Water Balance Assessment and Rainwater Harvesting Structures using Remote Sensing and GIS Techniques in Vadnagar Study Area, Gujarat

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Abstract— The paper aims at defining water balance assessment and to probe the water harvesting techniques using remote sensing and GIS. The study area falls in survey of India topo sheet no 46/A/9. The satellite data from GLDAS-NASA are used for calculation of runoff. Also THORNTHWAITE-MATHER (TM) MODEL is used for calculation of soil water status through time. This model was used to calculate Potential evapotranspiration (PET), Accumulated Potential water loss (APWL),Soil Moisture (SM), Change in SM (Δ SM), Actual Evapotranspiration (AET) ,Deficit, Surplus, Storage, Runoff , Detention.

Key words: Water Balance Assessment, Rainwater Harvesting

I. Objectives

- To prepare a runoff potential map from hydrological soil texture and Land use/Land cover map.
- To estimate runoff of STUDY AREA watershed by SCS Curve Number Method.
- To establish rainfall-runoff relationship.
- To study the Water Balance of the watershed using the Thornthwaite and Mather (TM) model.
- To compare the observed runoff with the computed runoff of STUDY AREA watershed.
- To identify suitable Sites for rainwater harvesting structures in study area watershed.

II. Data Used

A. *Remote Sensing Data*

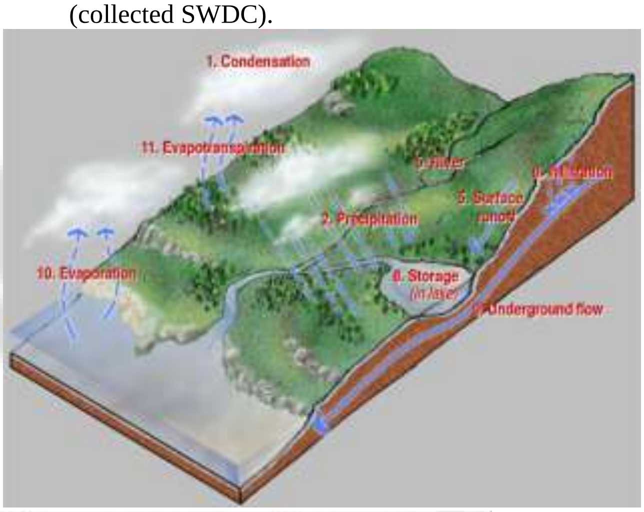
Indian Remote Sensing Satellite -1D (IRS-1D) Panchromatic (PAN) + Multispectral (LISS-III) merged digital data (1:50000) scale acquired on 21 Dec. 2002.

Indian Remote Sensing Satellite -1D (IRS-1D) Panchromatic (PAN) + Multispectral (LISS-III) merged digital data (1:25000) scale acquired on I Nov. 2002.

Image No.	Sensor	Path	Date	Scale
46-E/04	D,B	93/55,56	30/01/01	1:25,000
46-E/07	D	93/55	30/01/01	1:25,000
46-E/08	B	93/56	30/01/01	1:25,000

B. *Ancillary Data*

- Survey of India (SOI) Topo sheet No. (46 A/9) on 1:50000 scale.
- Daily Rainfall Data of 2006 (collected from SWDC).
- Daily Temperature data of 2006 (collected from SWDC).
- Soil texture map from Bureau of Soil, Nagpur for preparing Hydrological soil group.
- Discharge data of river Sarswati and Rupen of 2006 (collected SWDC).



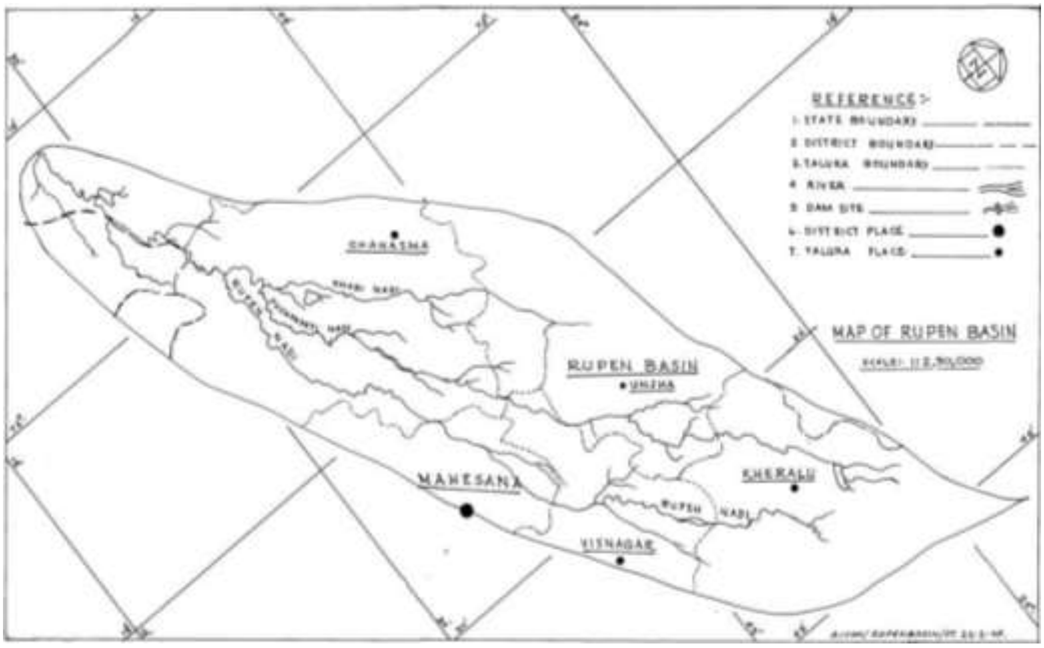


Fig. 1: RUPEN River Basin

Fig. 2: LANDSAT 7 IMAGE 2124309709

III. STUDY AREA CHARACTERISTICS

A. Climate:

The study area falls in the hot arid/semiarid regions of Western India & experiences three distinct seasons, namely Winter, Summer & monsoon.

- Winter - November to February
- Summer – March to June
- Monsoon – Middle of June to Middle of October

The area has traditionally average rainfall is around 600 mm January is the coldest month

B. Physiography:

The Physiography of the study area is gently sloping pediments to gently sloping alluvial plains.

C. Main crops:

The main crops were Maize, Grams & custard, Potato, Cotton, Tobacco, Oilseeds, Castor Seeds, Cumin,

D. River and Irrigation facility:

Sabarmati, Rupen, Saraswati, Khari, Pushpawati are major rivers in district. Mostly well irrigation Rupen river originates from Taranga hills and meets in little rann of kuchchh. Its length is 156 km. & 2500 sq.km. catchment area Pushpavati and Khari are right bank tributaries and Khari is left bank tributary of Rupen river.

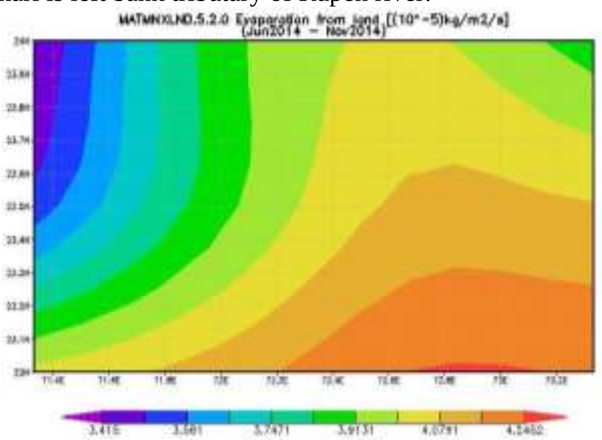


Fig. 3: EVAPORATION FROM LAND JUNE TO NOV 2014 (couryesy ; GLDAS—NASA)

E. Watershed Characteristics

(that affect the behavior of receiving and disposal of water)

1) Size

Determines the quantity of precipitation received, retained and drained off.

2) Shape

The longer the watershed, the greater is the time of concentration. The longer the time of concentration, the greater the time available for the water to infiltrate, evaporate and got utilized by vegetation.

3) Slope

It affects the time of concentration, infiltration, runoff and soil loss.

4) Hydrologic Soil Group

Soil characteristics reflect the rate of water transmission and runoff potential.

5) Vegetal Cover

It affects the infiltration rate, soil erosion, evapotranspiration, sediment production, etc.

6) Drainage

Drainage density reflects the overall runoff in an area

7) Climate

Climate parameters like precipitation, humidity, temperature, wind etc. will affect the hydrological behavior of the watershed.

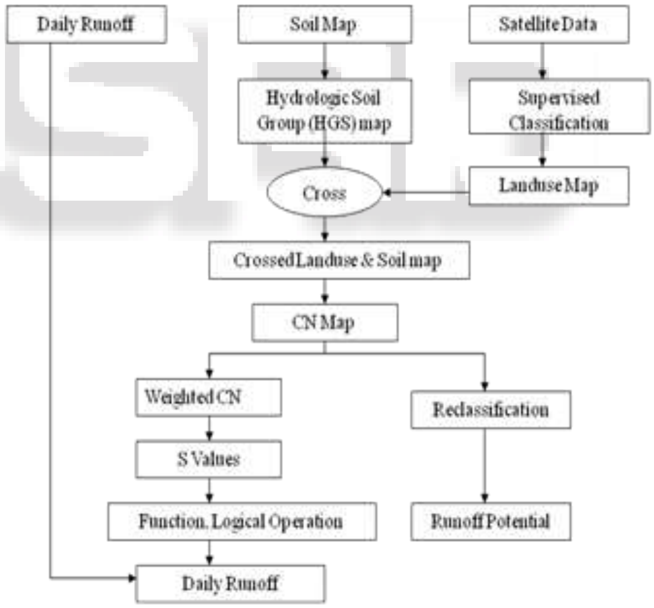


Fig. 4: Runoff Estimation using Remote Sensing & GIS by SCS Curve Number Method

F. AMC Classes with respect to 5 Days Antecedent Rainfall

AMC Class	5 days antecedent rainfall, mm	
	Dormant season	Growing Season
I	<12.5	<35
II	12.5 – 27.5	35 – 52.5
III	> 27.5	>52.5

Table 1: AMC Classes with respect to 5 Days Antecedent Rainfall

G. Runoff (Q) calculated for Daily rainfall

S. No.	Rainfall P (mm)	Runoff Q (mm)
1	97.06	44.87

2	49.62	11.91
3	52.63	13.62
4	25.93	1.70
5	43.23	0.67
6	23.45	1.09
7	28.57	2.46
8	25.18	1.50
9	33.83	0.01
10	48.12	11.08
11	45.86	9.87
12	30.82	3.21

Table 2: Runoff (Q) calculated for Daily rainfall

The relationship between rainfall (P) and runoff (Q) which is derived by using SCS curve number method is as follows:

$$Q = 0.005 P^2 - 0.0106 P - 2.5675$$

Where, Regression coefficient R is 0.9603

H. CN and runoff values for different land use-soil classes

Landuse	Soil Texture	CN	RUNOFF (INCH)	RUNOFF (MM)
Built -up Area	Clay Loam	85	7.3	185.42
Built -up Area	Fine Sandy Loam	72	5.6	142.24
Built -up Area	Silt Loam	79	6.5	165.1
Agricultural Land	Clay Loam	77	6.2	157.48
Agricultural Land	Fine Sandy Loam	62	4.3	109.22
Agricultural Land	Silt Loam	71	5.5	139.7
Open Forest	Clay Loam	60	4.2	106.68
Open Forest	Fine Sandy Loam	28	0.6	15.24
Open Forest	Silt Loam	44	2.2	55.88
Barren Land	Clay Loam	85	7.3	185.42
Barren Land	Fine Sandy Loam	71	5.5	139.7
Barren Land	Silt Loam	80	6.6	167.64
Dense Forest	Clay Loam	58	4	101.6
Dense Forest	Fine Sandy Loam	26	0.5	12.7
Dense Forest	Silt Loam	40	1.7	43.18
Water	Clay Loam	100	9	228.6
Water	Fine Sandy Loam	100	9	228.6
Water	Silt Loam	100	9	228.6

Table 3: CN and runoff values for different land use-soil classes

CN → Hydrologic Soil Cover Complexes

Runoff (inch) → SCS rainfall-runoff equation solution for various curve numbers

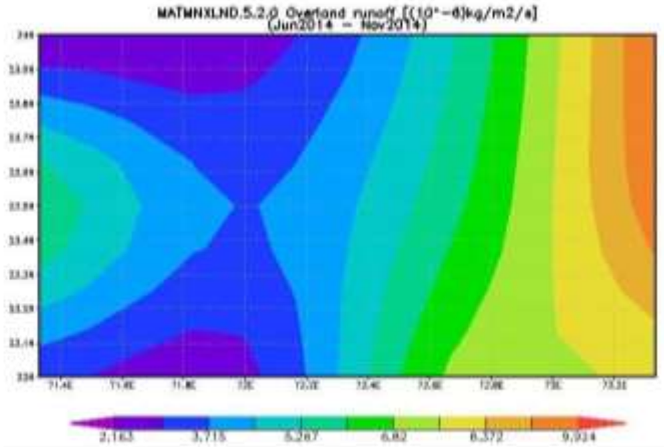


Fig. 4: OVERLAND RUNOFF DERIVED FROM SATELITE (CORTESY GLDAS-NASA)

I. Water Balance:

Def:- Water balance refers to the balance between incoming water from precipitation and outgoing water by evapo transpiration, groundwater recharge and stream flow.

The water balance of a small drainage basin underlain by impervious rock can be expressed by the following equation:

$$P = I + AET + OF + \Delta SM + \Delta GWS + GWR$$

Where

P is Precipitation
OF is Overland flow
I is the Infiltration
ΔGWS is Change in ground water storage
AET is Actual Evapo-transpiration
GWR is Ground Water Run-off
ΔSM is Change in soil moisture

J. THORNTHWAITE-MATHER (TM) MODEL

The T-M model tracks the soil water status through time.
It is a lumped model that tracks soil water through time.
The entire watershed is treated as one unit (hence ‘lumped’).
Is appropriate for modeling at daily, weekly or monthly time steps.
This model was used to calculate:-

1) Potential evapotranspiration (PET)
2) Accumulated Potential water loss (APWL),
3) Soil Moisture (SM)
4) Change in SM (Δ SM),
5) Actual Evapotranspiration (AET)
6) Deficit,
7) Surplus
8) Storage
9) Runoff
10) Detention

Summary of the P, PET, AET and runoff in (mm) for STUDY AREA watershed

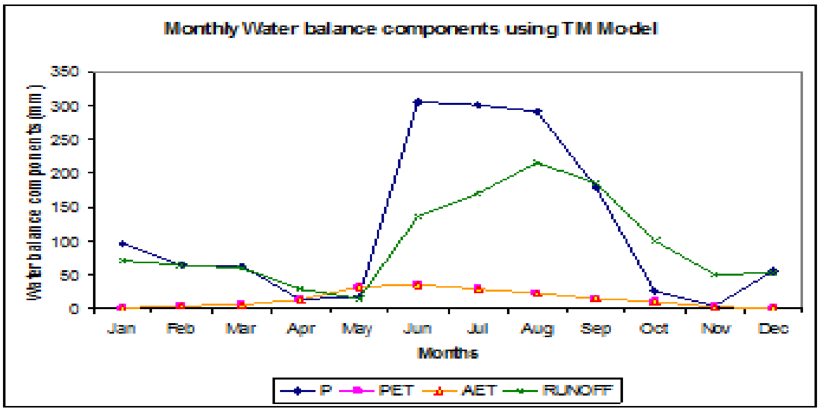


Fig. 5: TM Model

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	96.47	65.02	64.05	14.28	18.78	307.17	301.82	292.63	181.18	26.61	5.25	56	1429.26
PET	1.21	4.63	6.36	14.08	32.42	35.03	29.44	23.78	15.8	10.9	3.09	1.53	178.27
AET	1.21	4.63	6.36	14.08	32.04	35.03	29.44	23.78	15.8	10.9	3.09	1.53	177.887477
RUNOFF	72.08	64.78	60.81	29.98	15.41	136.96	171.80	215.68	187.2515	101.59	51.76	52.432	1160.48313

K. *Rain Water Harvesting:*

1) *Why Rainwater harvesting is essential?*

- An ideal solution to water problems in areas having inadequate water resources
- The ground water level will rise
- Mitigates the effects of drought & achieves drought proofing
- Reduces the runoff which chokes the storm water drains
- Flooding of roads and low land areas are reduces
- Quality and quantity of water improves
- Soil erosion will be reduced

Saving of energy per well for lifting of ground water-a one meter rise in water level saves about 0.40 KWH of electricity.

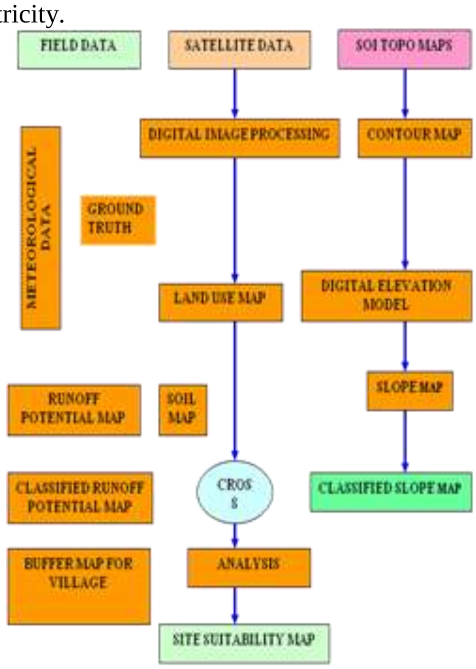


Fig. 6: Flow chart for Remote Sensing and GIS methodology

IV. CONCLUSION

1) Remote sensing technique can be successfully used to determine the water balance and its potential in the water shed area
2) The satellite images have given sufficient guidance in determini9ng the watershed and overland runoff
3) It is possible to raise the ground water level.
4) It can Mitigates the effects of drought & achieves drought proofing
5) The rain water harvesting technique Reduces the runoff which chokes the storm water drains
6) With proper utilization and management of water shed runoff ,flooding of roads and low land areas are reduces
7) The Quality and quantity of water can be improved
8) Soil erosion will be reduced

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