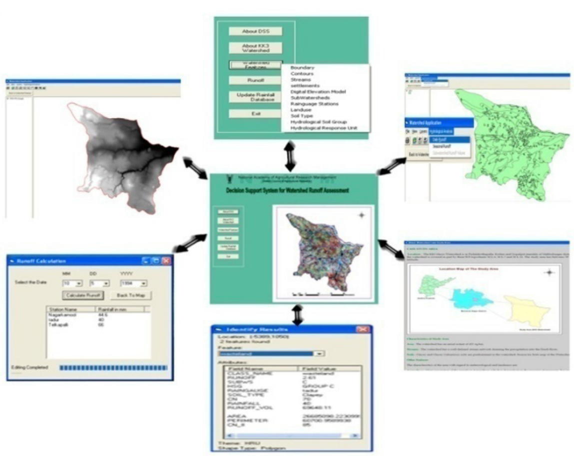

Fig. 10. Customized GIS-GUI DSS runoff assessment interfaces

5. CONCLUSION

Remote sensing data are of great use for the estimation of relevant hydrological data when conventional hydrological data are inadequate for the purpose of design and operation of water resources system. Remote sensing data can be used as model input for determination of catchment characteristics, such as land use/ land cover, morphology, depth elevation model, drainage etc. In the present study, watershed runoff assessment decision support system was developed and is integrated with GIS and VBA. It is a user-friendly approach and also much more efficient than other software's. The automation of runoff estimation is an important factor in assessment and management of water resources in the watersheds. The developed model is less expensive and can be customized for identified watersheds rainfall-runoff estimation. The developed GUI based DSS is very user friendly and decision makers can take better decisions without much GIS and hydrological process knowledge.

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