Integrated Management of Bineru and Thurpukalava Sub-Watersheds using Geospatial Technologies and Hydrological Modeling

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Abstract**:** ***The River Errakalava, one of the major hydrological systems experiences perennial flooding in the lower part of Lower Errakalava watershed, damaging vast extents of Kharif crop and submerging several villages in the area of W.G. district, Andhra Pradesh during monsoon season. The flooding menace has continued despite the regulation of heavy flows in the river and its tributary systems by construction of Water Harvesting Structures. Watershed is a natural geographical area in which all running water drains to a single common outlet and making it as striking unit for methodological efforts to supervise land and water resources development and conservation. Moreover, man-made interventions to the flow patterns, the flooding is mainly attributed to the physiographical set-up, geological and geomorphological processes, and various other terrain elements that have direct bearing on the geometry of the watershed particularly in the lower part. A geo-scientific attempt which includes geo-spatial technologies has been made in the present study to assess various natural resource parameters in the Lower Errakalava watershed and ascertain the scientific reasoning of flooding. The study also provided suitable and lasting solutions to avert the perennial flooding in this area and the work conducted by watershed projects on protecting and developing non-arable lands, recharging ground water, improving the management of agricultural land and raising agricultural production.***

Index Terms**:** ***Watershed, Flooding menace, Water Harvesting Structures***

I. INTRODUCTION

Most hundred millions of inhabitants living in the Indian semi-arid tropics depend on agriculture and natural resources. So development planners are enthusiastic to implement productive, environmentally sustainable land and water management systems. Watershed improvement schemes are intended to optimize the use of all available resources in a conservative way while raising agricultural productivity, both by conserving moisture in the ground and increasing irrigation through aquifer-tank-based water harvesting. Watershed or catchment is a geographic unit that drains to a single common point, which makes it an remarkable unit for scientific efforts to preserve earth and make best use of surface and sub surface water for crop production with administrative and property boundaries[1]. Watershed management is the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources and the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within the watershed boundary.

Andhra Pradesh has a distinction in watershed program. Since 1995, nearly 9326 watershed projects, highest in the country, are being implemented in the state[2]. Initially W.G. district old Godavari district and later came into continuation in the year 1925. Agriculture is as dominant activity. The extent of the area is about 8506 sq.km. with population concreteness of 470 per sq.km. [3].

In the present era, rapid development in Industrialization and Urbanization affects the natural resources quality including Land and Water. The increasing populations and enlarging aspirations of them converting the natural forests lands into irrigation fields up to the marginal hill slopes. Upland of West Godavari is inescapable from such scenario. This is now question the sustenance of the future of natural resources.

II. OBJECTIVES

The prime object of the study is the assessment of geohydrological conditions of Baineru and Thurpukalava sub-watersheds of Lower Errakalava watershed to suggest measures to avert flooding in the lower reaches of Errakalava. The underlying objectives of the proposed study area is to formulate a multi-disciplinary technological model that includes modern geospatial techniques, hydrological modeling coupled with traditional / conventional data sets, to create a large scale spatial and micro-level statistical database on all the associated resource parameters of land, water, soil and other terrain characteristics, to convert all datasets into GIS format to facilitate integration and analysis, hydrological modeling of persistent flooding of Errakalava and associated submergence phenomena, to critically address the flooding issues of lower Errakalava etc. on watershed basis and to suggest appropriate land and water management strategies in the area.

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III. STUDY AREA

The Study Area is located in the Lower Errakalava watershed and it is bounded by Upper Errakalava Watershed at West, Kovvadakalava Watershed at East, Godavari Right Bank at North and Paletivagu Sub-watershed at South. The location of the study area stretches from northern boundary to southern margin of West Godavari district lies between 16°59' and 17°21' north latitudes and 81°14' and 81°27' east longitudes. The Study Area covered in Jangareddygudem, Buttayagudem, Koyyalagudem, Gopalapuram and Devarapalli mandals of Upland area, West Godavari district. The study area geographical extent is 405.56 sq.km. The crops in the area are grown under rain-fed and by utilizing surface and groundwater resources. It is covered in three Survey of India (SOI) toposheets of 65 G/7, G/8 and H/5 on 1:50,000 scale. The map of the current location is presented in fig. 1.

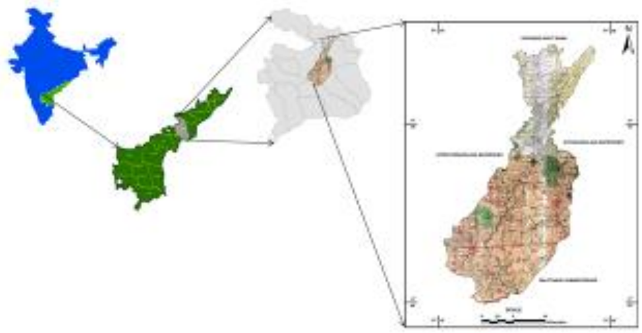

Fig. 1 Location Map of the Study Area

IV. METHODOLOGY

The intensive human activities colligated with the naturally occurring degradation processes is wielding detrimental impact and causing extensive changes in the proposed study area. The rapid population growth and the resulting overuse of natural resource potential are inducing harmful effects and substantial degradation of geo-environment. The geo-environmental evaluation is for managing land and water resources often requires a large amount of spatial information on various terrains and associated hydrological characteristics. A multidisciplinary integrated approach which includes remote sensing and geographic information systems along with conventional datasets aid to the geo-environmental evaluation particularly in establishing the present status and future prediction of various Earth's resource parameters. Hydrological modeling, HEC-HMS, is employed to evaluate the run-off characteristics of Bineru and Thurpukalava sub-watersheds.

V. RESULTS AND DISCUSSIONS

The geo-environmental phenomenon of Bineru and Thurpukalava of West Godavari district is in a state of drastic change due to variety of natural, man-made and environmental factors. The natural resources such as land, water and bio mass are being subjected to rampant human intervention and causing detrimental impact on geo-environment. The present research study with apt multidisciplinary methodologies have ensured in generating a sound scientific spatial and non-spatial database on various geo-environmental parameters and thus facilitating integrated analysis. The results are coherently presented in the form of maps, tables, graphs etc.

A. Slope and DEM

One of the most important terrain parameter plays a critical role in geomorphological and surface run-off processes, erosion of soil and planning of land use. Any development and planning, it is exceptionally needed to have a perceptive of the geographical allocation of slopes. Slope classes 1 and 2 representing nearly level to very gently sloping areas cover about 69.23% of the area. In general, the slopes 3 and 4 representing gently sloping to moderately sloping foothill areas occupy about 8.28% of the area. Slope class 5 representing strongly sloping area covering an area of 0.5%. Moderately to very steep sloping classes 6 and 7 mostly cover the area of 21.99 %. The Slopes of the area is publicized in fig. 2.

The generation of the digital elevation information is especially important in the remote areas, where coverage of information by topographic maps is limited. The digital elevation models (DEM) deliver basic information on several natural phenomena that area existing in this tectonically complex area. In general, DEM is used to extract information on hydrological patterns, lineaments, morphological structures etc. The DEM of the study area is presented in the fig. 3.

B. Lithology and Structure

Lithology is defined as the study of the general physical characteristics of rocks. The water reaching the earth's surface in the form of precipitation percolates through the soils, rocks and forms underground water. Generally, the morphology specify the textural and structural deviations and the tone on the image indicates the compositional variations. On merging, morphological and spectral characteristics, different rock types are to be mapped[5], [6].

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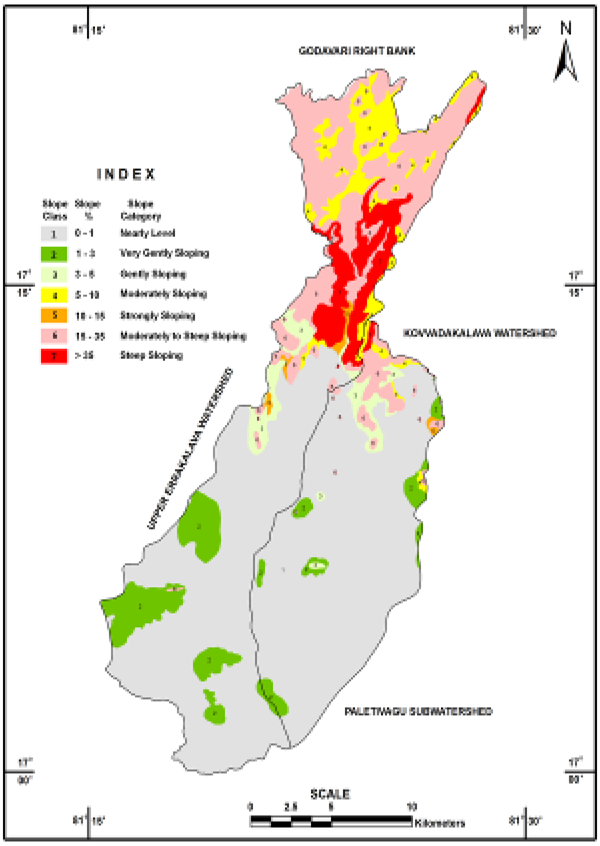

Fig. 2 Slope Map of the Study Area

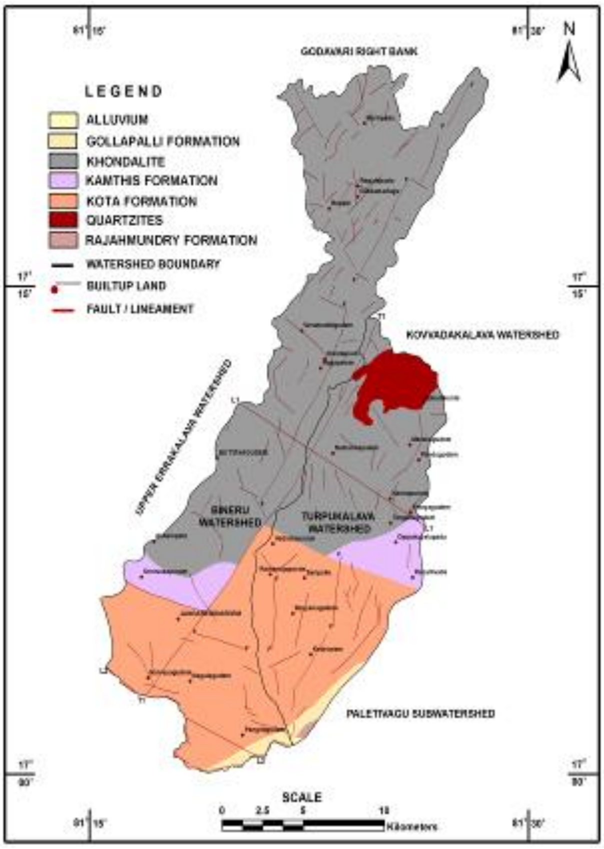

Fig. 4 Lithology and Structure map of the Study Area

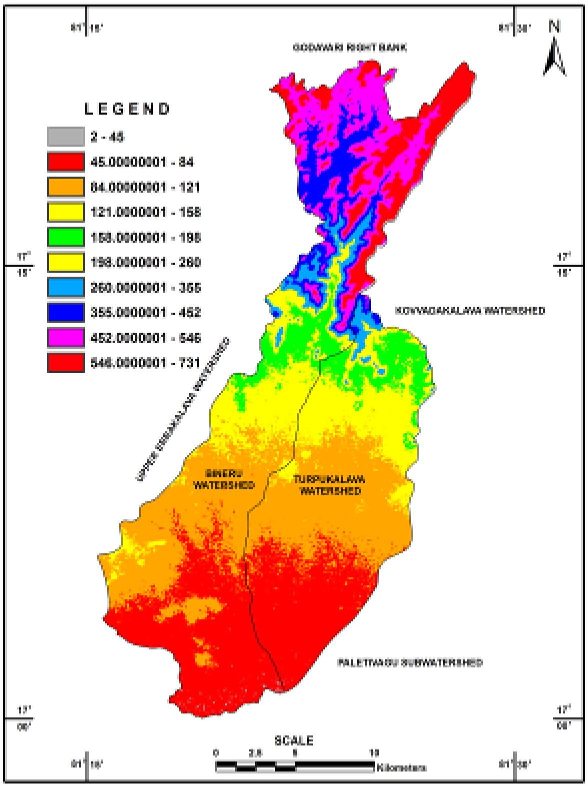

Fig. 3 DEM of the Study Area

There are seven different geological formations Alluvium, Gollapalli formation, Khondalite, Kamthis formation, Kota formation, Quratzites, Rajahmundry mainly khondalite formation covers the maximum area of about 229.203 sq.km. The lithology and structure plot of the present study is given in fig. 4.

C. Geomorphology

It is defined as the study of the physical condition of the earth's exterior part. The geomorphological maps have been prepared by using remote sensing techniques in the present study. Satellite image with its encyclopedic view facilitate improved appreciation of geomorphology and helps in mapping of different land forms and understanding their basis, succession of progress, matter content and other uniqueness [6].

Based on the different classifications mentioned on legend shown in figure 5, the maximum area covered is Pediplain of Rajahmundry Sandstones with Deep Weathering (Kota formations) (PPD(kts)) which is about 103.967 sq.km.

D. Soils

The knowledge about soils is very important for various purposes. The important soil groups in the area are Brown forest soil, red clayey soils, red loamy soil and red shallow gravelly soil. They are permeable and well to moderately well drain soils. They are moderately to slowly permeable with moderate to poor drainage. Among all soil types, Red clayey soils covers the maximum area i.e., 240.688 sq.km. The soils of the current chosen area is demonstrated in fig. 6.

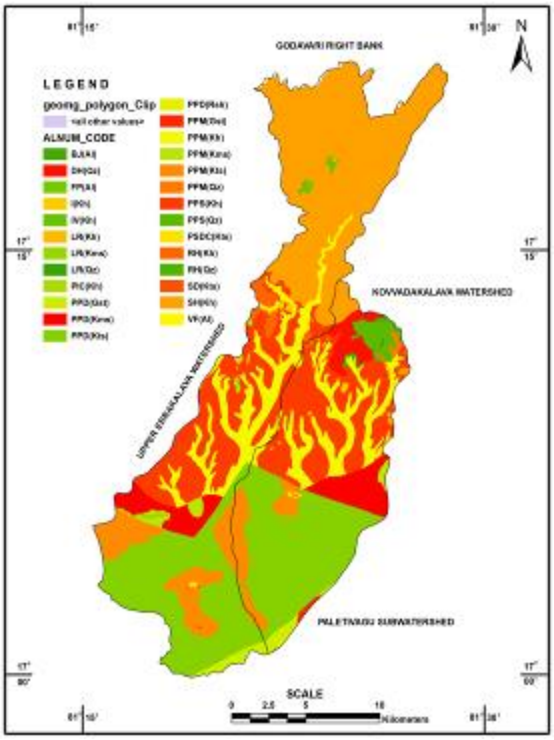

Fig. 5 Geomorphology of the Area

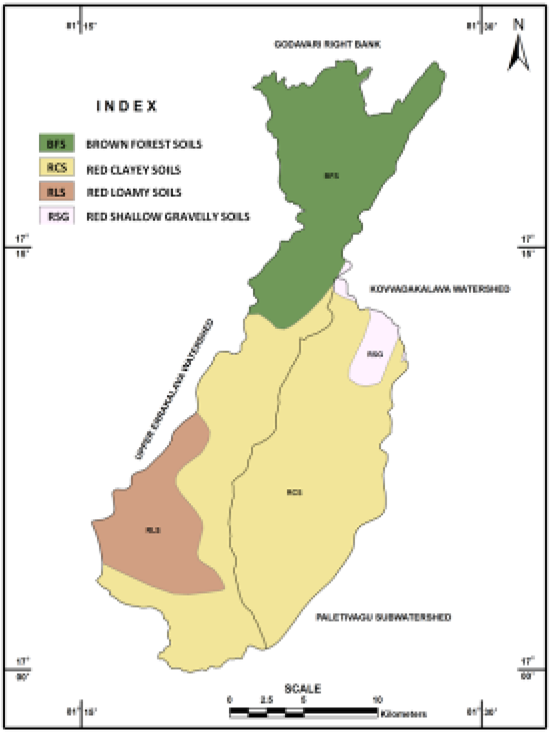

Fig. 6 Soils Map of the Study Area

E. *Land Use and Land Cover*

Wide-ranging information on land use and land cover is essential for land resources evaluation, utilization and organization. At the moment, pressure is rising on land and the resulting changes in the land use pattern and processes due to increasing population, a significant degree of land alteration and environmental deterioration is being witnessed. In the current examination, the land use and land cover analysis made to have an understanding of the surface and ground water resource utilization for irrigation, drinking, and industrial purposes. The main components of this analysis are built-up land, forest cover and plantation. The Built-up land extends up to 8.700 sq.km, maximum forest area covered in the investigated area is 109.594 sq.km. and the maximum crop covered is Kharif which is about 113.662 sq.km. The details of the LULC (land use and land cover) are presented in the fig. 7.

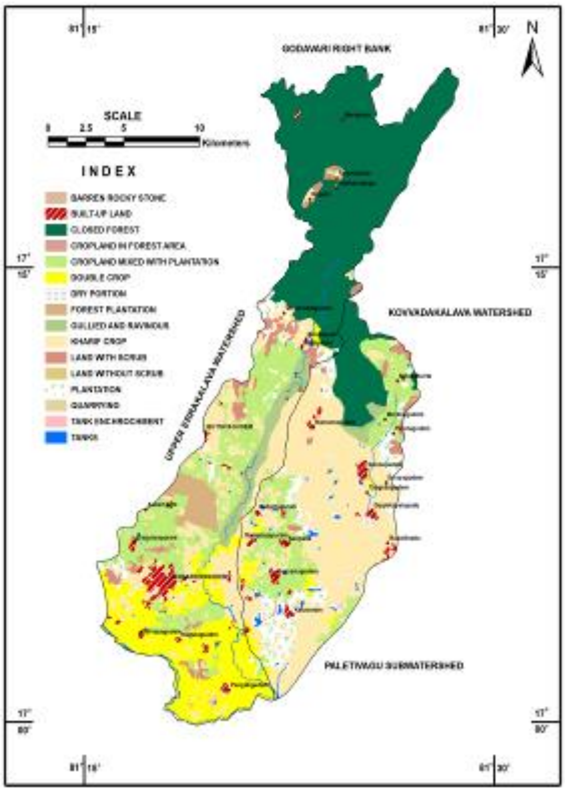

Fig. 7 Land Use / Land Cover Map of the Study Area

F. *Settlements and Transportation*

The overall development of any region is purely depending on transport network of that area. These maps provide information on the location of Settlements, Major and Minor roads.

The Settlement and Transport network map will provides the suggestions / recommendations for the best possible exploitation of natural resources like water and land. Also, these maps can be effectively used not only for the integrated analysis but also implementing the sustainable strategies in the for management of land and water resources. The Settlements and Transport Network of the selected site is demonstrated in fig. 8.

G. *Rainfall*

The amount of precipitation executes an important function in the accumulation of surface and sub-surface water resources. Among all Polavaram mandal records the maximum rainfall i.e., 1250.90mm. The geographic location of Polavaram is 17.25 north latitude and 81.64 east longitude. According to the study area the rainfall data is collected at corresponding five mandals and those are represented in table 1 and the corresponding graph is shown in fig. 9. The spatial distribution of the rain is displayed in fig. 10.

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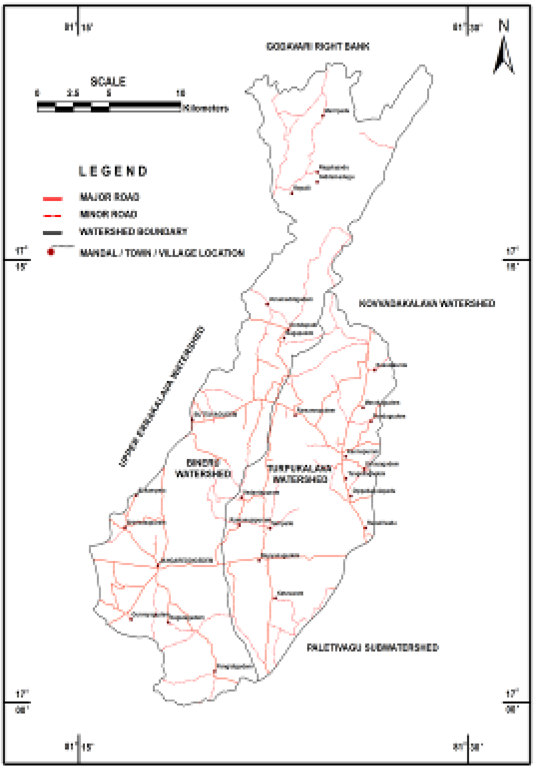

Fig. 8 Settlements and Transportation Map of the Study Area

Table 1 Average Annual Rainfall Recorded during 1990-2018 in the Study Area

Mandal	Rainfall in mm	Geographic Location	
		North Latitude	East Longitude
Polavaram	1250.90	17.25	81.64
Buttayagudem	1248.64	17.2	81.32
Devarapalli	891.92	17.03	81.56
Gopalapuram	1016.88	17.1	81.54
Jangareddygudem	1140.22	17.12	81.3
Koyyalagudem	1206.58	17.45	81.65

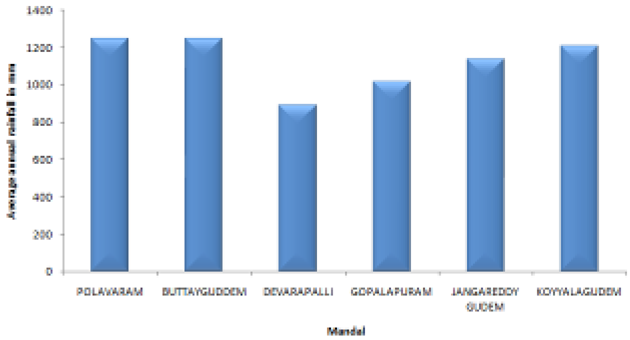

Fig. 9 Graphical Representation of Average Annual Rainfall Recorded during 1990-2018

H. *Drainage and Surface Water Resources*

The Errakalava, southern boundary in the area, is the river draining in the study area. Thurpukalava, Padamatikalava and Baineru are other significant streams draining the area and feed the irrigation tanks. These rivers are ephemeral in nature and flow in response to rainfall and are influent to effluent in nature. Bineru, Padamatikalava, Thurpukalava streams are main tributaries of Errakalava in the study area. The drainage in the area epitomizes mostly dendritic to sub-dendritic patterns in nature with pinnate pattern and parallel at places[5]. The surface water resources, which are sources of water is very important because it is needed for life to exist. Human beings require water for several purposes that include agriculture, industrialized, domestic, frivolous and environmental practices. It is anticipated that seventy percent of water being used in irrigation worldwide. The drainage and surface water resources are presented in fig. 11.

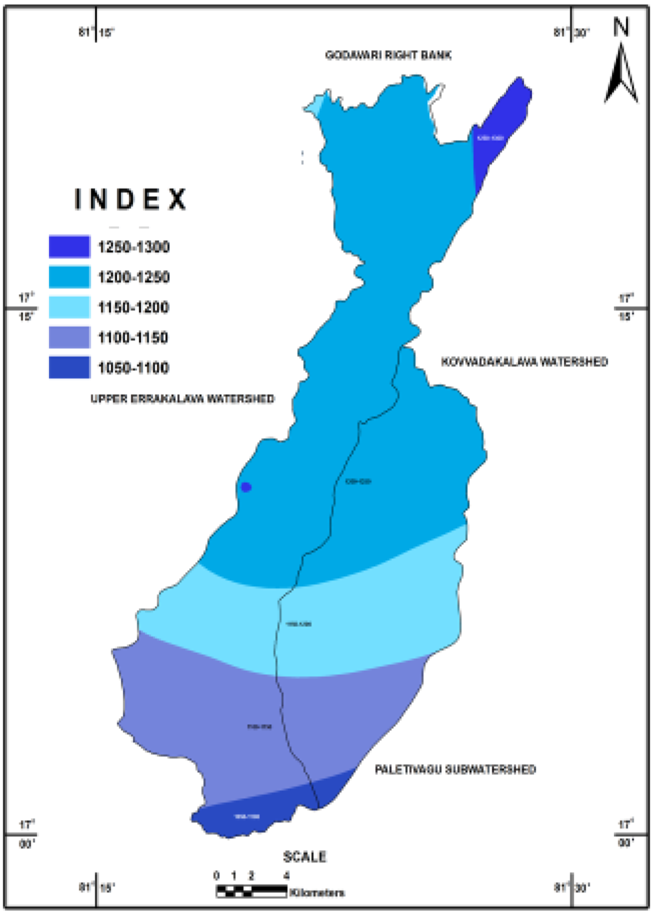

Fig. 10 Rainfall Distribution of the Area

I. *Ground Water Resources*

Ground water remains principal source of irrigation, drinking and industry in the study area. The disproportionate distribution and haphazard tapping in certain zones are the major reasons for scarcity of groundwater in many parts of the area[10]. The occurrence of ground water and its movement in an area is a result of a finite amalgamation of topography, climate, hydrology, lithology, structure, geomorphology and pedagogy related factors, which collectively form an included vibrant system. All these aspects are interactive and inter dependable, each providing a close approach into the entire execution of this dynamic system. These are classified into eight categories which is shown in figure 5 based on the classifications the maximum extended area is about 119.736 sq.km which is classified as good. The ground water resources map is shown in fig.12.

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Fig.11 Drainage and Surface Water Resource Map of the Study Area

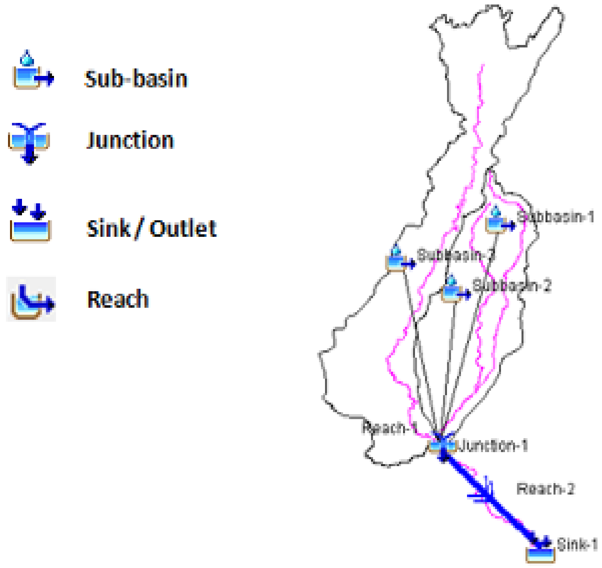
J. Hydrological Modeling of Bineru and Thurpukalava

In the evaluation process, a model model developed by Hydrological Engineering Centre-Hydrological Modeling System (HEC-HMS) is adopted for Bineru and Thurpukalava sub-watershed. This system is designed to simulate the precipitation-runoff processes of dendritic watershed systems[4]. The HEC-HMS has been principally adopted for Bineru and Thurpukalava sub- watershed to address the following issues:

- To identify sub-watersheds contributing **more run-off** to the inundation.
- To spot the **peak downpour** that submerges lower watershed.
- To make out the location for **flood manage structures** in the sub-watersheds.

The entire study area contains three sub-basins as shown in fig. 13. Thurpukalava comes under sub-basin1, Padamatikalava comes under sub-basin2, Bineru comes under sub-basin3 and the outlet /sink is taken at Ananthapalli.

The area of sub-basin1 is 53.1983 sq.km, sub-basin2 is 98.0523 sq.km and sub-basin3 is 254.3079 sq.km. Tables 2, 3 represents the rainfall and discharge data of 2008, tables 4, 5 and 6, 7 represents the corresponding rainfall and discharge data of 2010 and 2018. The corresponding graphs are represented in fig. 14, 15 and 16.



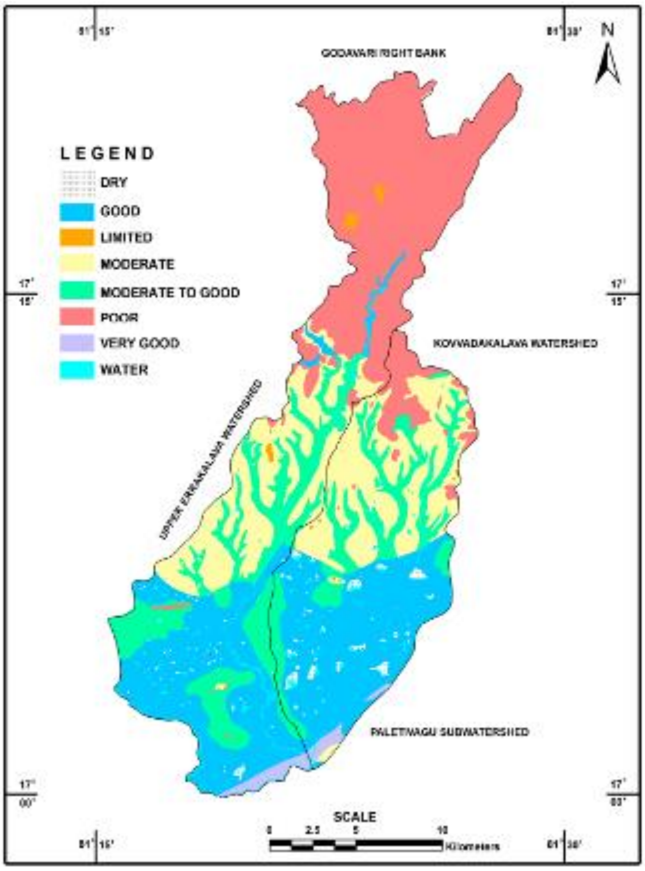


Fig. 12 Ground water resources Map of the Study Area

Fig. 13 Block diagram of HEC-HMS

Table 2 Daily Rainfall (mm) of the Bineru and Thurpukalava Sub-watershed during 06th to 15th August 2008

Date (August 2008)	Buttayagudem	Devarapalli	Gopalapuram	Jangareddygudem	Koyyalagudem
06	3.4	4	3.6	3.2	4.80
07	8.2	4.2	3.4	3.4	7.80
08	15.2	0	2.2	14.2	3.20
09	44.2	46.2	33.8	35.4	44.00
10	122.8	66.6	69.2	114.4	110.60
11	21.2	4.6	3.4	13.8	18.20
12	0	0	4.6	0	0.00
13	0	0	0	0	0.00
14	1.4	3.2	14.4	10.8	6.80
15	5.6	5	0	4	3.80

Table 3 Experiential streamflow (m^3/sec) at Ananthapalli Gage during 06th to 15th August 2008

Date (August 2008)	Observed streamflow, m^3/sec
06	238.9
07	31
08	15.69
09	347.3
10	**637.5**
11	571
12	545.2
13	194.1
14	116.8
15	44.5

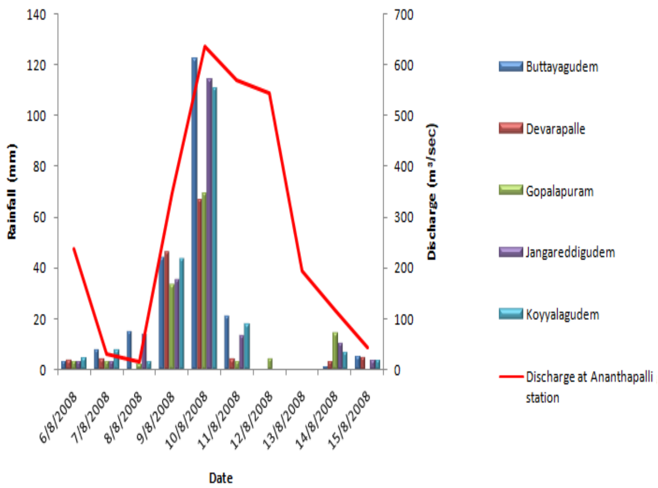


Fig. 14 Graphical Representation of Rainfall data during 06th to 15th August 2008

Table 4 Daily Rainfall (mm) of the Bineru and Thurpukalava Sub-watershed during 22nd to 31st August 2010

Date (August 2010)	Buttayagudem	Devarapalli	Gopalapuram	Jangareddygudem	Koyyalagudem
22	0.00	2.40	0.00	5.00	0.00
23	19.40	9.80	2.60	11.40	2.20
24	0.00	0.00	6.80	0.00	7.80
25	1.20	0.00	1.20	0.20	1.60
26	36.60	6.20	5.40	26.40	34.60
27	1.20	0.00	1.20	1.60	0.00
28	0.00	5.40	5.80	17.40	17.20
29	14.20	36.20	2.40	6.80	47.20
30	83.40	35.40	137.80	158.40	100.40
31	25.40	20.00	25.60	21.20	5.20

Table 5 Experiential Streamflow (m^3/sec) at Ananthapalli Gage during 22nd to 31st August 2010

Date (August 2010)	Observed stream flow (m^3/sec)
22	41.73
23	35.42
24	30.95
25	30.17
26	30.17
27	29.4
28	42.45
29	131.1
30	354.1
31	**609.6**

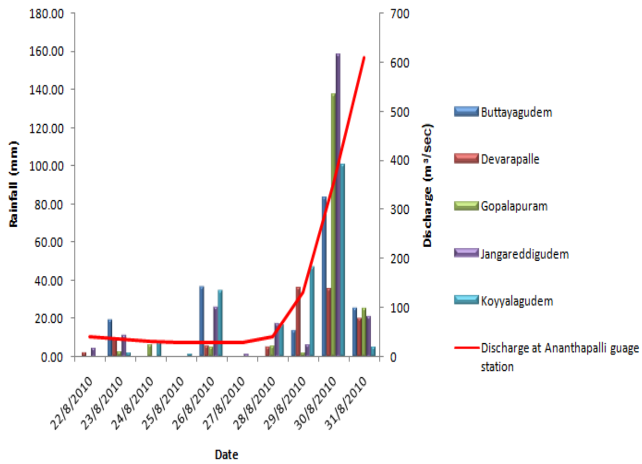


Fig. 15 Graphical Representation of Rainfall during 22nd to 31st August 2010

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Table 6 Daily Rainfall (mm) of the Bineru and Thurpukalava Sub-watershed during 16th to 25th August 2018

Date (August 2018)	Buttayagudem	Devarapalli	Gopalapuram	Jangareddygudem	Koyyalagudem
16	12.6	20.7	21	24.9	22.7
17	3.6	7.4	4.3	13.3	9.6
18	29.8	8	3.8	14.7	14
19	446.2	40	27.4	237.7	128
20	441.2	38.2	28.9	242.2	129.7
21	23.3	3.6	4.6	17.4	12.7
22	2.3	0	0.3	0	1.3
23	24.9	18.9	3.1	25.5	21.7
24	23.6	23.2	5.7	39.7	22.7
25	1	6	2.9	15.6	5.6

Table 7 Experiential Stream flow (m^3/sec) at Ananthapalli Gage during 16th To 25th August 2018

Date (August 2018)	Observed stream flow (m^3/sec)
16	132.9
17	112.4
18	109.4
19	192.3
20	**1253**
21	1133
22	656.1
23	355.1
24	150.2
25	132.9

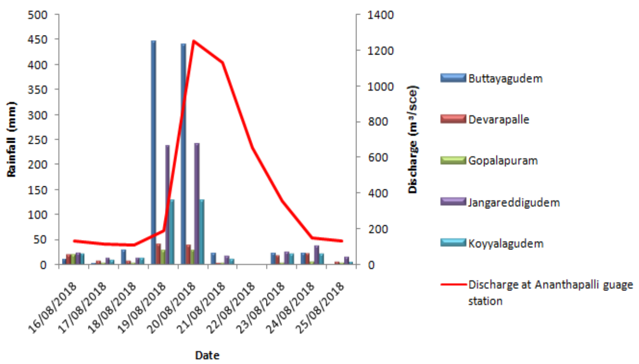

Fig. 16 Graphical Representation of Rainfall during 16th to 25th August 2018

The initial step in model, calibration, is a manual adjustment of model parameters using the trial-and-error method. The results of the model and its performance during calibration and validation are presented in the tables 8 and 9 respectively. The rainfall events between 06th to 15th August 2008 and 22nd to 31st August 2010 represented a good calibration of the HEC-HMS model. The deviation of the peak during calibration period obtained as "0" and "24" designate the peak flood incident, which is closely envisaged by the model. The calibrated model performance was evaluated using the Nash-Sutcliffe model efficiency[7], [8].

Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of 1 (NSE=1) corresponds to a perfect match between the modeled and observed time series, where as efficiency of 0 (NSE=0) indicates that the model predictions are as accurate as the mean of the observed data[9]. The observed and simulated hydrographs of 06th to 15th August 2008, 22nd to 31st August 2010 and 16th to 25th August 2018 are represented in fig. 17, 18 and 19.

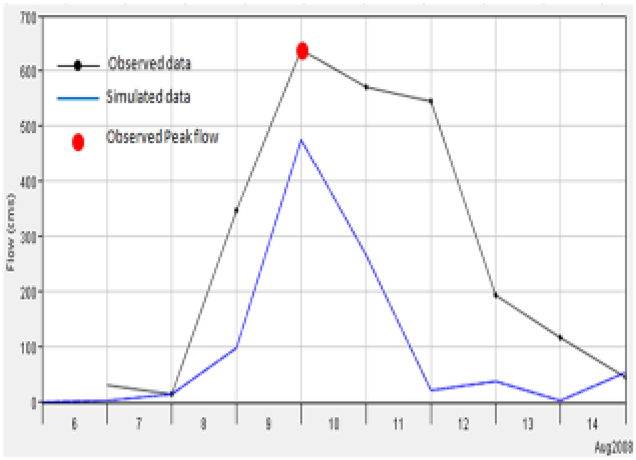

Fig. 17 Experiential and Simulated Hydrographs of Rainfall Event during 06th to 15th August 2008

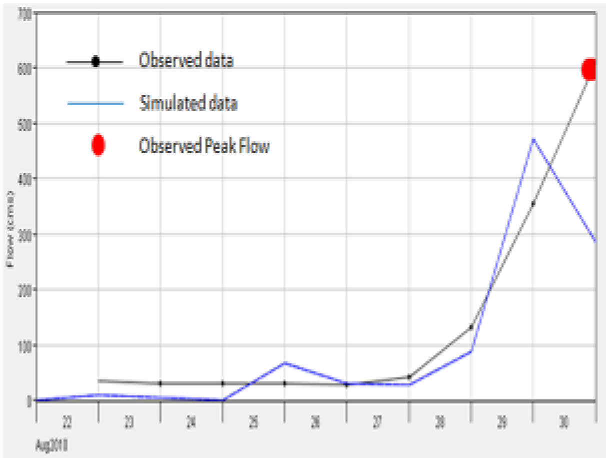

Fig. 18 Experiential and Simulated Hydrographs of Rainfall Event during 22nd to 31st August 2010

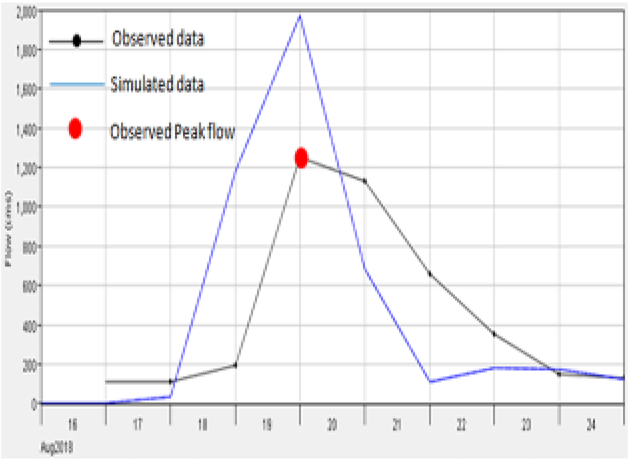

Fig. 19 Experiential and Simulated Hydrographs of Rainfall Event during 16th to 25th August 2018

Table 8 Calibration and Validation results of model for the study area

Phase	Period	Observed			Simulated		
		V_o (MM)	Q_o (m^3/sec)	Time of peak	V_s (MM)	Q_s (m^3/sec)	Time of peak
Calibration	6th Aug 2008 to 15th Aug 2008	528.52	637.5	10th Aug 2008 00:00	202.85	476.3	10th Aug 2008 00:00
Calibration	22nd Aug 2010 to 31st Aug 2010	210.6	609.6	15th Aug 2010 00:00	180.8	472.3	15th Aug 2010 00:00
Validation	16th Aug 2018 to 25th Aug 2018	858.11	1253	30th Aug 2018 00:00	939.27	1969.7	31st Aug 2018 00:00
Q_o = Observed Discharge; Q_s = Simulated Discharge; MM = Million Cubic Meters				V_o = Observed Volume V_s = Simulated Volume			

Table 9 Model Performance during Calibration and Validation

Event Schedule	Statistics			
	NSE	D_p (%)	D_v (%)	ΔT, hrs
06th Aug 2008 to 15th Aug 2008	0.047	-25.28	-61.62	0
22nd Aug 2010 to 31st Aug 2010	0.633	-22.52	-14.15	24
16th Aug 2018 to 25th Aug 2018	-0.227	57.19	9.46	0
NSE – Nash- Sutcliffe model Efficiency; D_v- Deviation of Runoff Volume;		D_P- Deviation of Peak discharge ΔT- Absolute error of Time to peak		

The presentation of the model for two calibrated periods are representing the Nash-Sutcliffe Model Efficiency(NSE) values of 0.047 and 0.633 are symbolize fine calibration of the model with an average NSE value of 0.340. Time for peak deviation "0" and "24" represents the good model calibration for predicting the flood occurrence. Based on the calibration values, the model has been run for its validation for a rainfall event during 16th Aug 2018 to 25th Aug 2018. During the validation period, all the parameters have an accord with the maximum release.

With the increasing use of both surface and groundwater for Domestic, Agricultural, and Industrial needs, the annual utilization and extraction of surface and groundwater are far in excess of net average availability and recharge from natural resources. There is an urgent need for artificial recharge of groundwater by augmenting the natural infiltration of precipitation into subsurface formation by some suitable recharge methods [10].

In this context, several water harvesting structures have been suggested at appropriate locations using spatial database analysis. In addition to the model results, the physically verified ground based study of the watershed is also very essential for the site selection to establish/propose suitable structure not only to control flood but also to harvest the water. Thus, a major irrigation project has been anticipated at the union point of Bineru and Thurpukalava with Errakalava,. Moreover, the tanks must be desilted, thus facilitating the reduction of submergence of command in Lower Errakalava. Fig. 20 shows the suggested locations of water harvesting and ground water recharge structures in Bineru and Thurpukalava Sub-Watersheds.

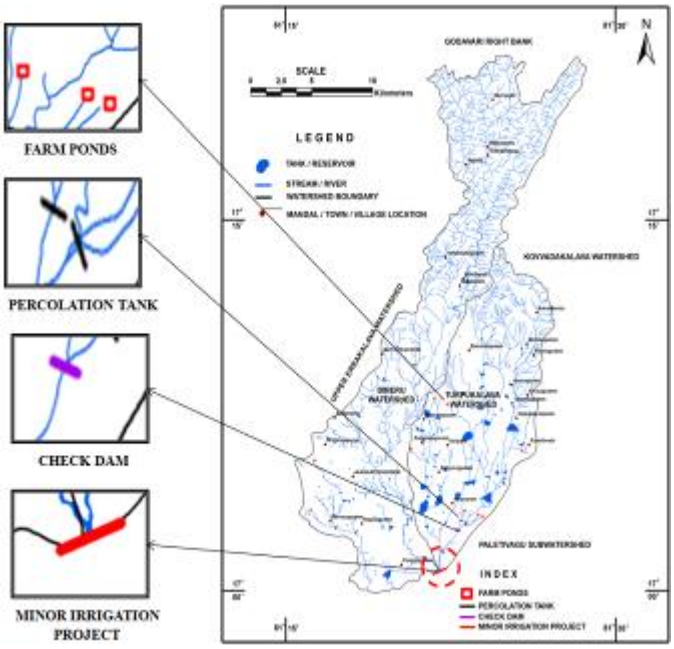

Fig. 20 Map Showing Suggested Locations of Rain Water Harvesting and Ground Water Recharge Structures in the study area

The study of individual resource maps on rainfall, slope, drainage, surface water resources, lithology-structure, geomorphology, land use and land cover, soils, groundwater resources and integration of the same have been effectively used in the spatial assessment of the relative variations of land and water resources [11].

The results of the HEC-HMS model revealed that there is a connection between the culminate discharge and flood submergence. The unchecked flow from Bineru and Thurpukalava directly joins the Errakalava downstream of the reservoir and makes inundation in the lower reaches. Also, it is the sign of towering rainfall within a diminutive time and steep slope of the contributing sub-systems.

VI. CONCLUSIONS

The study of individual resource maps and integration of the same have been effectively used in the spatial assessment of the relative variations of soil and water resources. The results of the HEC-HMS model reveals there is an association between the maximum release and flood submergence. The unchecked flow from Bineru and Thurpukalava directly joins the Errakalava downstream of the reservoir and makes inundation in the lower reaches due to high rainfall within a tiny period and vertical gradient in the area. The current research evaluation concluding that there is a reservoir to be planned along with the desilting of all surface water bodies. A detailed site investigations are also be required for implementing any water harvesting structures in the region.

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