Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. **M.Tech. Geological Technology and Geoinformatics**

Course code : **MTIGT0604**

GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

Unit-2 : Geoinformatics in Surface Water Resources

Dr. K. Palanivel
Professor, Department of Remote Sensing

Course Objectives

- ❖ To know the potential sources, origin, occurrences of water resources
- ❖ To understand the concepts of water resources prospecting, water quality mapping and conservation
- ❖ To learn the capabilities of Geoinformatics and its applications for water resources targeting, quantification, budgeting and management
- ❖ To learn the Geological Technology and Geoinformatics in understanding the functions of aquifers and groundwater movement
- ❖ To learn the basics and applications of hydrogeological models.

MTIGT0604: GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

--- 4 Credits

1. Surface Water Resources: Hydrological Cycle - Global Distribution of Surface water Bodies – Drainage Morphometry – Sources of Surface water – Snow, Rainfall and groundwater table. Modelling assumptions - choice of equation - phenomena and model geometry - choice of variables and parameters - data and knowledge acquisition - model building – calibration and verification, results presentation. **12Hrs.**

2. Geoinformatics in Surface Water Resources: Satellite data based Surface water budgeting and Quantification – Automated drainage Mapping Using DEM – Spectral Response Pattern of Water – Water quality mapping and monitoring using Remote Sensing – Infra Red data based Water Quantity Forecasting – Water quality Mapping and Monitoring using satellite data. **12 Hrs.**

3. Groundwater Resources: Groundwater Origin & Occurrence: Sources of Groundwater – Classification of Groundwater. Aquifer Types**:** Crystalline Aquifer, Sedimentary aquifer, Unconsolidated Sedimentary Aquifer, Geomorphic aquifer. Darcy's Law in homogeneous and heterogeneous media, Groundwater quality, Application of H and O isotopes in groundwater studies; Targeting: General Investigations - Geological mapping- Geological Cross sections - Well inventory – Geophysical Methods – Drilling and Exploration - Pump tests **-** Groundwater Assessment and Budgeting - Issues and conservation Strategies**.** **16 Hrs.**

4. Geoinformatics in Groundwater Resources: Geoinformatics and evaluation of lithologically controlled, Structurally controlled and Geomorphologically controlled aquifers – Concept of Hydro geomorphic mapping. Natural and Artificial recharge site selection - detection of site specific mechanisms – Quantification of allowable recharge. **12 Hrs.**

5. Hydrological Models: Surface Water Hydrological Models: Snow melt Runoff modeling – GIS based Runoff modeling – Various hydrological models using Geoinformatics. Models for Inter watershed water transfer. Groundwater models: Stochastic – MOD Flow- Linear – Finite Element Modeling. **12 Hrs.**

Course outcomes

After the successful completion of this course, the students are able to:

- ✓ Understand the availability, sources and importance of the water resources prospect for both surface and groundwater resources using Geoinformatics technology
- ✓ Determine the types of aquifers, their characteristics and their recuperation ability
- ✓ Delineate suitable sites and mechanisms for natural and artificial recharge
- ✓ Understand the application of Geoinformatics technology for surface and groundwater resources exploration, targeting, quantification, budgeting, conservation and management
- ✓ Learn the application of Geological technology and Geoinformatics tools in developing various hydrological models.

Text Books:

1. David Keith Todd, Groundwater Hydrology, Wiley Student Edition.
2. Raghunath H.M., Ground Water, New Age International (P) Limited Publishers, 1987.
3. Ramakrishnan. S. Groundwater, 1998.

References:

1. Chang, H.H. Fluvial processes in river engineering, John Wiley and Sons, New York. 1988.
2. Bedient, P.B, Hydrology and flood Plain analysis, Addision westery publishing company. 1988.
3. Driscoll, F.S. Groundwater & Wells, 2nd Edition, Scientific Publishers, Joclpur, 1986.
4. Karanth K.R., Groundwater Assessment Development and Management, Tata McGraw Hill Publishing Company Limited, New Delhi, 1987.
5. Clorer. R.C., Groundwater Management.
6. Scalf M.R., Manual of SW Quality Sampling procedure
7. Mutreja, K.N Applied Hydrology, Tata McGraw Hill Publishing Company Limited, New Delhi, 1986.
8. Thomann R.V, Principles of Surface Water Quality Modeling and Control, HIE, Harper & Row, Publishers, New York, 1987.
9. Mohammed Ali, George E Radosevich, Water Resource Policy for Asia, A. A. Balkema/Rotterdam/Boston, 1987.

10. Mc Donald AT, Water Resources: Issues and Strategies, Longman Scientific & Technical, 1988.
11. Pillai, K.M., Water Management and Planning, Himalaya Publishing House, 1987.
12. Gower. A.M., Water Quality in Catchment Ecosystem, John Willey & Sons, 1980.
13. Ramesam. V. Trends in Groundwater Research, The Geological Society of India, Bangalore, 1987.
14. Trivedi, R.N., Shatrunjay Kumar Sing, Water Resources and Quality Management, Commonwealth Publishers, New Delhi, 1990.
15. Fetter C.W. Applied Hydrology, CBS Publishers & Distributors, 1988.
16. Gautam Mahajan. Groundwater Surveys and investigations, Ashish Publishing House, New Delhi, 1995.
17. Chow V.T., maidment, D.R., and Mays, L.W. applied Hydrology, McGraw Hill, New York, pp.530 to 537. 1988.
18. Deman, MCJ. Smith G.S and H.T.Verstappen (eds), Remote Sensing for resources development and environmental management, A.A. Ballkema Publishers, Totterdam, Netherlands. 1986.

UNIT - 2

GEOINFORMATICS IN SURFACE WATER RESOURCES

Unit - 2: Geoinformatics in Surface Water Resources: Satellite data based Surface water budgeting and Quantification – Automated drainage Mapping Using DEM – Spectral Response Pattern of Water – Water quality mapping and monitoring using Remote Sensing – Infra Red data based Water Quantity Forecasting – Water quality Mapping and Monitoring using satellite data. **12 Hrs.**

Remote Sensing and GIS for Water Resources – Certain Principles

- Maximum absorption in Visible range of EMR, i.e., **EMR Reflectance of Surface Water is Very Little**
- Total absorption in IR range
- Suspended sediments, shallow bottom topography, smooth flow of running water bodies will have reflectance to some extent
- Elements dissolved in water may also change the reflectance property of water
- Microwave will have smooth and coarse texture.

Remote Sensing and GIS for Water Resources – Certain Principles

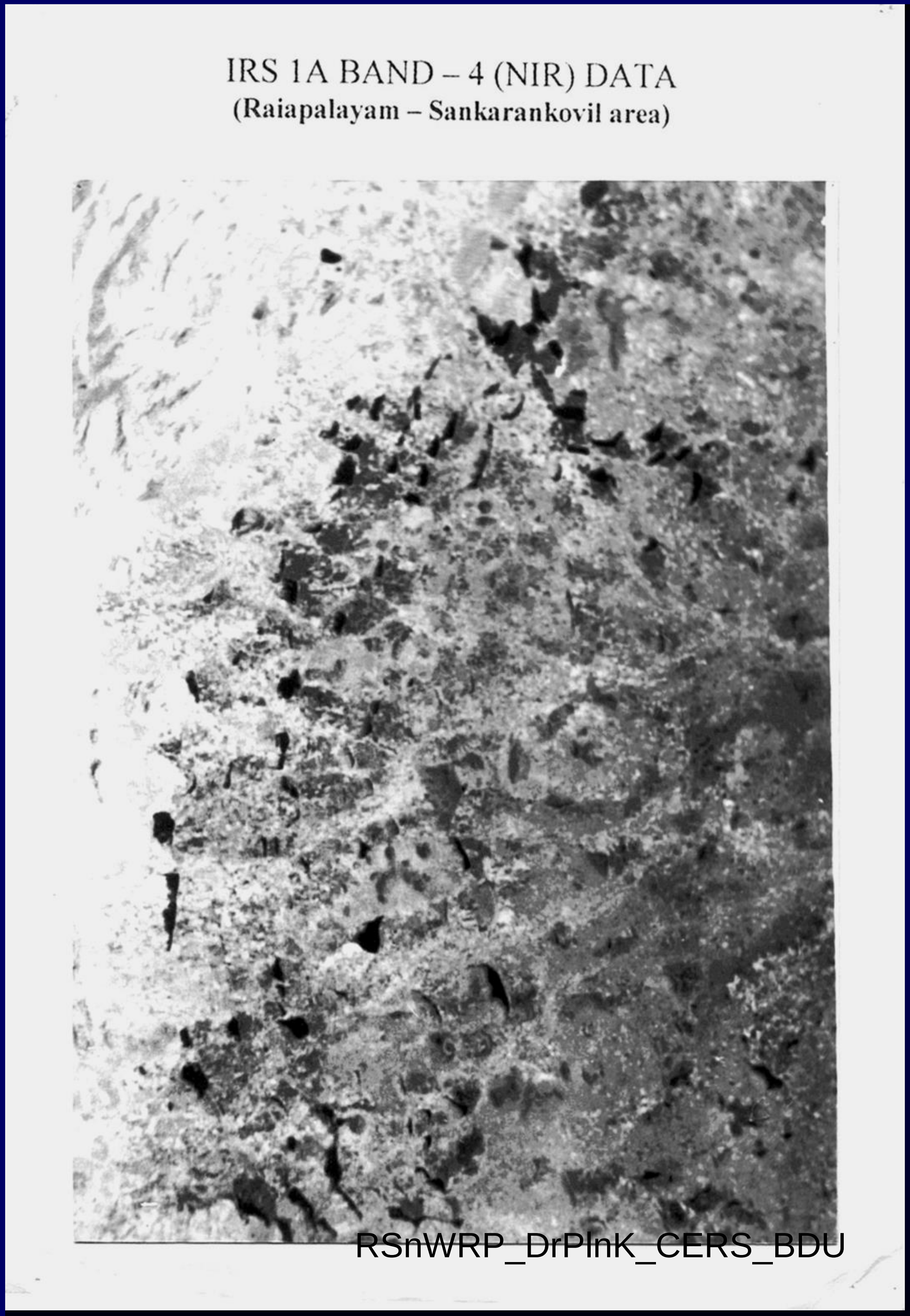
- Ice caps reflects very high and appears bright in visible region
- Reflectance vary depends on depth to the bottom of water body – reflectance from river bed, tank bed, coast, etc., gives little brighter signature
- Polluted waters will reflect little high and differently than the normal water bodies
- There are very good vistas for water resources management using fast emerging Geotechnology.

Microwave / RADAR Data

- Surface water quantification
- Flood inundation mapping
- Flood forecasting
- Palaeo-channel mapping for
  – GW Prospecting
  – Linking of adjacent rivers and tanks
  – Placer mineral deposits
  – Understanding of palaeo-tectonic activities
  – Past habitat/civilization related excavations….

RS and GIS for WRC

- **Surface Water – Running and Static**
  - Mapping
    - Drainages, Canals, Rivers, Reservoirs, Lakes, Tanks
    - Watershed Delineation, Density maps….
  - Periodic / Daily Estimation of SW quantity
  - Budgeting (Available resources vs Usage)
  - Flood Hazard Zonation & Forewarning
  - Prioritization of watersheds using Drainage Morphometric Analysis
  - Surface water Quality Estimation
  - Soil erosion control and Siltation Mapping



Surface Water Resources – NIR band of IRS 1A

Mapping of Surface Water Resources / Water Spread Area

- **NDWI – Normalized Difference Water Index**

$$\boxed{NDWI = (GREEN - NIR) / (GREEN + NIR)}$$

- **Modified NDWI**

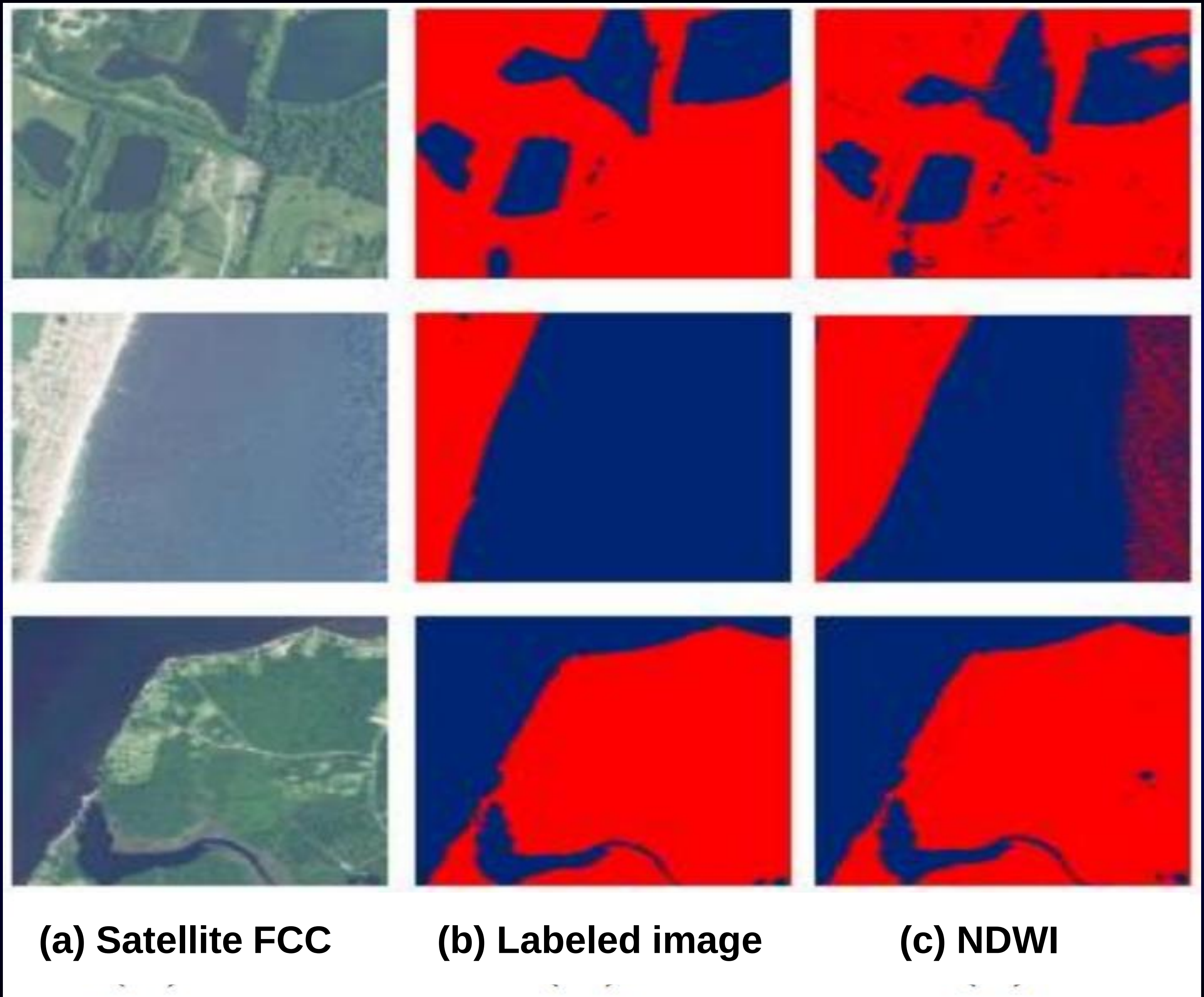
$$\boxed{MNDWI = (Green - SWIR) / (Green + SWIR)}$$

- **Normalized Difference Moisture Index (NDMI)** is used to determine vegetation water content. It is calculated as a ratio between the NIR and SWIR values in traditional fashion.

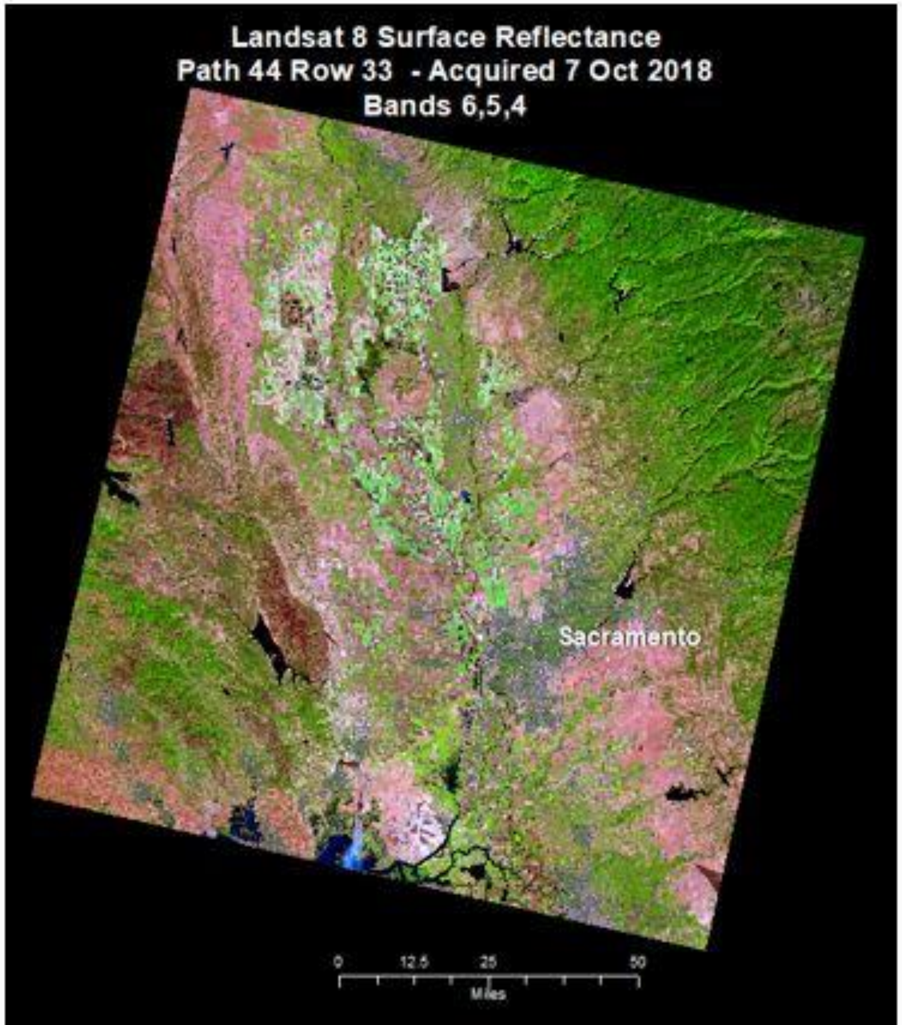
$$\boxed{NDMI = (NIR - SWIR) / (NIR + SWIR)}$$

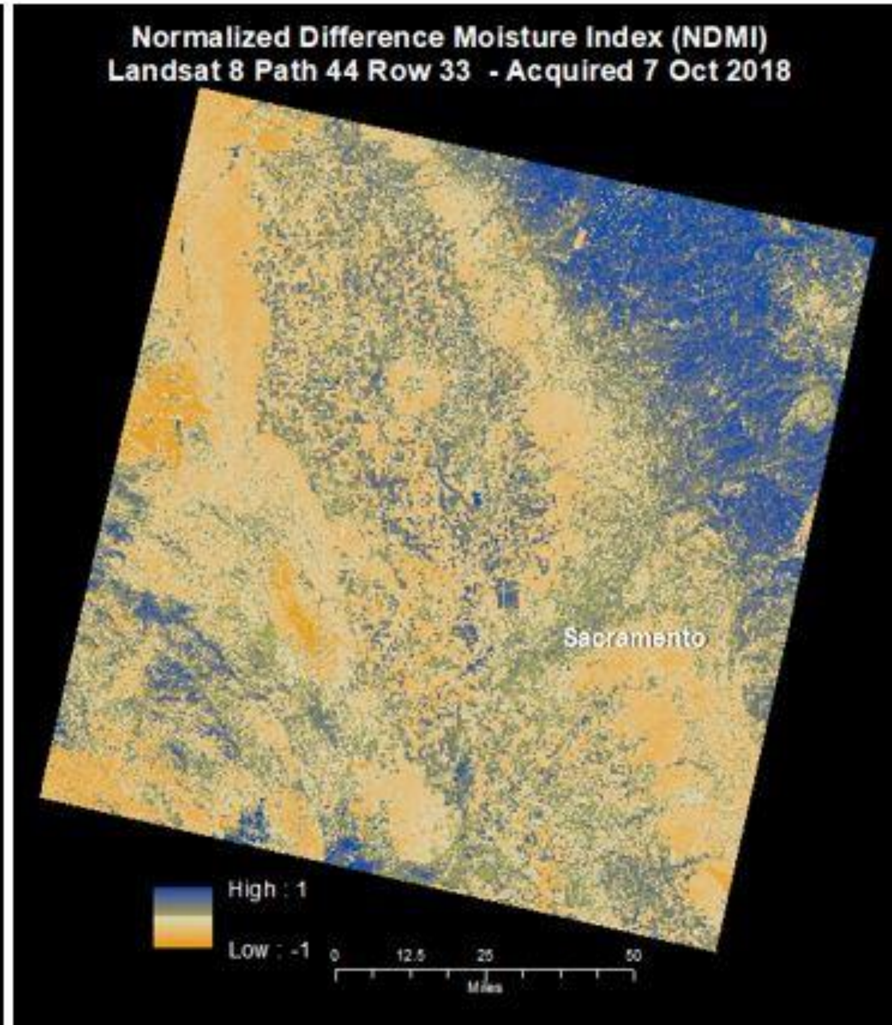
- NDVI for comparison,

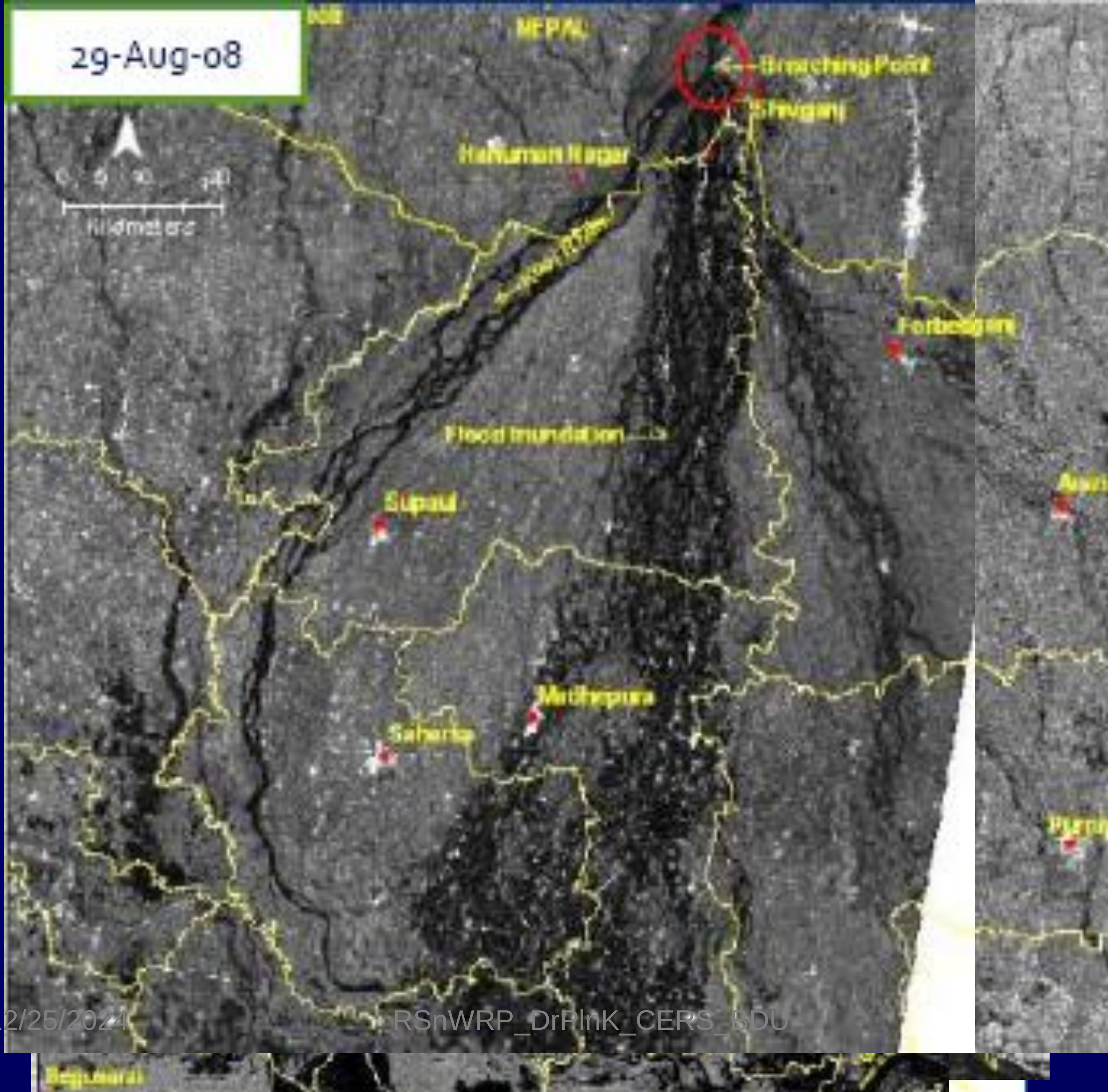
$$\boxed{NDVI = (NIR-Red) / (NIR+Red)}$$


(a) Satellite FCC
(b) Labeled image
(c) NDWI

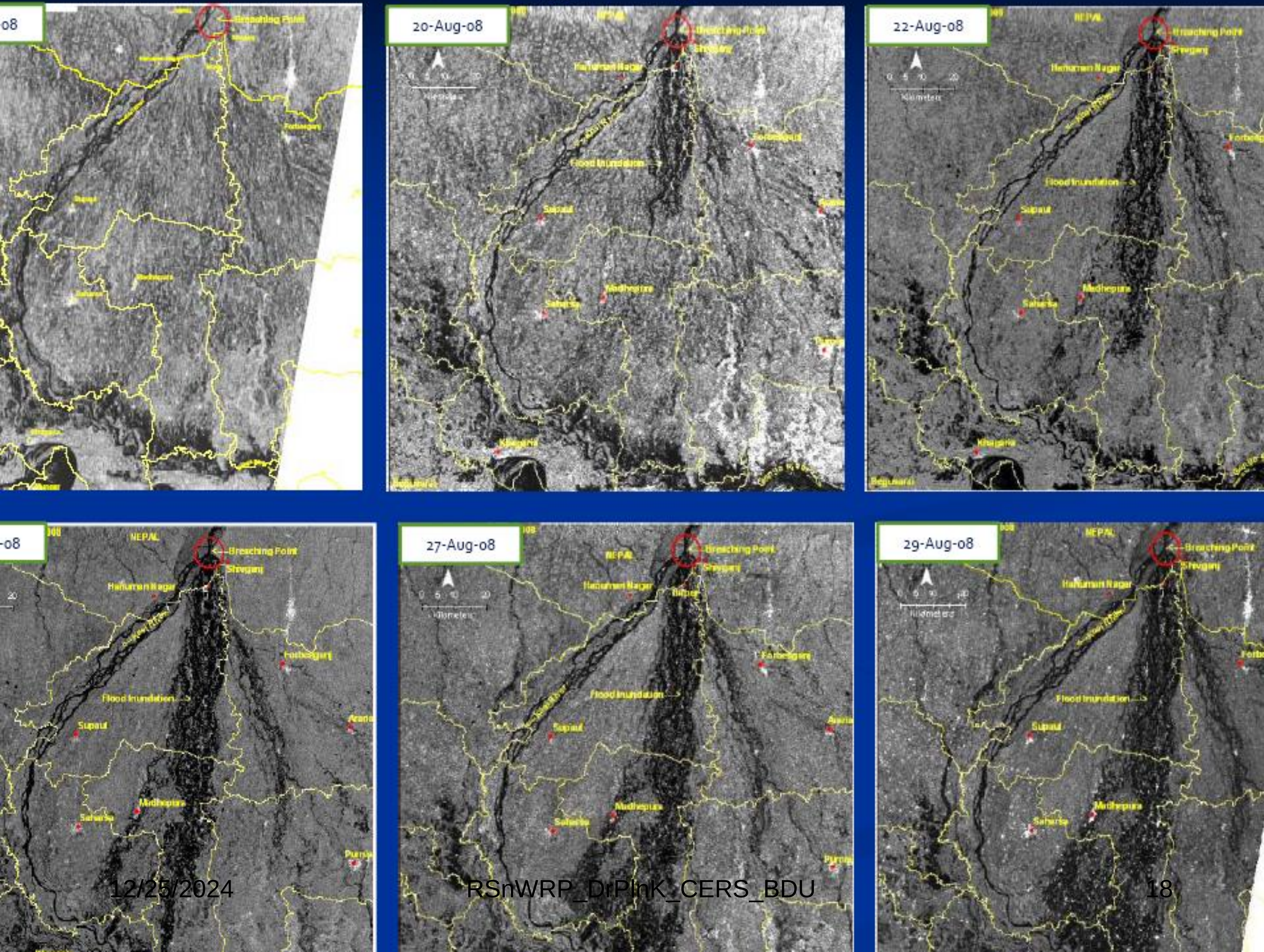
The left image displays the Landsat 8 Surface Reflectance (SR) of Sacramento area and the right side image is the SR-derived Normalized Difference Moisture Index (NDMI)



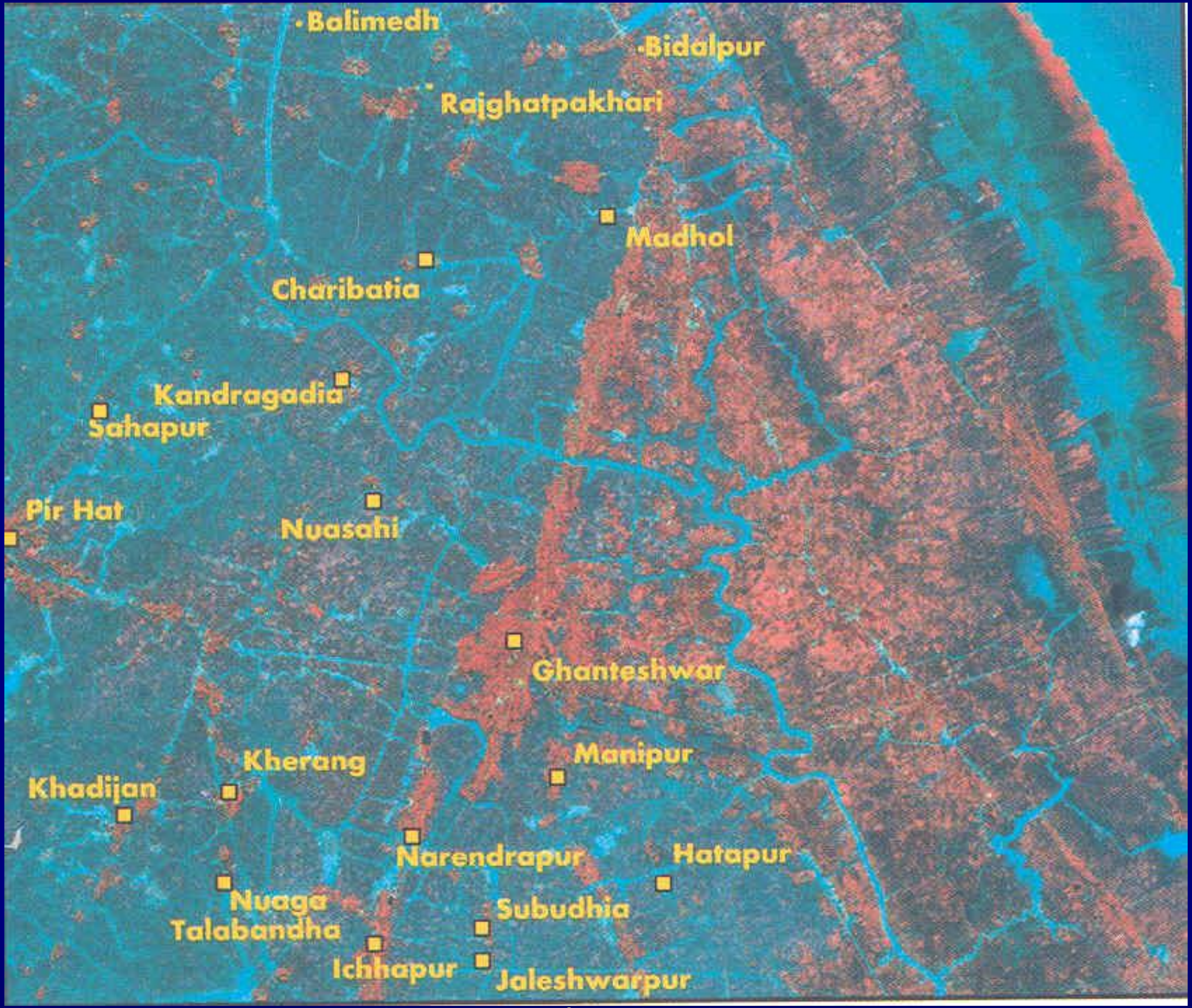




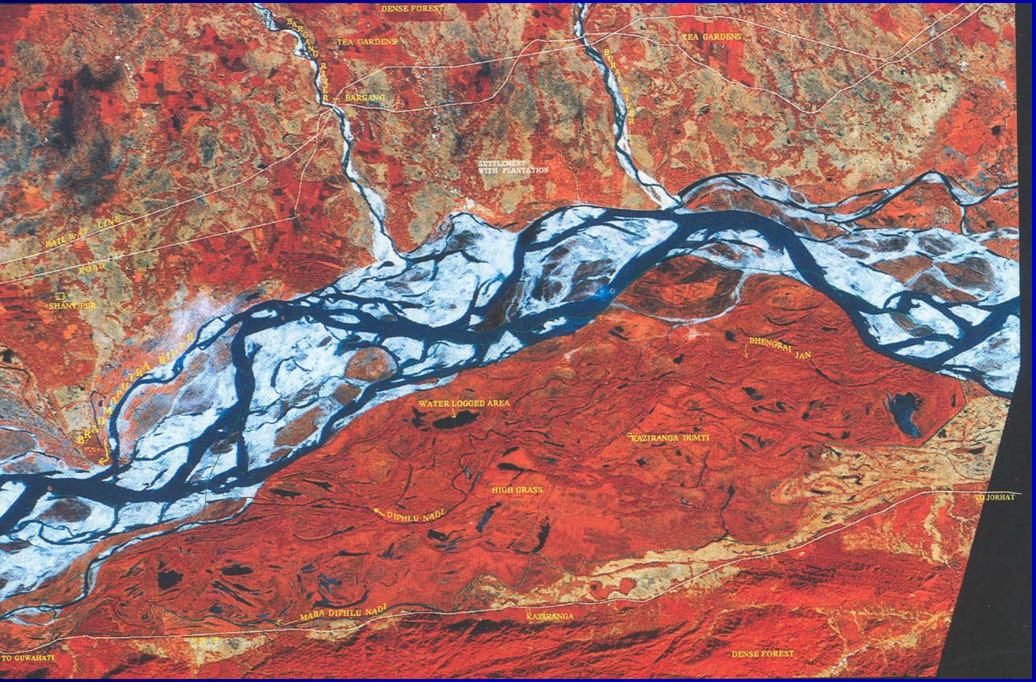
29-Aug-08
NEPAL
Branching Point
Hanuman Nagar
Kilometers
Forbesganj
Flood Inundation
Supaul
Madhepura
Saharsa

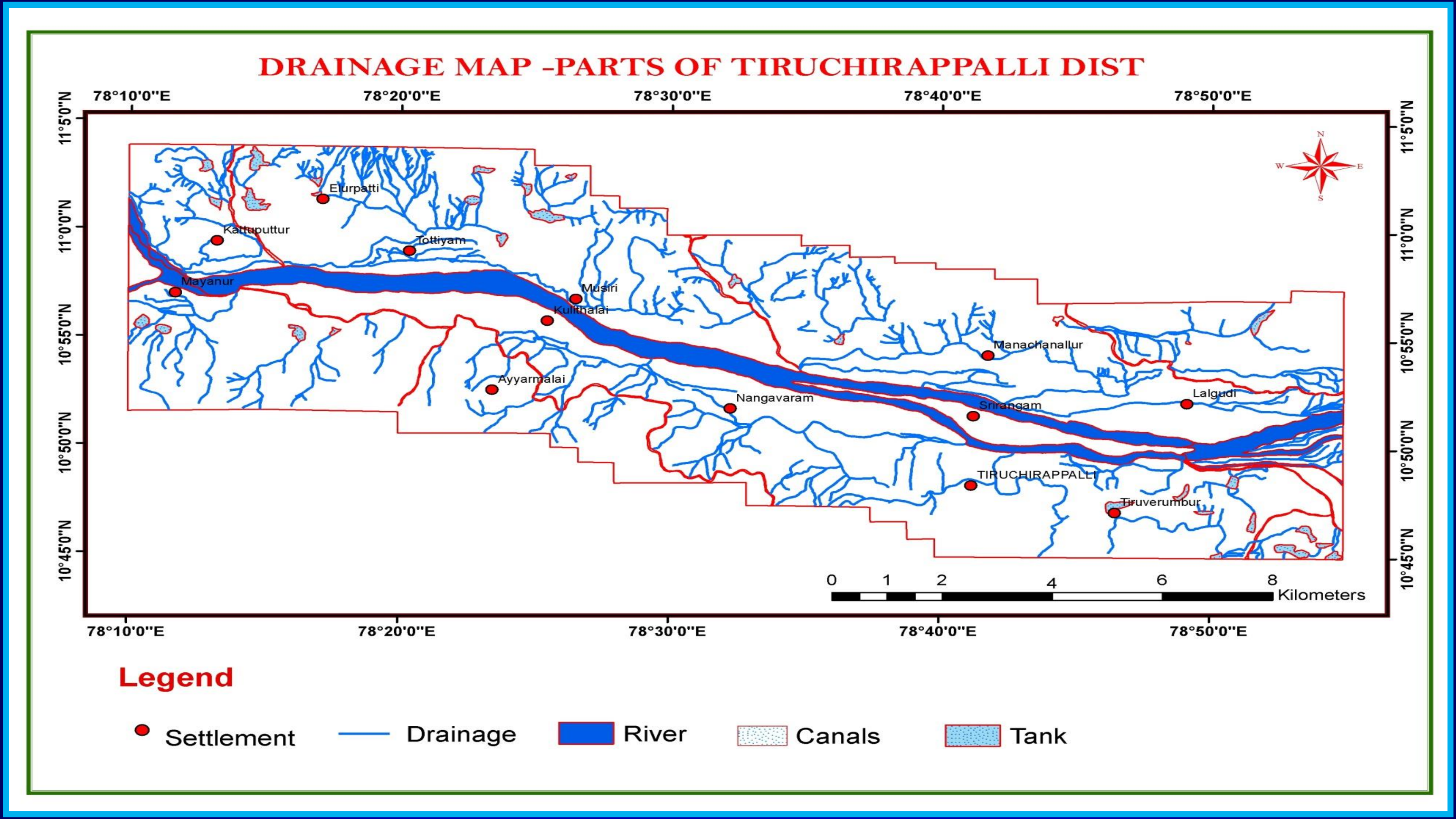

20-Aug-08
22-Aug-08
27-Aug-08
29-Aug-08
NEPAL
Breaching Point
Shivganj
Hanuman Nagar
Forbesganj
Flood Inundation
Supaul
Madhepura
Saharsa
Khagaria
Araria
Purnia
Begusarai
Kilometers

RADARSAT – ORISSA – POST – CYCLONE



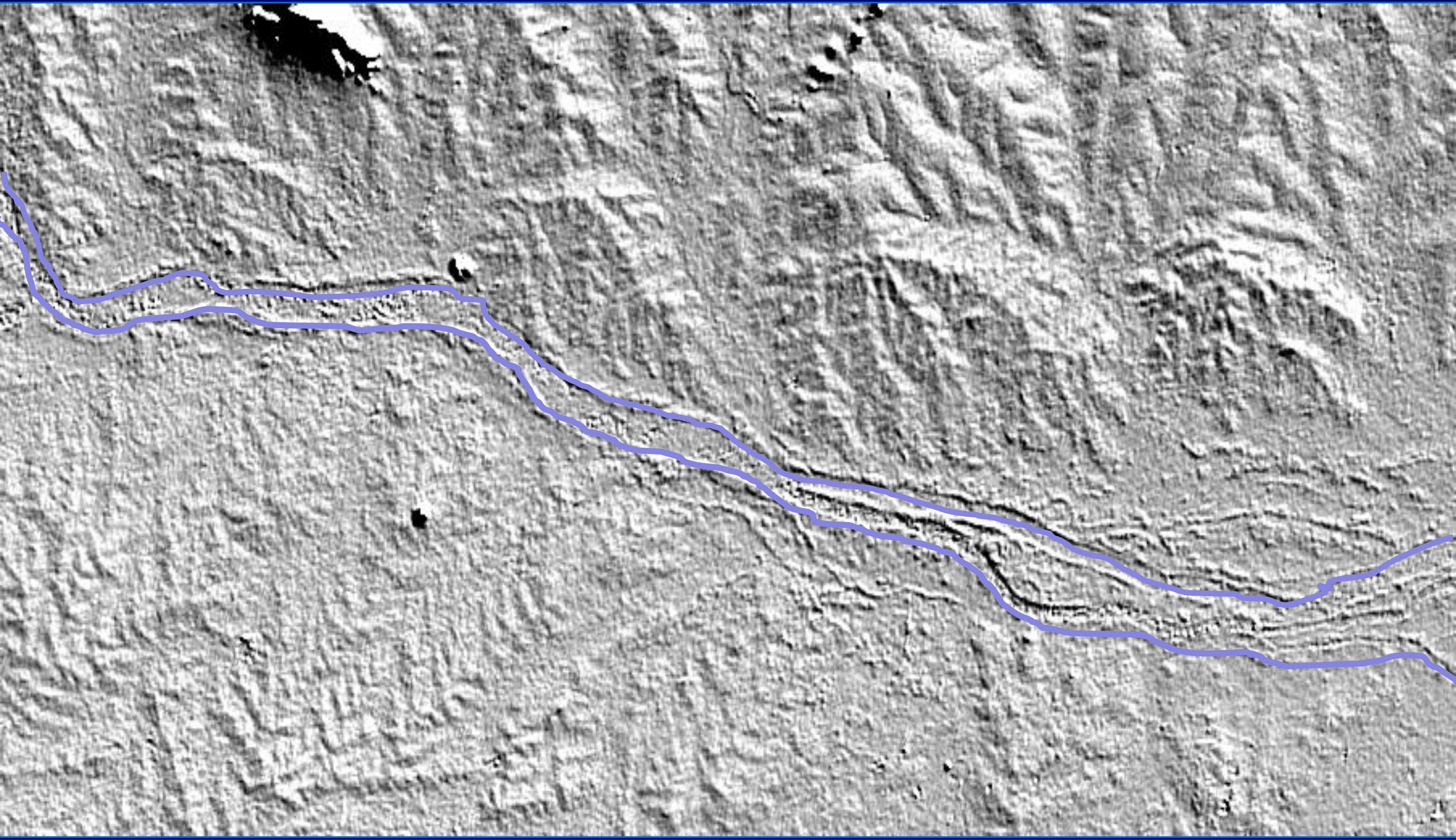
Disaster due to Flooding





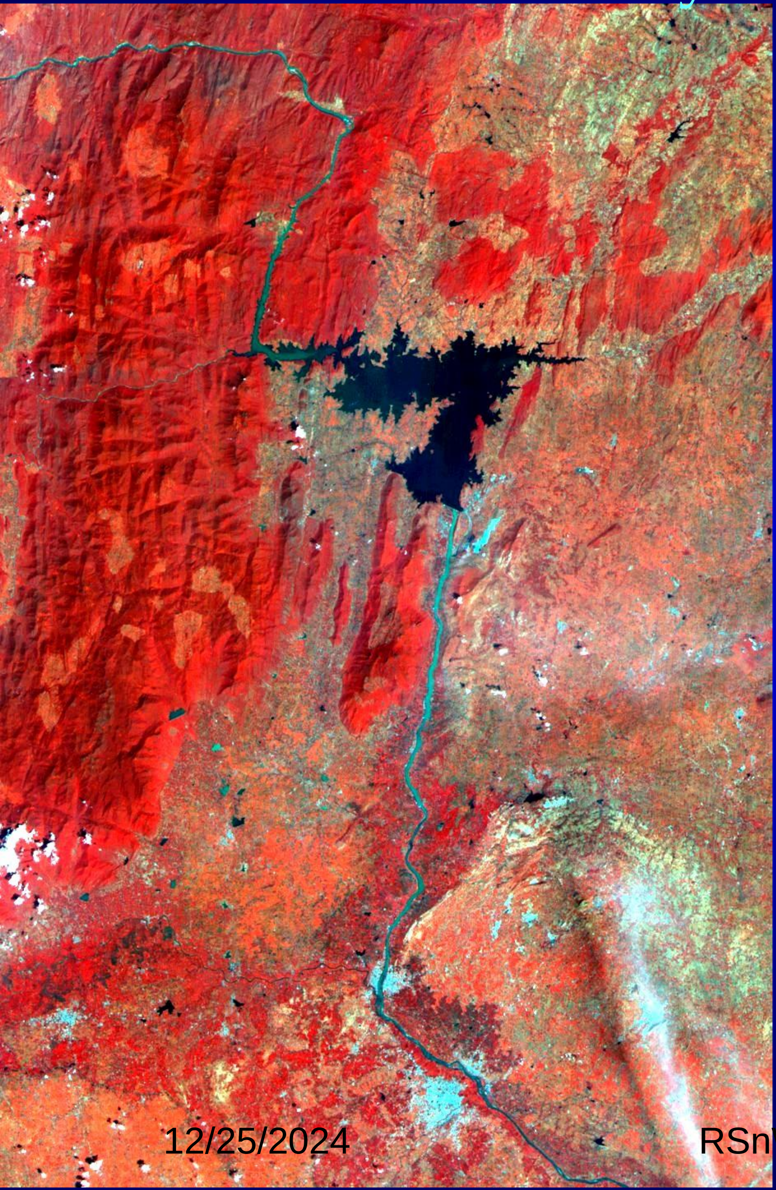
- Drainage map was prepared from the SOI Toposheets 58J/1, 5, 9 & 13, 58I/4 & 5.
- The drainages, streams, rivers, canals and tanks prepared as separate layers are staked to prepare this map.
- High resolution DEM of the same area can be used to derive all micro drainages useful for management.
- It is necessary to keep them without silt soak and obstruction by vegetal cover and human encroachment

SHADED RELIEF MAP

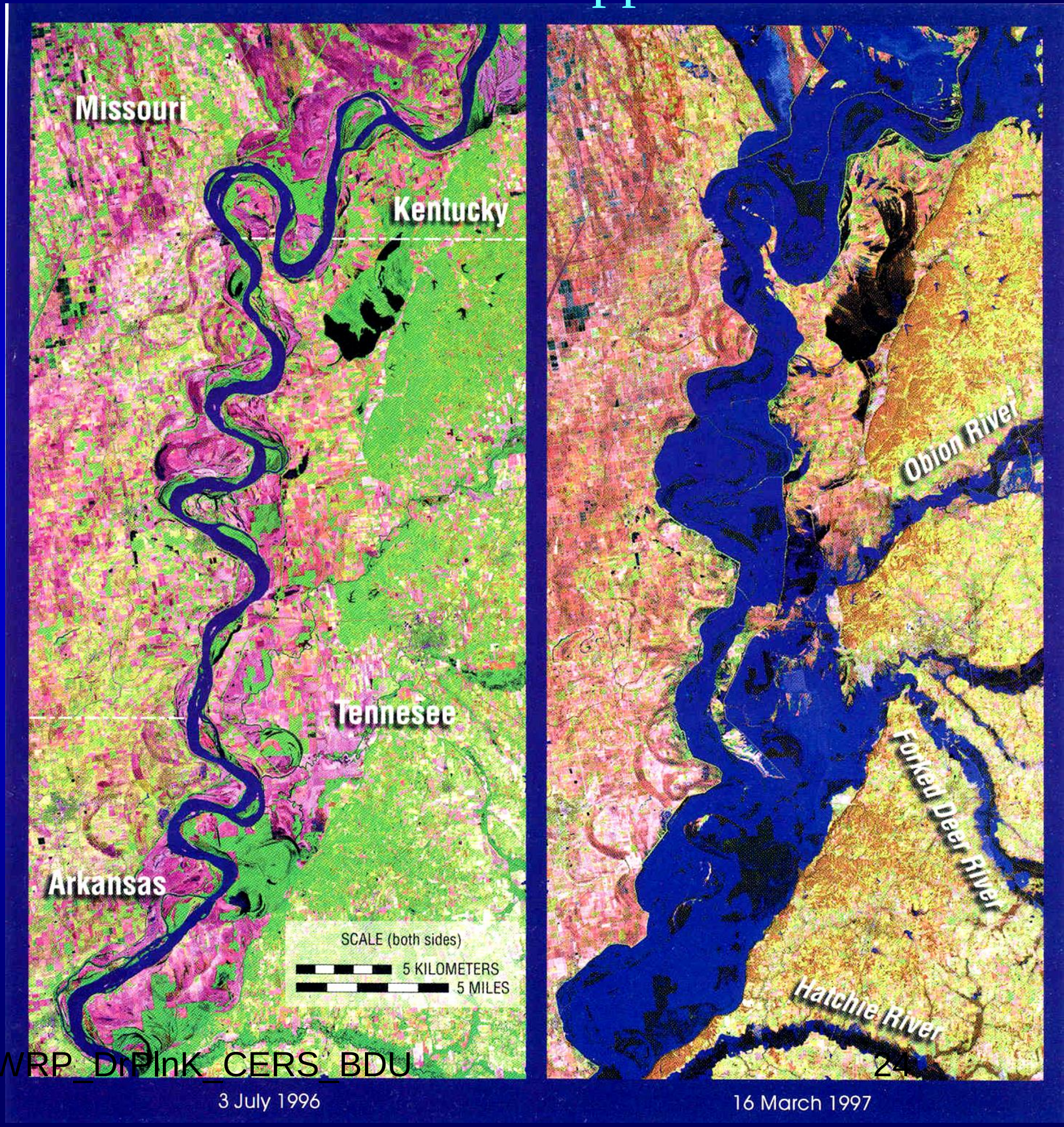


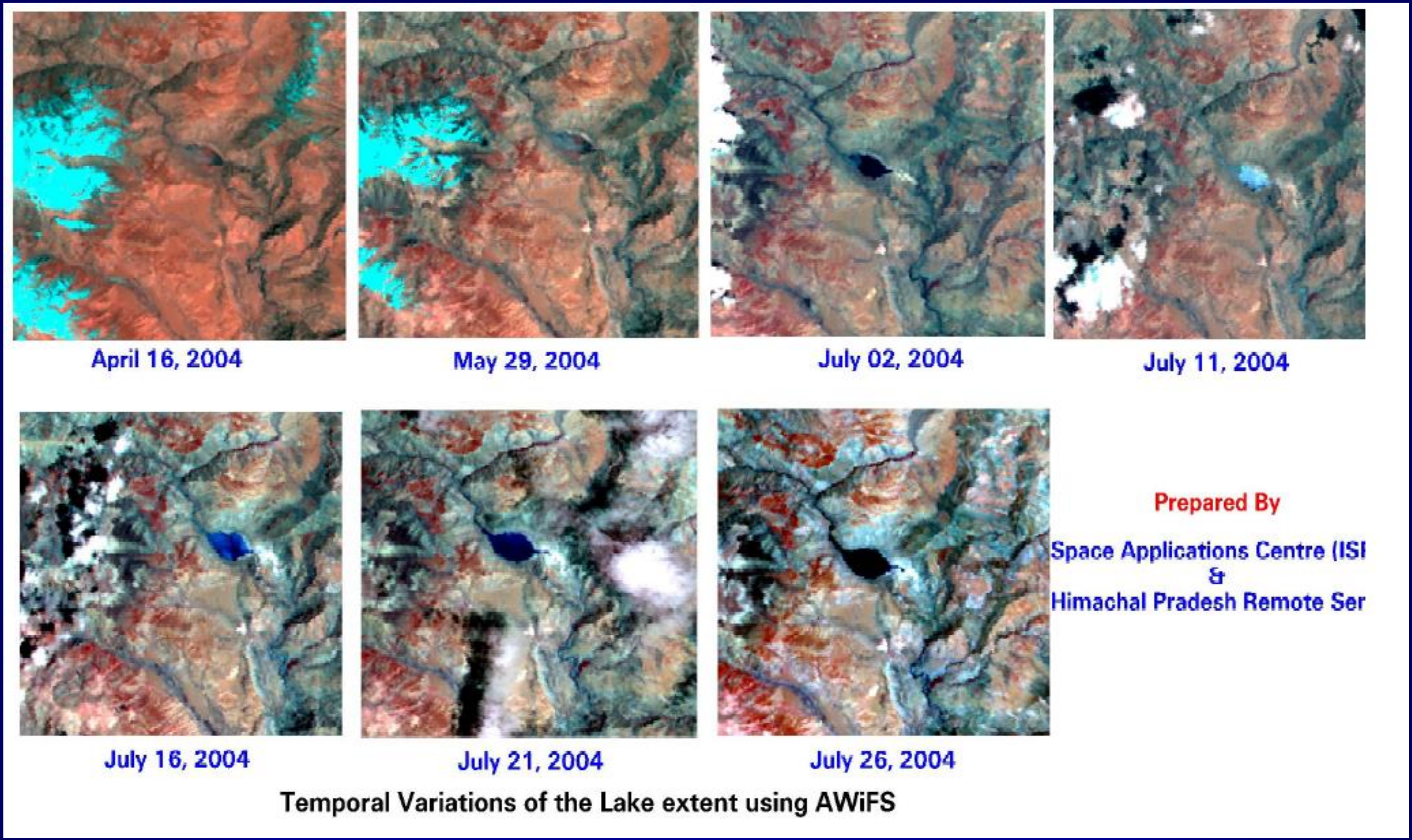
SURFACE WATER RESOURCES - FLOODS

Mettur Dam – Cauvery river



Mississippi River





The quantum of blocked water stored in this temporary reservoir was estimated later to understand the danger and to safeguard the people in its downstream.

14th Aug. 2004

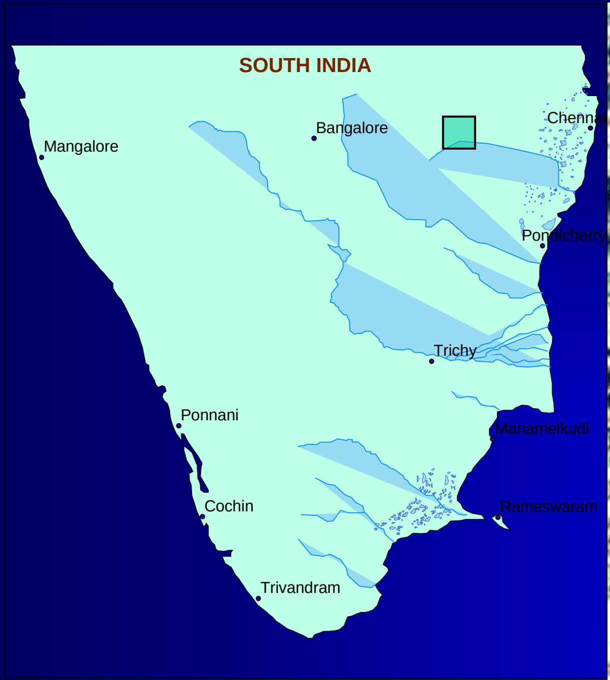
Back

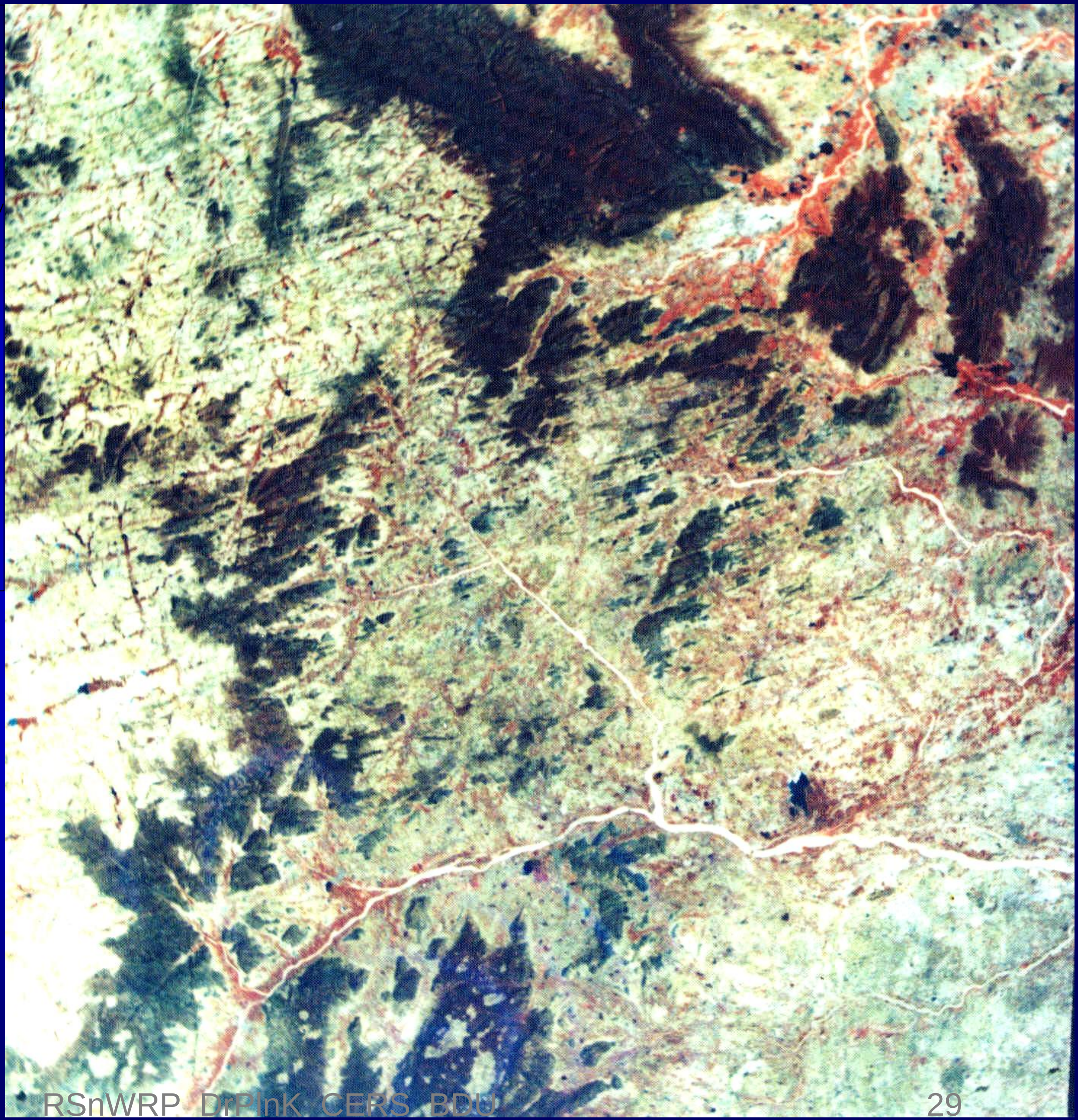
Buried channels of mighty river Sarasvathi

Eolian plain – Thar Desert

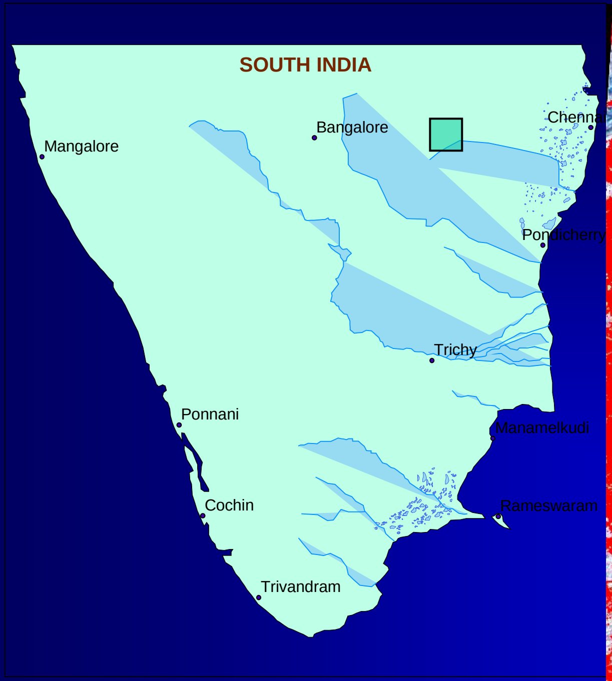
Back

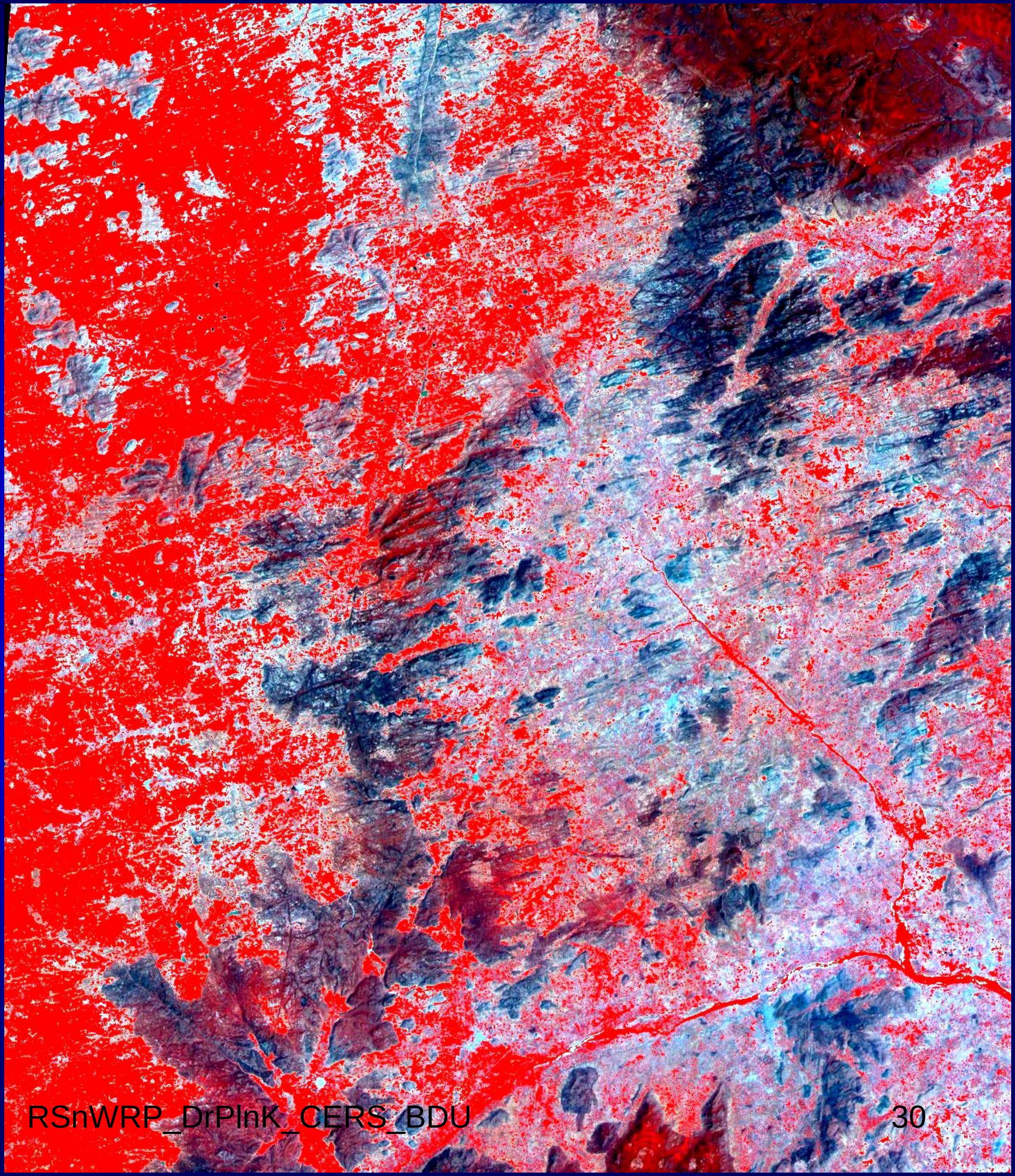
Central Pivot irrigation system in Kansas using Ogallala Aquifer – Circular crop fields (200m – 500m radii)





SOIL EROSION – TIRUTTANI & TIRUMALA REGION





SOIL EROSION – TIRUTTANI & TIRUMALA REGION

PROCESSED IMAGE

Research & Development studies conducted and Pilot Models developed, validated & implemented with success in several places, on various aspects of Surface Water Resources Conservation and Management at Centre for Remote Sensing, Bharathidasan University are:

1. **Watershed wise Runoff Modelling**
2. **Tank – Reservoir Water Storage Forecasting**
3. **Surface Water Targetting**
4. **Surface Water Quality from Satellite data**
5. **Soil Erosion – Reservoir Siltation and Remedial Measures**
6. **Inter-watershed water transfer**
7. **Flood water Harvesting**
8. **GIS based Drainage Morphometric Analyses & Runoff Estimation**

STUDY - 1A

WATERSHED WISE RUNOFF MODELLING

Back

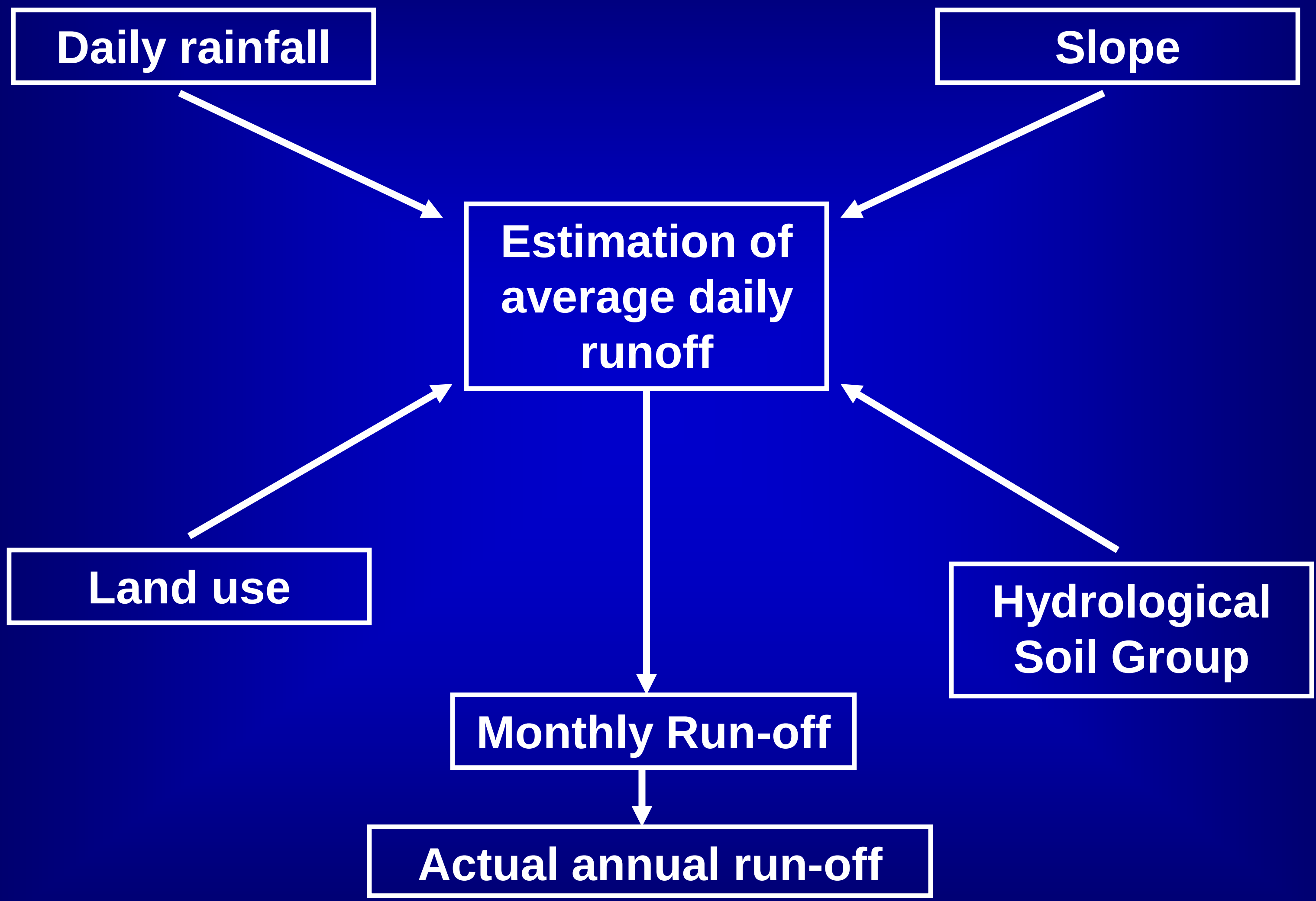
STUDY 1

WATERSHED WISE RUNOFF MODELLING

- **INPUT DATA**
  - **Daily Rain Fall**
  - **Slope**
  - **Hydrological Soil Group**
  - **Land Use and Land Cover**

- **OUTPUT DATA**
  - Monthly **Run off**
  - **Annual Run Off**

ESTIMATION OF SURFACE WATER POTENTIAL / RUNOFF ESTIMATION

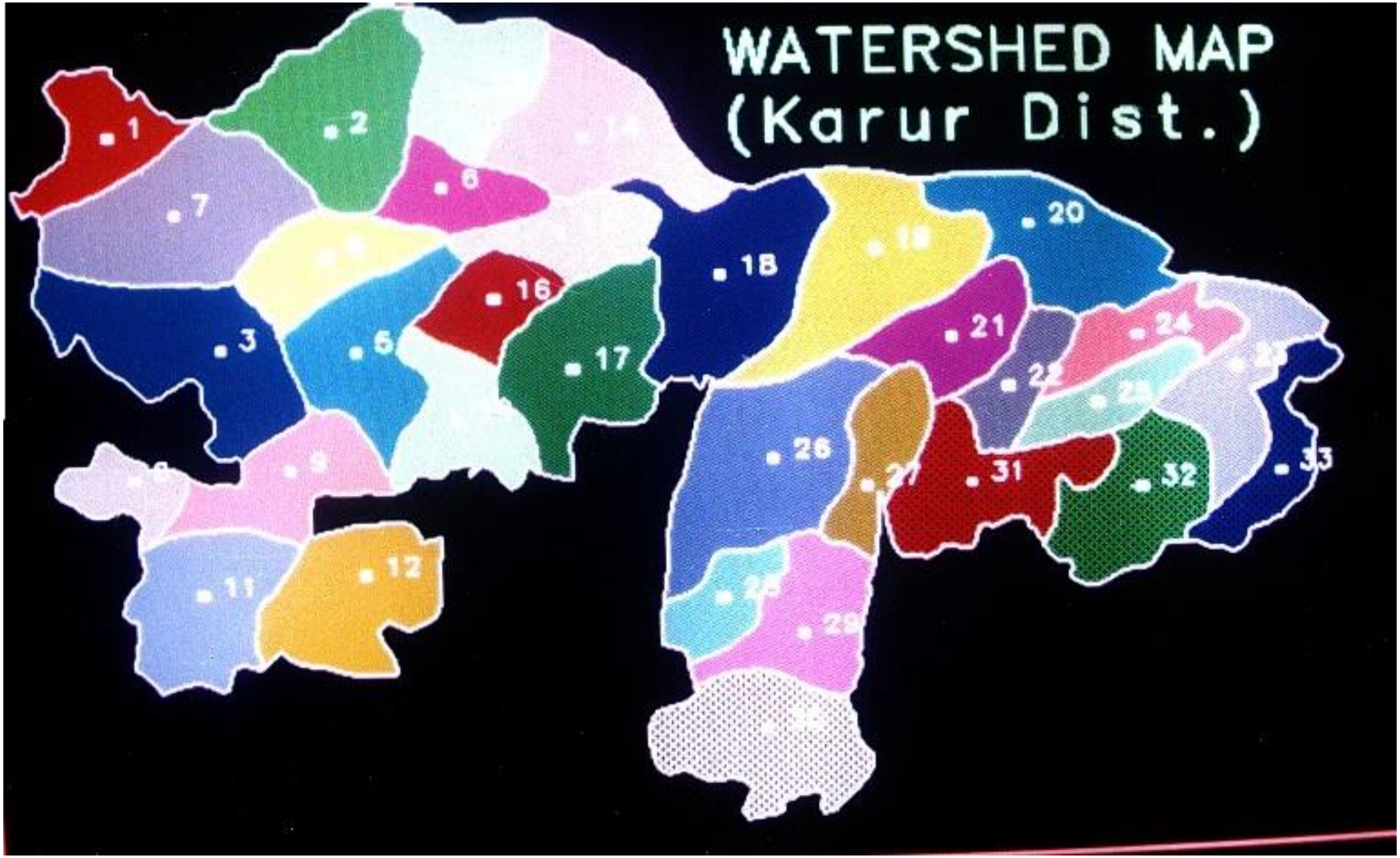


The Surface water potential on watershed basis, DRY-DAMP-WET method
For Example,

In the Karur District, 33 sub watersheds were mapped using drainage map.

Subsequently other data bases were generated on

- **Daily Rainfall for 30 Years (from 23 rain gauge stations)**
- **Mean Slope for each Watershed**
- **Landuse and Land Cover and**
- **Hydrological Soil Group**


WATERSHED MAP
(Karur Dist.)
1
2
6
7
3
16
17
18
20
21
22
24
26
31
32
33
11
12

Criteria for classification of Hydrological Soil Group

Soil Character	HSG-A	HSG-B	HSG-C	HSG-D
Infiltration Rate	High	Moderate	Slow	Very slow
Soil Texture	Sand/Gravel-coarse	Moderately Coarse	Moderately fine	Clay-fine
Soil depth	Deep	Moderately deep to deep	Moderately deep	Shallow over an impervious layer or clay pan or high/shallow water table
Drainage	Very slow	Moderately drained to slow	Moderately well drained to well drained	Well to excess
Water transmission	High	Moderate	Slow	Very slow
Remarks	**Low runoff potential**	**Moderate runoff potential**	**Moderate runoff potential**	**High runoff potential**

TABLE 1

SLOPE DATA

SL.NO.	WATERSHED NO.	SLOPE IN RADIANCE
1	1	0.02616
2	2	0.27610
3	3	0.02035
4	4	0.02442
5	5	0.01744
6	6	0.01744
7	7	0.03198
8	8	0.01453
9	9	0.02035
10	10	0.15180
11	11	0.04797
12	12	0.06154
13	13	0.01744
14	14	0.01744
15	15	0.02350
16	16	0.01599
17	17	0.01686
18	18	0.01744
19	19	0.01279
20	20	0.01221
21	21	0.01162
22	22	0.01279
23	23	0.01628
24	24	0.01762
25	25	0.16280
26	26	0.01162
27	27	0.01744
28	28	0.12210
29	29	0.01192
30	30	0.22677
31	31	0.04797
32	32	0.03488
33	33	0.03458

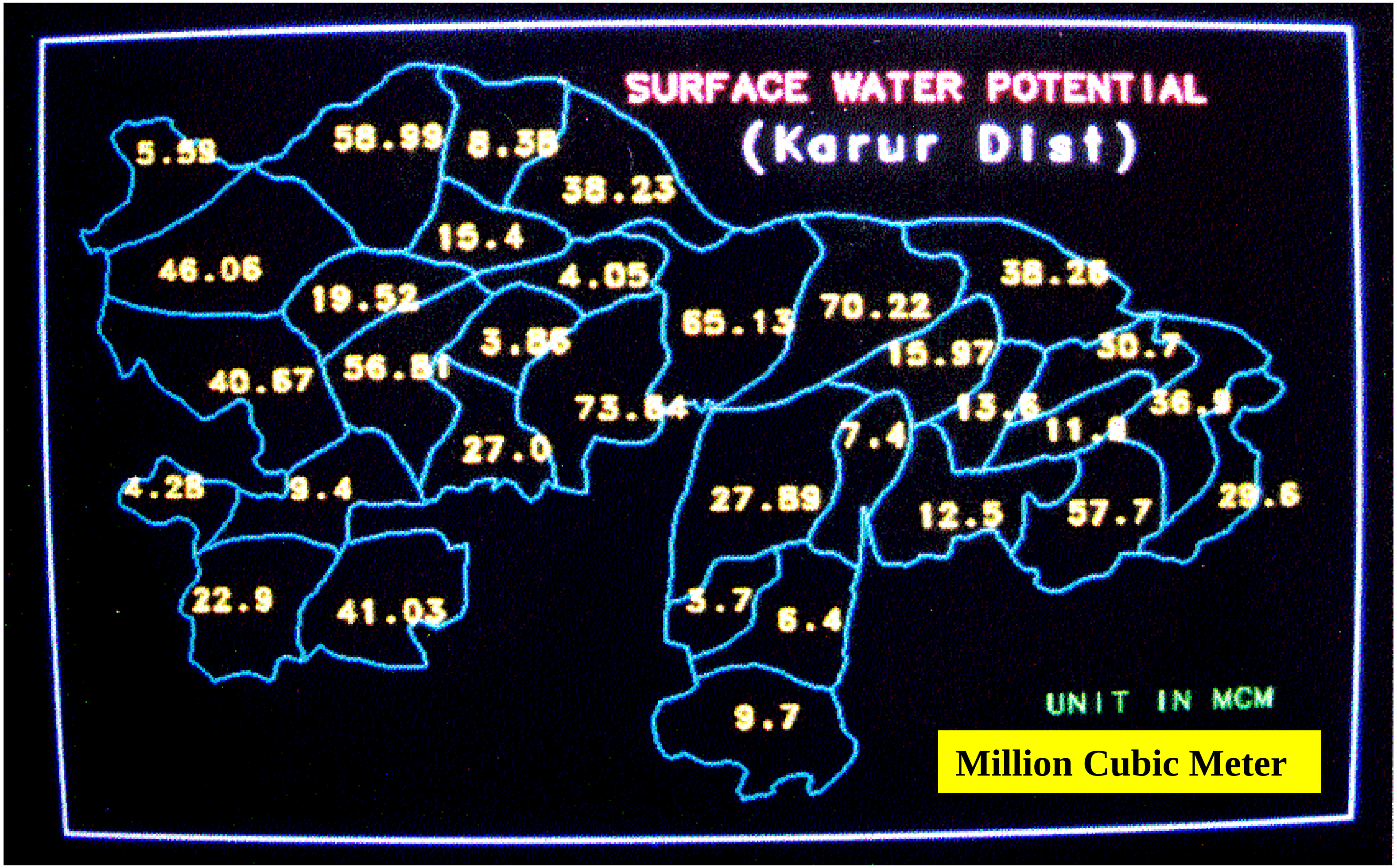
TABLE 2

HYDROLOGICAL SOIL GROUP DATA

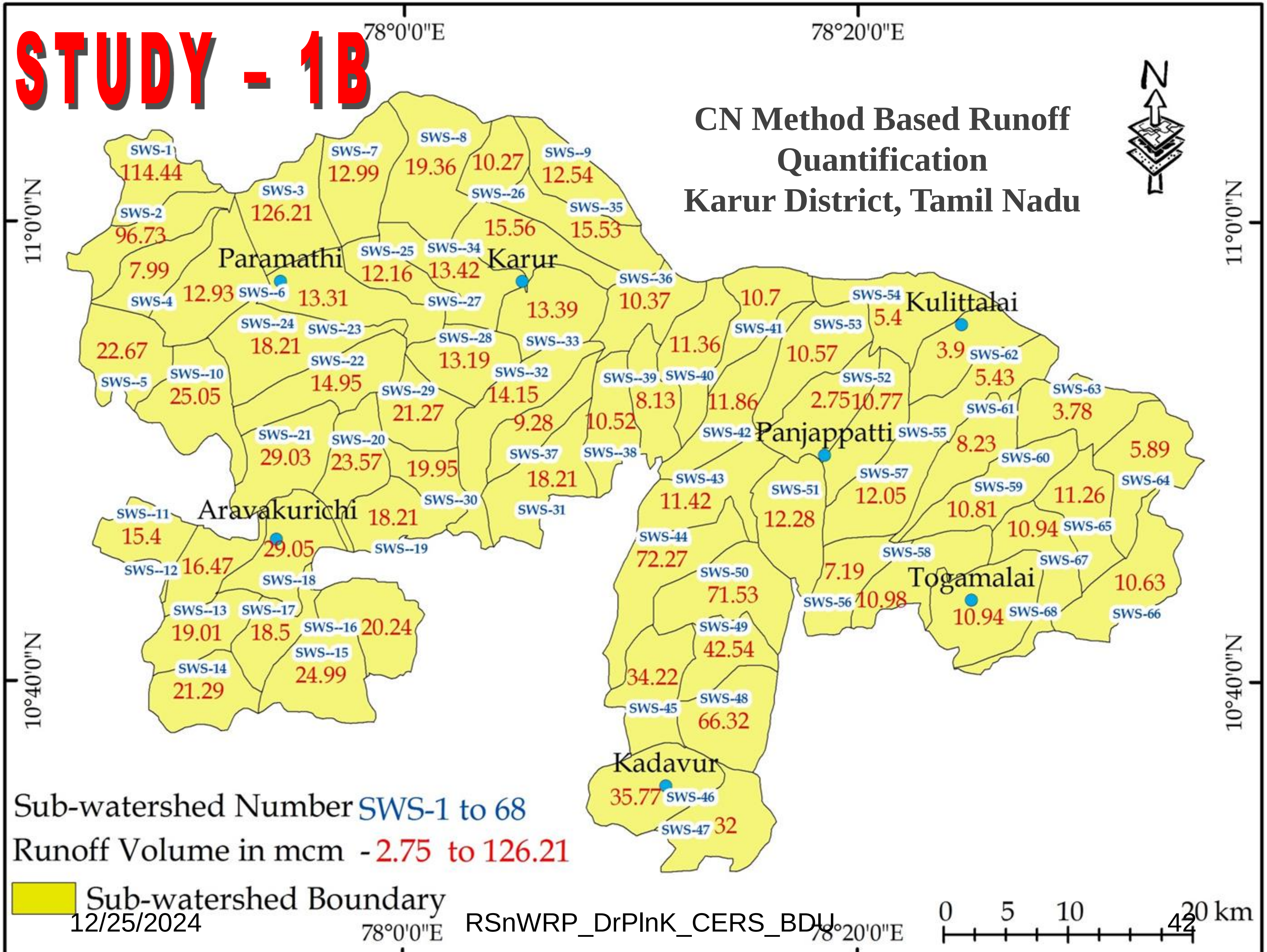
SL.NO.	WATERSHED NO.	AREA IN Sq.Km. A	B	C	D
1	1	0.30	69.96	0.00	0.00
2	2	0.00	127.00	3.08	0.00
3	3	0.50	148.17	0.64	0.00
4	4	2.30	64.55	0.04	0.00
5	5	0.00	96.77	2.22	0.00
6	6	1.06	50.41	0.87	0.00
7	7	0.03	150.80	3.14	0.00
8	8	0.00	38.67	0.00	0.00
9	9	0.02	80.16	0.14	0.00
10	10	2.73	64.95	1.07	0.00
11	11	0.34	107.25	0.00	0.00
12	12	0.11	106.71	0.23	0.00
13	13	0.00	69.79	2.31	0.00
14	14	0.00	105.00	2.73	0.00
15	15	0.00	50.58	0.99	0.00
16	16	0.00	47.06	2.37	0.00
17	17	0.84	110.35	0.78	0.00
18	18	0.83	122.82	4.61	0.00
19	19	0.00	130.31	7.99	0.00
20	20	0.03	103.94	3.84	0.00
21	21	0.00	65.63	0.86	0.00
22	22	0.00	43.66	0.19	0.00
23	23	0.13	82.71	3.85	0.00
24	24	0.00	55.22	0.33	0.00
25	25	0.00	44.77	0.25	0.00
26	26	0.18	138.03	8.66	0.00
27	27	0.00	56.37	0.12	0.00
28	28	0.10	41.86	0.58	0.00
29	29	2.96	79.14	0.00	0.00
30	30	2.47	90.65	17.94	0.00
31	31	0.11	93.21	6.61	0.00
32	32	[illegible]	87.28	[illegible]	0.00
33	33	0.00	62.57	0.00	0.00

TABLE 3
LANDUSE AND LANDCOVER DATA

SL.NO.	WATERSHED NO.	AREA IN Sq.Km. WETCROP	DRYCROP	NATURAL VEGETATION	BARREN LAND
1	1	5.56	4.12	0.00	61.07
2	2	19.25	7.25	0.00	106.96
3	3	14.75	3.43	0.00	111.95
4	4	1.81	2.06	0.00	67.63
5	5	12.65	3.87	0.00	72.85
6	6	15.62	10.06	0.00	33.44
7	7	3.75	1.43	0.00	145.20
8	8	31.30	5.75	0.00	14.95
9	9	6.25	13.87	0.00	69.56
10	10	6.47	7.81	0.00	68.95
11	11	5.50	3.93	0.00	98.82
12	12	7.43	8.75	3.25	94.07
13	13	96.06	7.60	0.00	44.38
14	14	45.56	10.62	0.00	58.32
15	15	15.93	3.00	0.00	33.05
16	16	7.25	13.50	0.00	39.50
17	17	9.94	23.62	0.00	95.01
18	18	29.93	5.75	0.00	87.94
19	19	12.62	38.12	0.00	79.60
20	20	82.87	2.00	0.50	27.16
21	21	6.27	8.39	0.25	29.53
22	22	8.06	17.75	0.00	42.35
23	23	27.50	0.25	0.00	64.88
24	24	28.00	7.00	0.00	18.50
25	25	7.13	9.25	0.00	31.00
26	26	13.08	7.82	1.00	106.35
27	27	11.24	6.25	0.00	42.35
28	28	6.00	1.50	6.75	22.15
29	29	12.93	2.00	16.00	57.57
30	30	7.50	1.80	38.50	45.80
31	31	11.30	12.68	0.00	70.70
32	32	16.50	15.87	0.00	52.78
33	33	22.31	3.00	0.00	42.31


SURFACE WATER POTENTIAL
(Karur Dist)
46.06
19.52
40.67
15.4
4.05
70.22
65.13
15.97
22.9
41.03
27.0
27.89
12.5
57.7
30.7
6.4
9.7
UNIT IN MCM
Million Cubic Meter

STUDY - 1B



CN Method Based Runoff Quantification
Karur District, Tamil Nadu
78°0'0"E
78°20'0"E
11°0'0"N
10°40'0"N
Paramathi
Karur
Kulittalai
Panjappatti
Aravakurichi
Togamalai
Kadavur
Sub-watershed Number SWS-1 to 68
Runoff Volume in mcm - 2.75 to 126.21
Sub-watershed Boundary
0 5 10 20 km

STUDY - 2

TANK - RESERVOIR STORAGE FORE CASTING

☛ **USING SATELLITE IR DATA**

Back

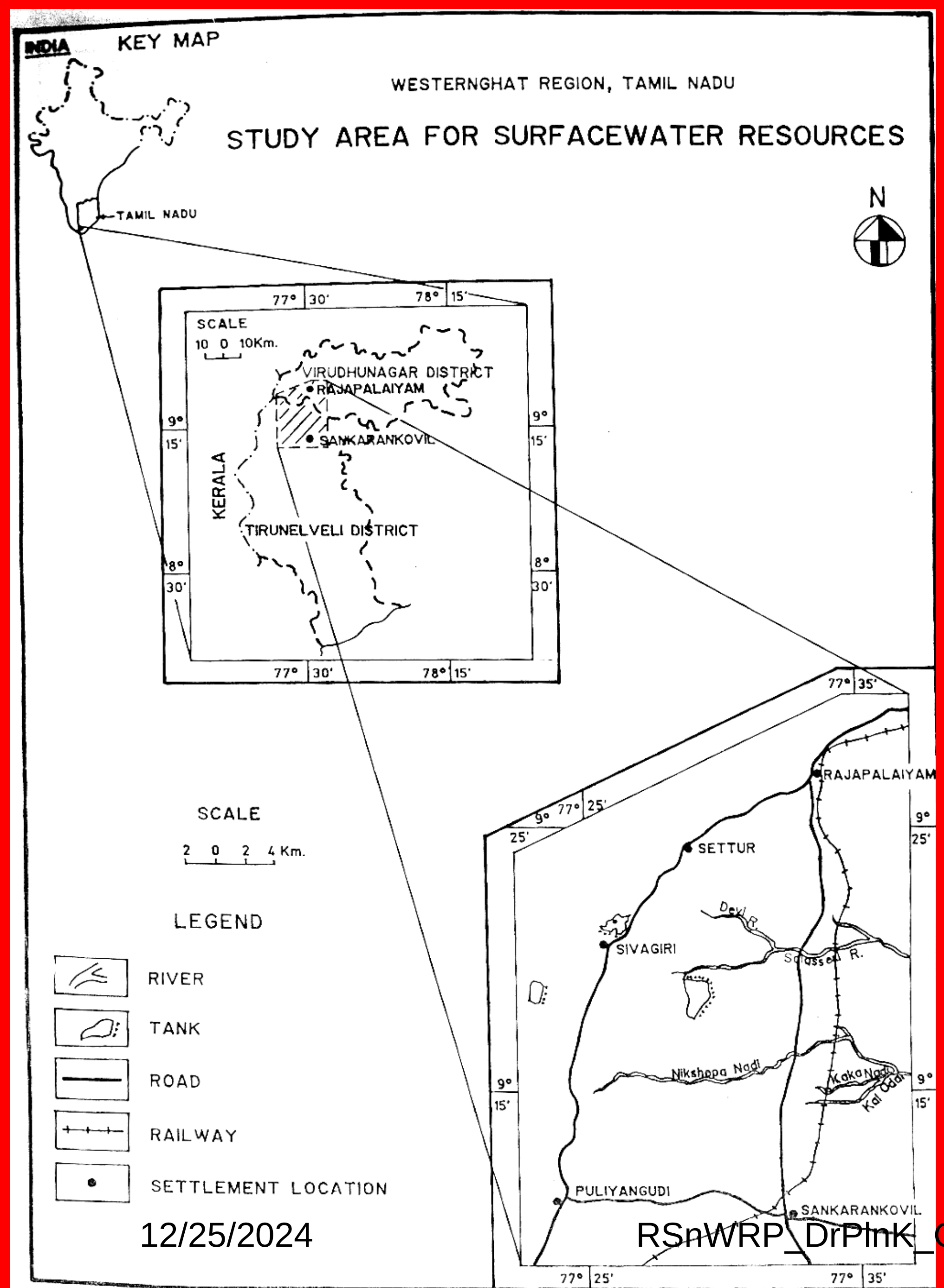
METHODOLOGY(in Brief)

STUDY - 2A

Identification of 30 Surface Water Bodies each in Small, Medium and Major Categories

- **Work out the Perimeter of Water Spread area from Satellite IR Data**
- **Work out bottom topography & Average Depth of Tanks**
- **Estimate Volume of Water in 30 Water bodies**
- **Establish the relation between WSA and WV**

Surface Water Resources



SURFACEWATER QUANTIFICATION

Sl.No.	Tank No.	Water Spread Area (in sq.mts)	Average Depth (in mts)	Water Volume (in cubic mts)
1	M-1	700000	1.50	1050000
2	M-2	640000	0.75	480000
3	M-3	700000	1.50	1050000
4	M-4	560000	2.50	1400000
5	M-5	470000	1.50	705000
6	M-6	420000	2.00	840000
7	M-7	480000	1.50	720000
8	M-8	200000	2.50	500000
9	M-9	140000	1.50	210000
10	M-10	100000	1.25	125000
11	I-1	160000	1.25	200000
12	I-2	60000	0.75	45000
13	I-3	150000	1.50	225000
14	I-4	250000	1.50	375000
15	I-5	120000	1.00	120000
16	I-6	250000	3.50	875000
17	I-7	280000	3.00	840000
18	I-8	180000	2.00	360000
19	I-9	150000	2.50	375000
20	I-10	100000	2.50	250000
21	I-11	130000	1.50	195000
22	I-12	150000	2.50	375000
23	I-13	170000	2.00	340000
24	I-14	180000	2.00	360000
25	I-15	260000	3.00	780000
26	I-16	80000	1.50	120000
27	I-17	120000	1.00	120000
28	I-18	100000	1.00	100000
29	I-19	80000	1.00	80000
30	I-20	230000	1.50	345000

M - Major Tank; I - Intermediate Tank; m - Minor Tanks

- Establish the relationship between **Tank Water Volume** and the **Water Spread Area** so as to develop a model, which will be of more easy to calculate the temporal availability of volume of water in water bodies at any time only with ***water spread area*** alone.

- Carry out Regression Analysis Between Water Volume Data of 30 tanks (Dependent Variable) and Perimeter of Water Spread area (Independent Variable) and Build up a Model:

$$\boxed{\text{Water Volume} = \text{Coefficient A} + (\text{Coefficient B} \times \text{Water Spread Area})}$$

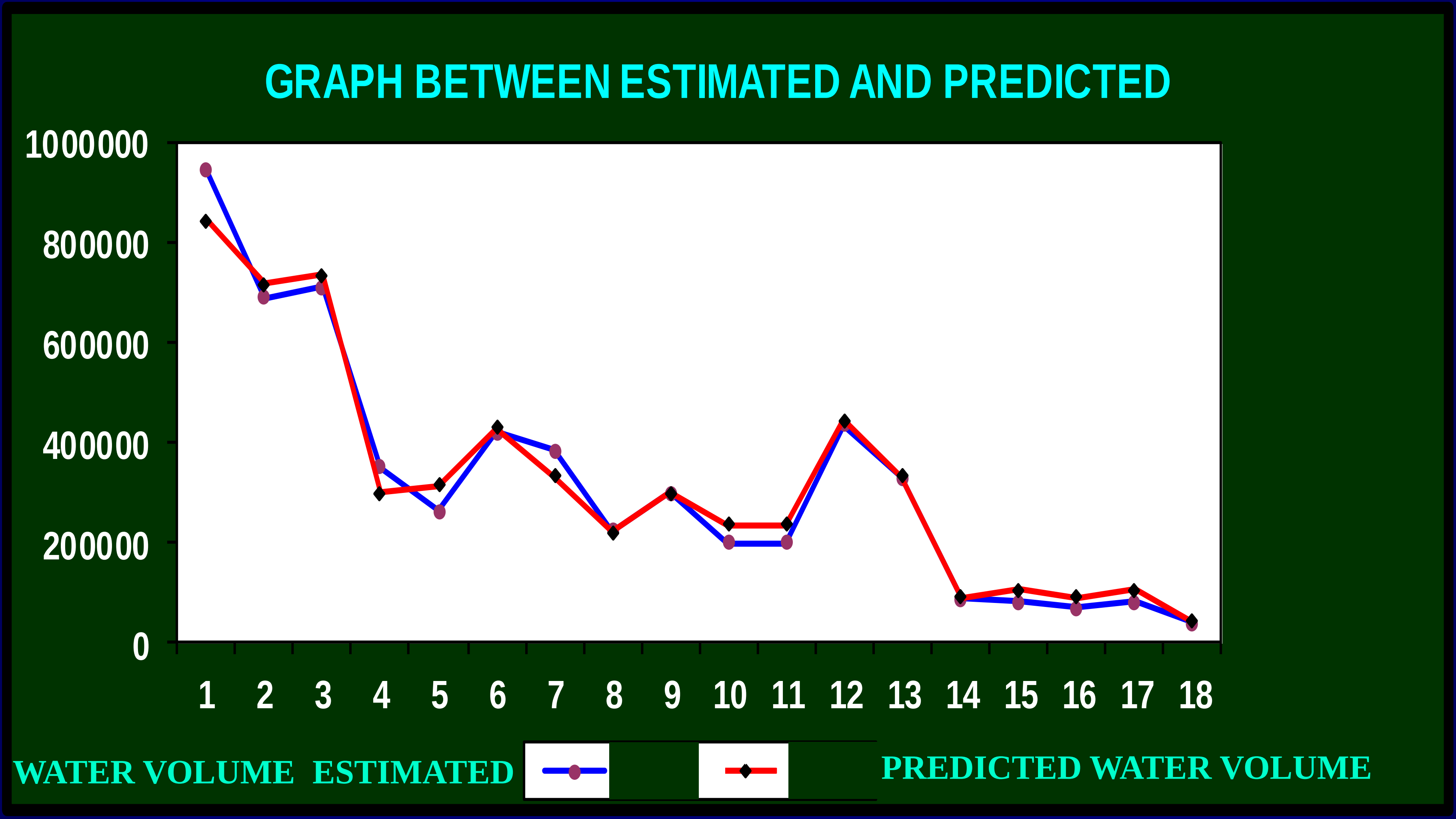
- Validate the model

- Feed the WSA data from temporal satellite data in the model and we can forecast the Water quantity.

SURFACEWATER - PERIODICAL ASSESSMENT MODEL VALIDATION

Sl.No. (1)	Tank No. (2)	Water Spread Area (WSA) (in sq.mts) (3)	Water Volume Calculated (in Cubic mts) (4)	Water Volume by model Coef.A+(Coef.BxWSA) (in Cubic mts) (5)
1	VM-1	540000	945000	847466
2	VM-2	460000	690000	718666
3	VM-3	475000	712500	738066
4	VI-1	200000	350000	300066
5	VI-2	210000	262500	316166
6	VI-3	280000	420000	428866
7	VI-4	220000	385000	332266
8	VI-5	150000	225000	219566
9	VI-6	200000	300000	300066
10	VI-7	160000	200000	235666
11	VI-8	160000	200000	235666
12	VI-9	290000	435000	444966
13	Vm-1	220000	330000	332266
14	Vm-2	70000	87500	90766
15	Vm-3	80000	80000	106866
16	Vm-4	70000	70000	90766
17	Vm-5	80000	80000	106866
18	Vm-6	40000	40001	42466

VM - Validation Tank - Major
VI - Validation Tank - Intermediate
Vm - Validation Tank - Minor


GRAPH BETWEEN ESTIMATED AND PREDICTED
1000000
800000
600000
400000
200000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
WATER VOLUME ESTIMATED
PREDICTED WATER VOLUME

CASE STUDY-2B

Geospatial Technology in Quantifying Seasonal Availability of Water Stored in Salaulim Reservoir Salauli, Goa State, India

12/25/2024

METHODOLOGY

Generation of Digital Database - Base Map, Contours, Spot Heights in GIS

Conversion of contour Lines into Points and Integration of Spot Heights in GIS to make a single point file

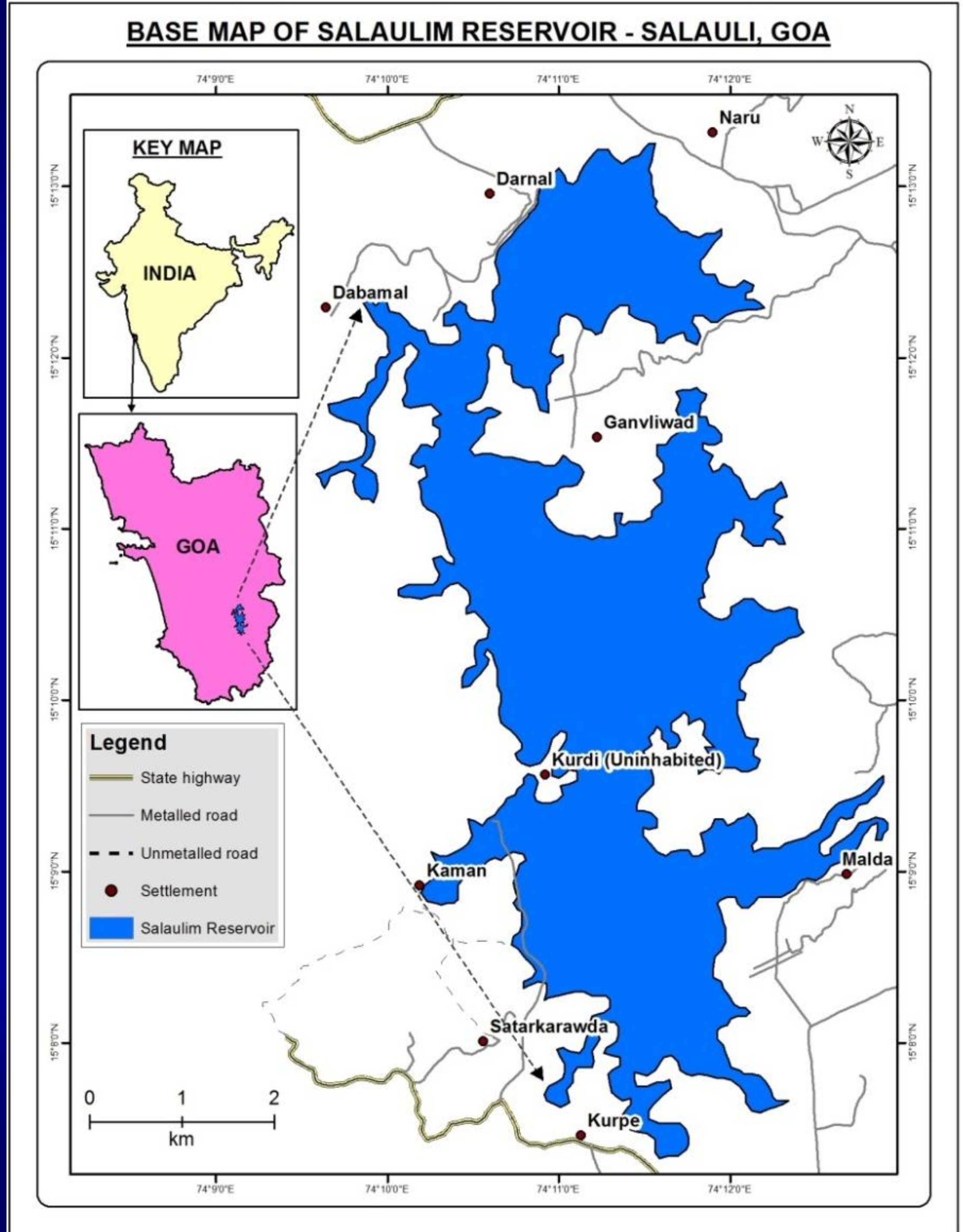
GIS interpolation, generation of 3D DEM and 1m Contours

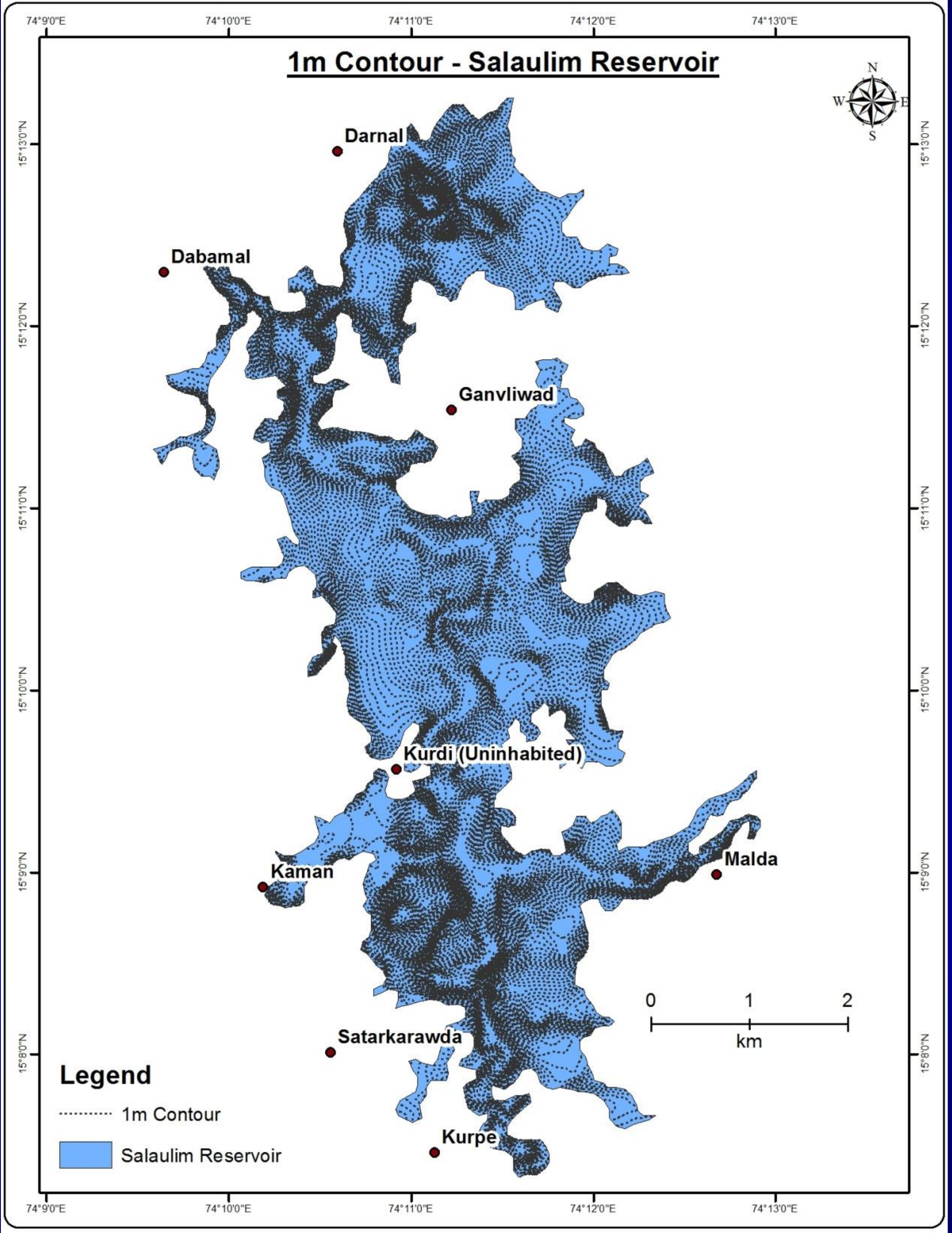
Conversion of raster grid file to point file

Delineation of Water Spread Area in Reservoir using temporal Satellite Data of a particular season

Identification of height of Water Level by Maximum Pattern matching of 1m Contours with Water Spread Area and Calculate the Thickness of Water Column for each pixel within the Water Spread Area using DEM

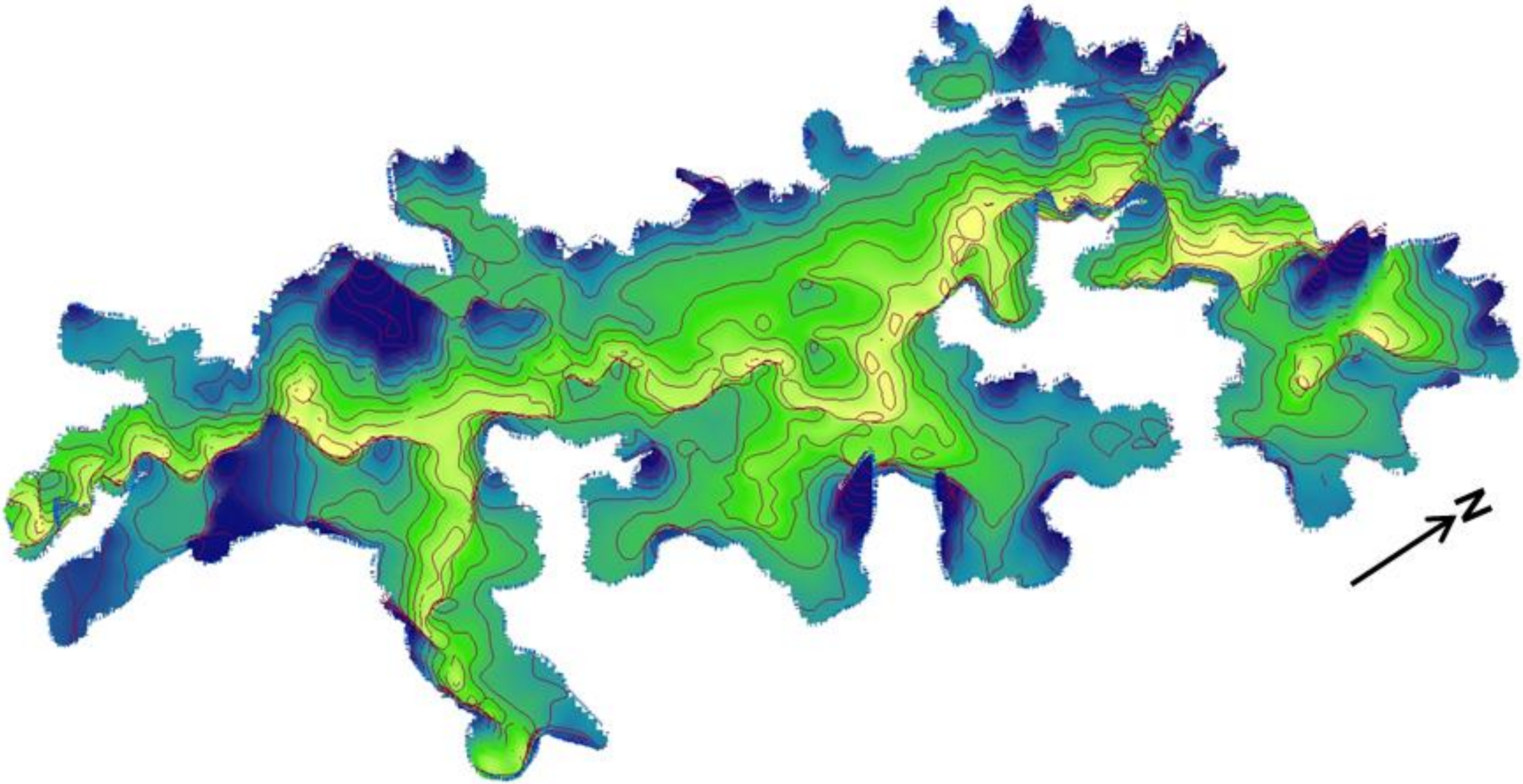
Estimation of Volume of Water in each pixel/point by multiplying the pixel area with Thickness of Water Column for each pixel and Summing up of Pixel wise Water Volume to get Total Volume of Water available in Reservoir

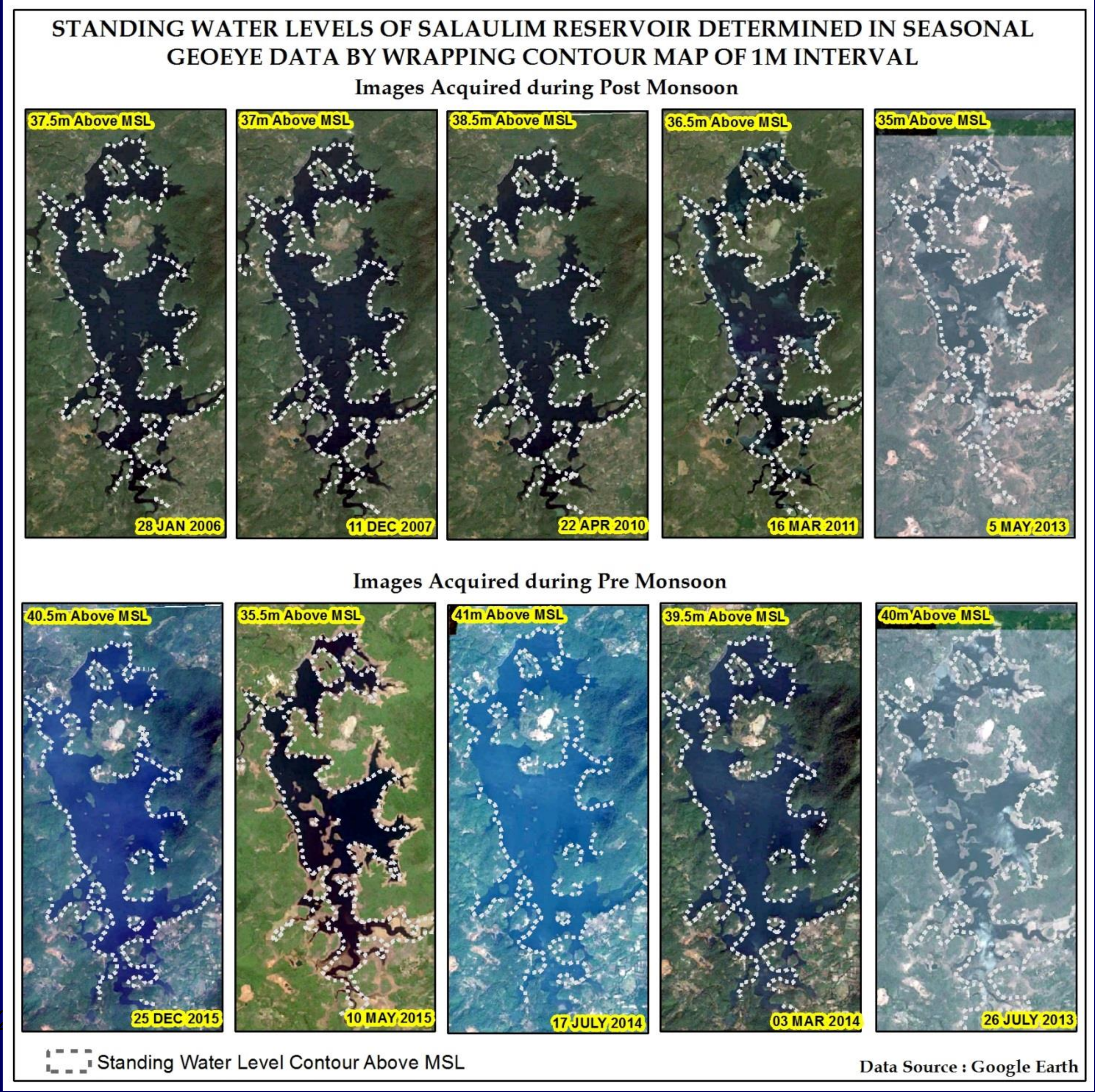

BASE MAP OF SALAULIM RESERVOIR - SALAULI, GOA
KEY MAP
INDIA
GOA
Legend
State highway
Metalled road
Unmetalled road
Settlement
Salaulim Reservoir
Naru
Darnal
Dabamal
Ganvliwad
Kurdi (Uninhabited)
Kaman
Malda
Satarkarawda
Kurpe
0
1
2
km
N
S
E
W



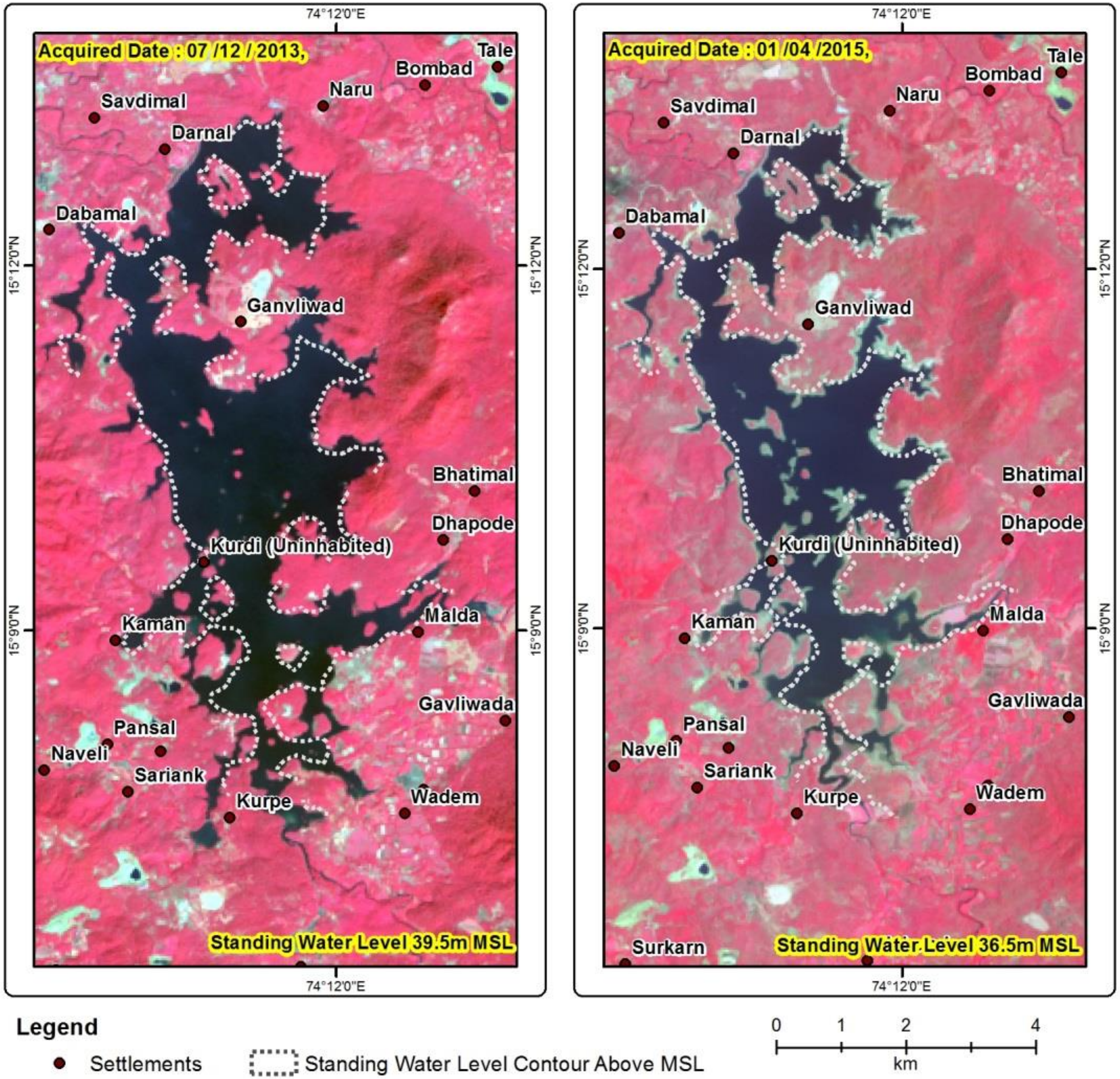
1m Contour - Salaulim Reservoir
Darnal
Dabamal
Ganvliwad
Kurdi (Uninhabited)
Kaman
Malda
Satarkarawda
Kurpe
0 1 2
km
Legend
1m Contour
Salaulim Reservoir
74°9'0"E
74°10'0"E
74°11'0"E
74°12'0"E
74°13'0"E
15°13'0"N
15°12'0"N
15°11'0"N
15°10'0"N
15°9'0"N
15°8'0"N

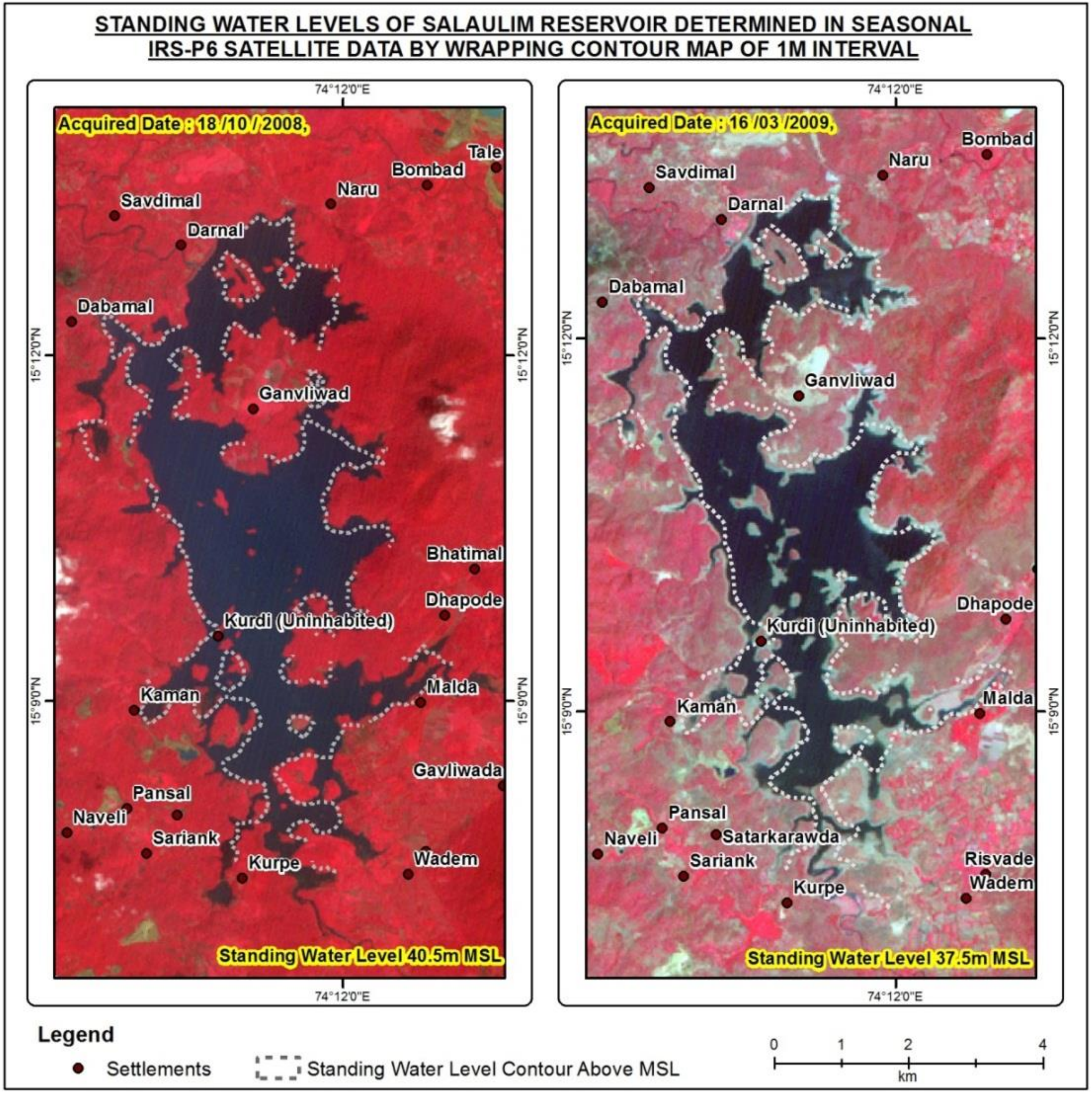
3D MODEL OF SALAULIM RESERVOIR BED AND BOTTOM TOPOGRAPHY




STANDING WATER LEVELS OF SALAULIM RESERVOIR DETERMINED IN SEASONAL GEOEYE DATA BY WRAPPING CONTOUR MAP OF 1M INTERVAL
Images Acquired during Post Monsoon
37.5m Above MSL
28 JAN 2006
37m Above MSL
11 DEC 2007
38.5m Above MSL
22 APR 2010
36.5m Above MSL
16 MAR 2011
35m Above MSL
5 MAY 2013
Images Acquired during Pre Monsoon
40.5m Above MSL
25 DEC 2015
35.5m Above MSL
10 MAY 2015
41m Above MSL
17 JULY 2014
39.5m Above MSL
03 MAR 2014
40m Above MSL
26 JULY 2013
Standing Water Level Contour Above MSL
Data Source : Google Earth

STANDING WATER LEVELS OF SALAULIM RESERVOIR DETERMINED IN SEASONAL LANDSAT8 SATELLITE DATA BY WRAPPING CONTOUR MAP OF 1M INTERVAL




STANDING WATER LEVELS OF SALAULIM RESERVOIR DETERMINED IN SEASONAL IRS-P6 SATELLITE DATA BY WRAPPING CONTOUR MAP OF 1M INTERVAL
Acquired Date : 18 /10 / 2008,
Standing Water Level 40.5m MSL
Acquired Date : 16 /03 /2009,
Standing Water Level 37.5m MSL
74°12'0"E
15°12'0"N
15°9'0"N
Tale
Bombad
Naru
Savdimal
Darnal
Dabamal
Ganvliwad
Bhatimal
Dhapode
Kurdi (Uninhabited)
Kaman
Malda
Gavliwada
Pansal
Naveli
Sariank
Satarkarawda
Kurpe
Wadem
Risvade
Legend
Settlements
Standing Water Level Contour Above MSL
0 1 2 4
km

Pixel-ID	Location data		GeoEye_10th May, 2015		GeoEye_25th Dec. 2015	
	X-Location	Y-Location	Thickness of Water Column	Pixel wise Water Volume	Thickness of Water Column	Pixel wise Water Volume
1	413264	1683032	0	0	0	0
2	413274	1683032	0	0	0	0
3	413284	1683032	0	0	0	0
4	413294	1683032	0	0	0	0
5	413214	1683022	0	0	0	0
….	…..	…..	….	…..	…..	…..
….	…..	…..	….	…..	…..	…..
….	…..	…..	….	…..	…..	…..
1870	413094	1682732	0	0	0.708	70.8
1871	413104	1682732	0	0	1.3981	139.81
1872	413114	1682732	0	0	2.0131	201.31
1873	413124	1682732	0	0	2.536	253.6
1874	413134	1682732	0	0	2.9608	296.08
….	…..	…..	….	…..	…..	…..
….	…..	…..	….	…..	…..	…..
….	…..	…..	….	…..	…..	…..
291012	413254	1671902	12.4897	1248.97	19.4897	1948.97
291013	413264	1671902	12.6999	1269.99	19.6999	1969.99
291014	413274	1671902	12.8768	1287.68	19.8768	1987.68
291015	413284	1671902	13.011	1301.1	20.011	2001.1
291016	413294	1671902	13.0731	1307.31	20.0731	2007.31
Total Volume of Water in Salaulim Reservoir			111.0978678 MCM		222.339146 MCM	

S.No.	Satellite Image Used	Acquired Date Of Seasonal Satellite Image	Standing Water Level of Salaulim Reservoir	Date wise Estimated Volume of Water In Salaulim Reservoir (In Mcm)
1.	GEOEYE (Satellite Data Source : Google Earth)	28/01/2006	37.5	165.0
2.		11/12/2007	37	156.4
3.		22/04/2010	38.5	183.1
4.		16/03/2011	36.5	148.0
5.		05/05/2013	35	117.8
6.		26/07/2013	40	212.0
7.		07/03/2014	39.5	202.1
8.		17/07/2014	41**	232.9**
9.		10/05/2015	35.5*	111.0*
10.		25/12/2015	40.5	222.3
11.	LANDSAT-8	07/12/2013	39.5	202.1
12.		01/04/2015	36.5	148.0
13.	IRS P6 LISSIII	18/10/2008	40.5	222.3
14.		16/03/2009	37.5	165.0

VALIDATION OF THE MODEL

- In the web page, www.WeatherinGoa.Blogspot.com, written by Atul Naik (2014), the water levels in Salaulim Reservoir were reported for the dates 26th, July 2013 and 17th July 2014, as 41.15m and 42.42m respectively.
- The differences in water levels determined through this research study are: -1.15m and -1.42m respectively on these dates.

This paper is available online @
https://www.ijariit.com/manuscripts/v3i2/V3I2-1535.pdf

Title of the Paper: Geospatial Technology in Quantifying Seasonal Availability of Water Stored in Salaulim Reservoir, Salauli, Goa State, India

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STUDY - 3

SURFACE WATER TARGETTING - A SPATIAL DESIGN

Back

METHODOLOGY IN BRIEF

- GIS Image Creation Showing Water Bodies Deduced from
  - Topo Sheets
  - Satellite FCC Data – Temporal (Pre-monsoon)

    &
  - Satellite IR Data - Temporal

Then, GIS Integration & Detection of Surface Water Target Areas showing seasonal availabilities.

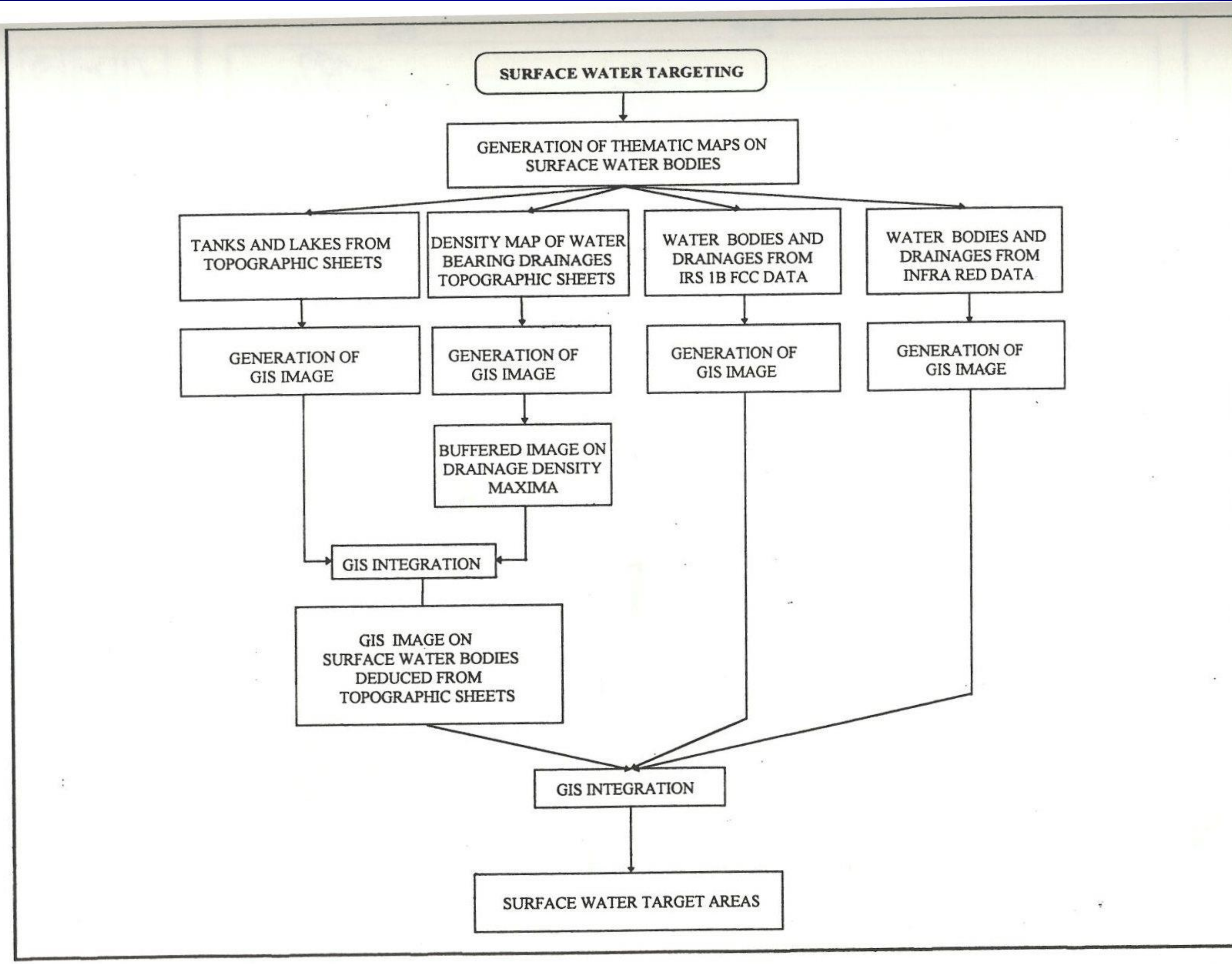
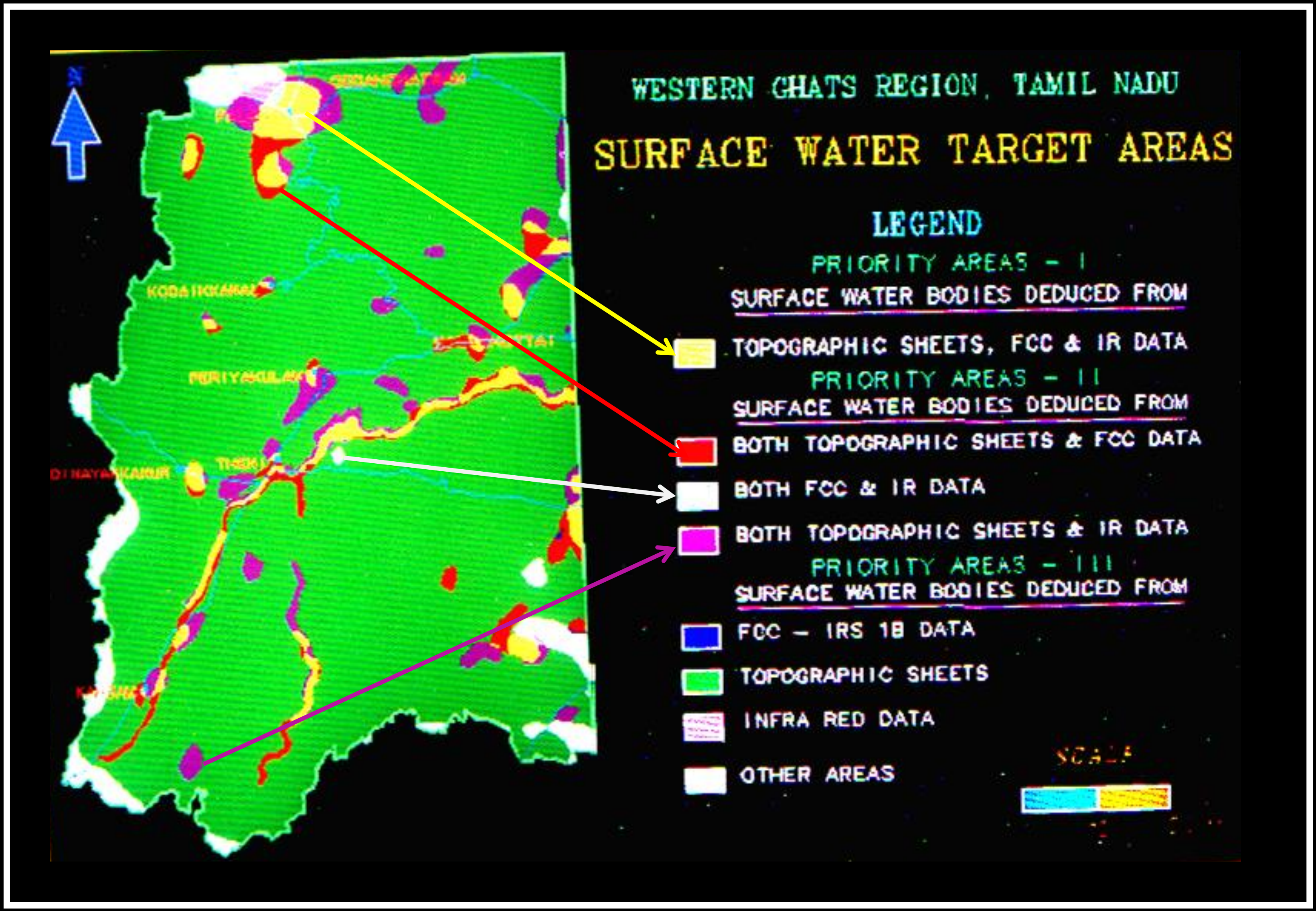


FIGURE 3.1 METHODOLOGY FLOW CHART


WESTERN GHATS REGION, TAMIL NADU
SURFACE WATER TARGET AREAS
LEGEND
PRIORITY AREAS - I
SURFACE WATER BODIES DEDUCED FROM
TOPOGRAPHIC SHEETS, FCC & IR DATA
PRIORITY AREAS - II
SURFACE WATER BODIES DEDUCED FROM
BOTH TOPOGRAPHIC SHEETS & FCC DATA
BOTH FCC & IR DATA
BOTH TOPOGRAPHIC SHEETS & IR DATA
PRIORITY AREAS - III
SURFACE WATER BODIES DEDUCED FROM
FCC - IRS 1B DATA
TOPOGRAPHIC SHEETS
INFRA RED DATA
OTHER AREAS
SCALE
KODAIKKANAL
PERIYAKULAM
THENI

Back

STUDY 4

SURFACE WATER QUALITY FROM SATELLITE DATA

- A Model from Cauvery River

Back

METHODOLOGY IN BRIEF

- Spectro-radiometric Survey in Six Pollution Points in Cauvery for 5 Days
- Thus, generation of 30 Data Bases on TM 4 bands, IRS 4 bands and SPOT 3 bands (30 x11)
- Water Sample Collection and Quality Analysis of 30 Samples on Temperature, Turbidity, B.O.D, C.O.D, Total Hardness, Nitrate, pH, Silica, Fluoride, etc.
- Carry out Graphical Correlation between water quality and spectral reflectance values to know the nature (+ve / -ve) and % of relationship
- Carry out Bivariate Regression Analysis to estimate the quantum of relationship with reflectance and water quality and
- Generation of Pollution Monitoring Model directly from satellite data.

CHINTHAMANI AREA

Physico - Chemical Parametes	*TM bands*				*Chinthamani IRS bands*				*Spot bands*		
	1	2	3	4	1	2	3	4	1	2	3
Temperature	F	N	N	N	N	N	N	N	N	N	N
Turbidity	–	–	–	–	–	–	–	–	–	–	–
Biological Oxygen Demand	F	⊕	F	F	F	⊕	N	⊕	N	⊕	⊕
Chemical Oxygen Demand	F	⊕	F	F	F	⊕	N	⊕	N	⊕	⊕
Total Hardness	F	⊕	F	F	F	⊕	N	⊕	N	⊕	⊕
Nitrate	N	⊕	N	F	F	⊕	N	⊕	N	⊕	N
pH	–	–	–	–	–	–	–	–	–	–	–
Silica	N	N	N	N	N	⊕	F	N	N	N	N
Flouride	–	–	–	–	–	–	–	–	–	–	–

+ **Positive correlation** **F** **Fair correlation**

- **Negative correlation** **N** **No correlation**

SARKARPALAYAM AREA

Physico - Chemical Parameters	*Sarkarpalayam* *TM bands*				*IRS bands*				*Spot bands*		
	1	2	3	4	1	2	3	4	1	2	3
Temperature	F	F	F	F	F	⊕	⊕	F	⊕	F	F
Turbidity	–	–	–	–	–	–	–	–	–	–	–
Biological Oxygen Demand	F	⊕	F	F	F	F	F	F	F	F	F
Chemical Oxygen Demand	F	F	⊕	F	F	F	F	F	F	F	F
Total Hardness	F	F	⊕	F	F	F	F	F	F	F	F
Nitrate	F	⊕	⊕	F	F	⊕	F	⊕	F	F	F
pH	–	–	–	–	–	–	–	–	–	–	–
Silica	F	⊕	⊕	F	F	⊕	F	⊕	F	F	F
Flouride	F	⊕	⊕	F	F	⊕	F	⊕	F	F	F

⊕ **Positive correlation** F **Fair correlation**

- **Negative correlation** N **No correlation**

RESULTS

- Water Temperature can be Monitored from TM band2, IRS band2 & 4
- B.O.D – TM band3, IRS band3
- C.O.D – TM band2, IRS band2.
- Total Hardness and Nitrate – Positive and Fair Correlation in all bands
- Turbidity and pH – Negative / opposite / indirect relationship with all bands

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STUDY – 5

SOIL EROSION - RESERVOIR SILTATION AND REMEDIAL MEASURES

Back

STUDY – 5A

Silted Water Bodies

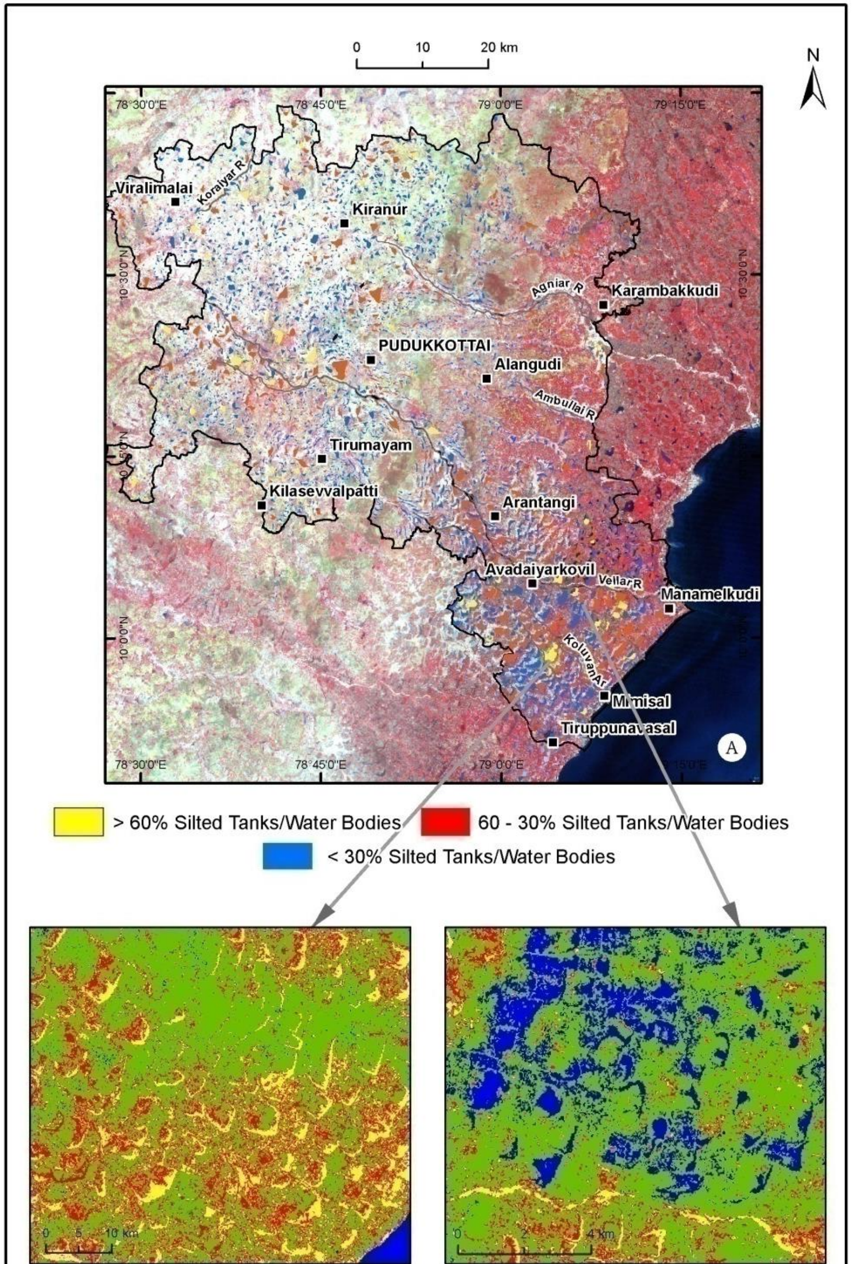


Fig. (B) - >60% Silted Tanks

Fig. (C) - < 30% Silted Tanks

Fig. 5.2 IRS FCC (A) and Density Sliced (B and C) Images showing Silted Water Bodies

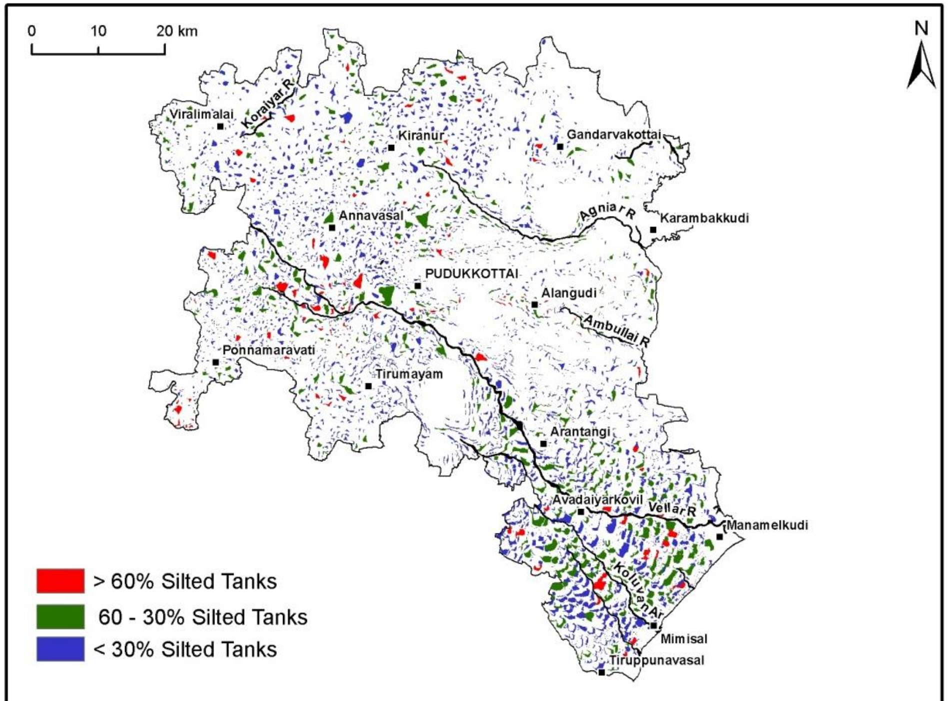


Fig. 6.22 Silted Tanks/Water Bodies

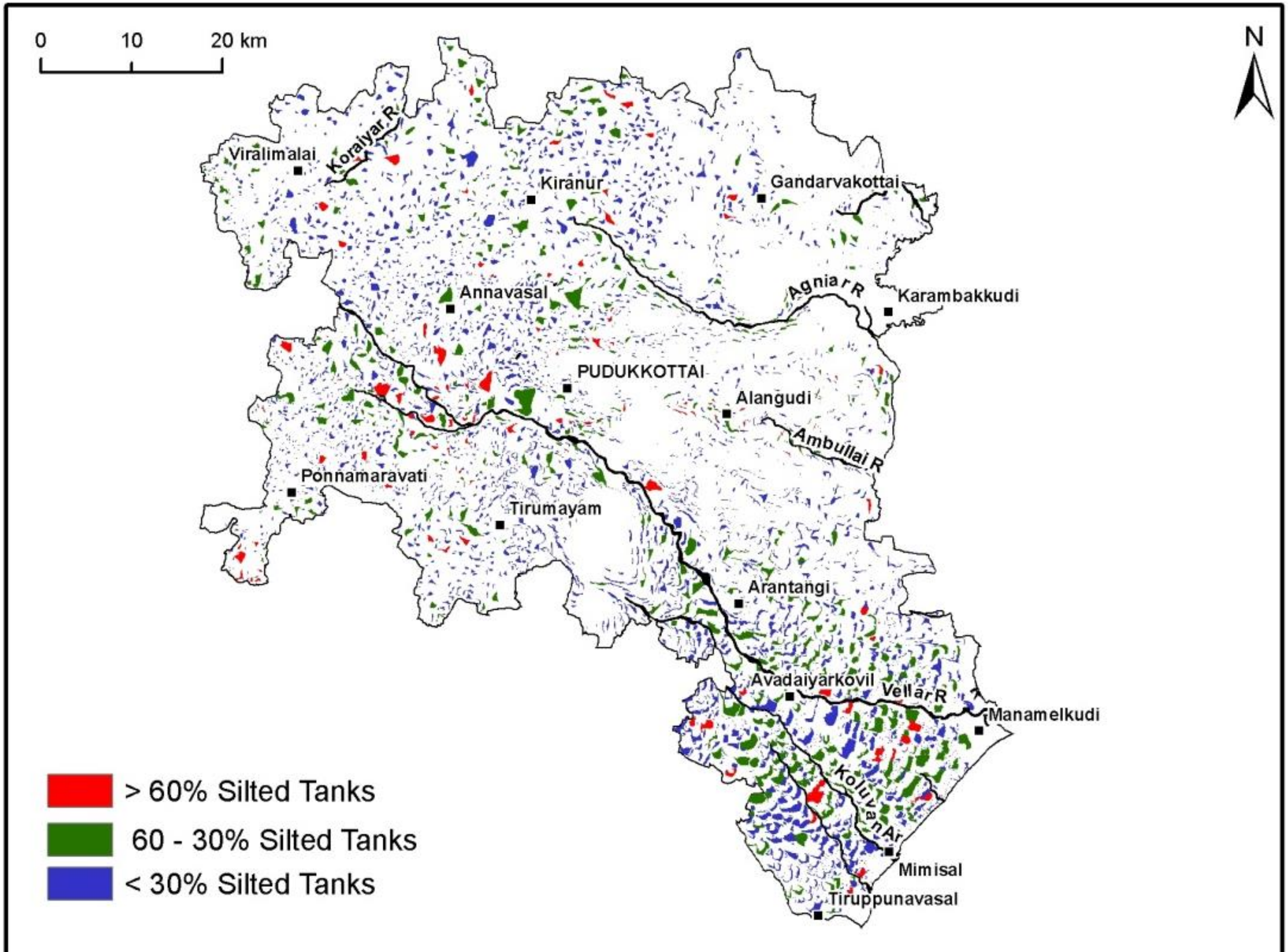
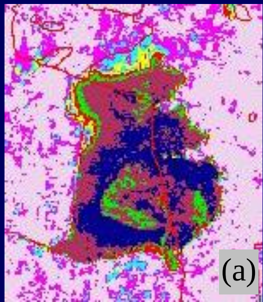
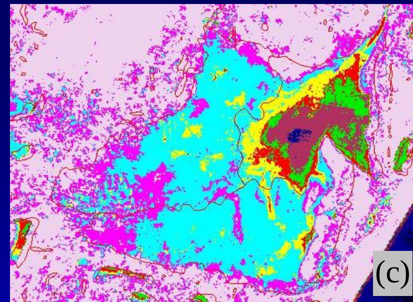
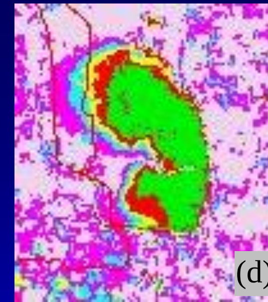


Fig. 6.22 Silted Tanks/Water Bodies

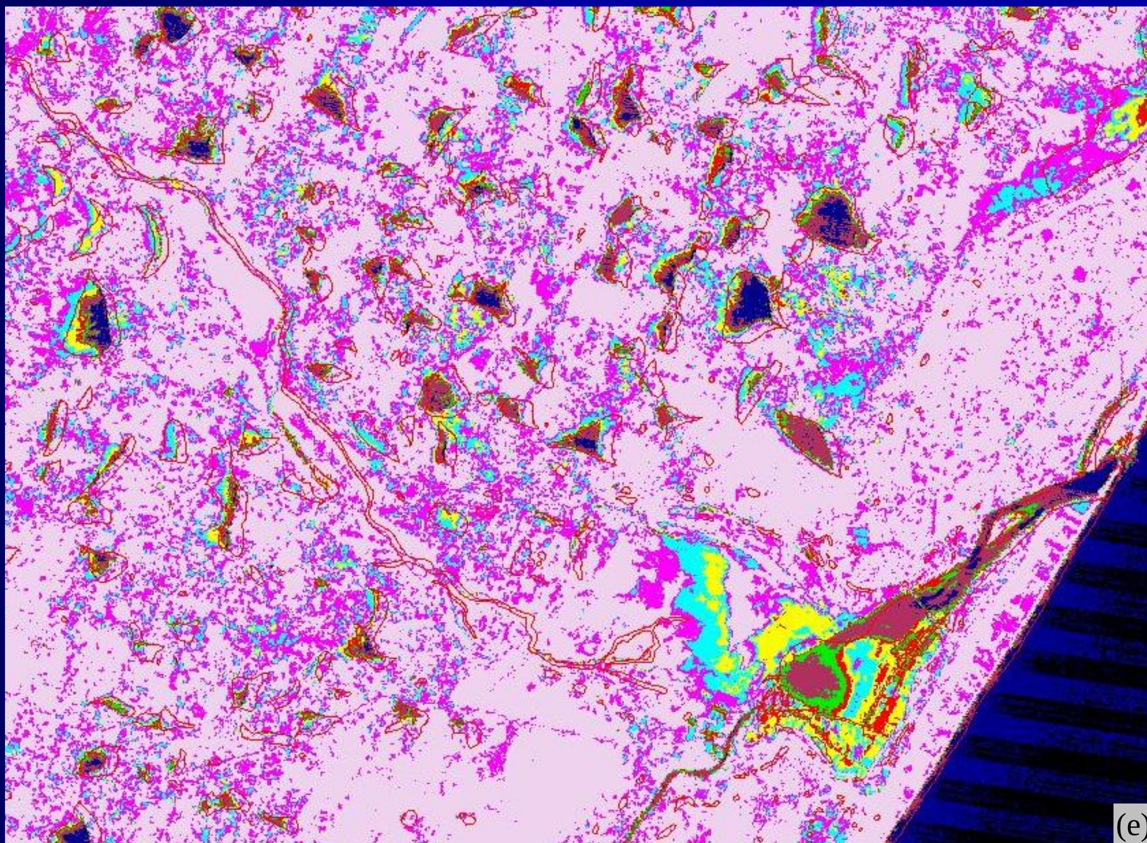
STUDY - 5B



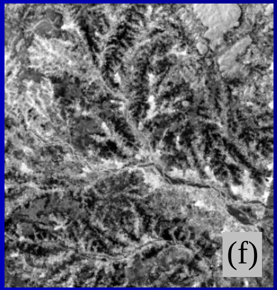


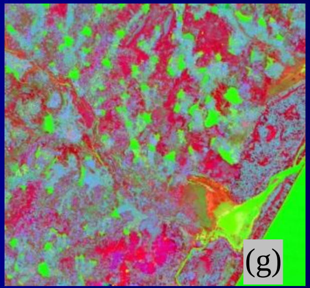


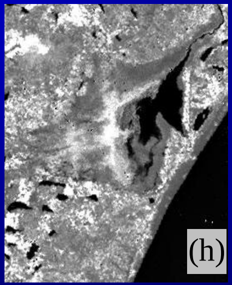
Density Sliced Images (a – e):
0-7 Black-Water
8-10 Blue-Muddy Water
11-15 Maroon-Less silted
16-20 Green-Moderately Silted
42-52 Cyan-Extinct Water Bodies
21-31 Red- Silted
32-41 Yellow-Heavily Silted
53-63 Magenda-Eroded/silted area
64-255 Thistle-Other Land areas

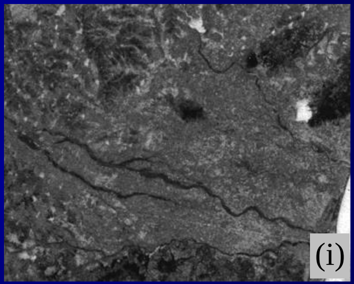


Digitally enhanced LANDSAT ETM Ddata





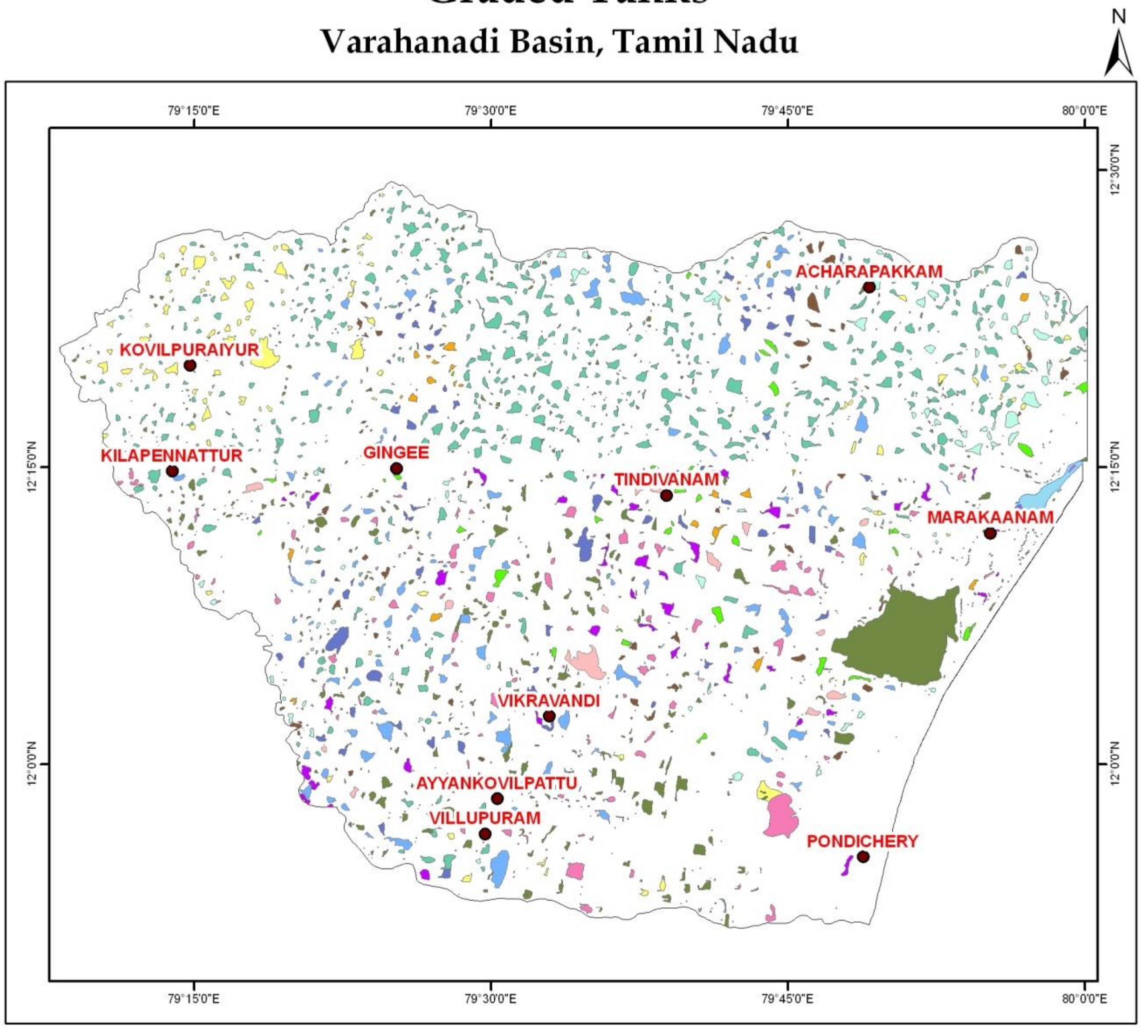




Principal Component Analyses: PC-3 Image-Gullies(f), PC-432 combination–Eroded upland(g),
Band Ratios: 1/3–Siltation levels(h), 4/3–Unpaired deltaic plain(i)

Graded Tanks

Varahanadi Basin, Tamil Nadu



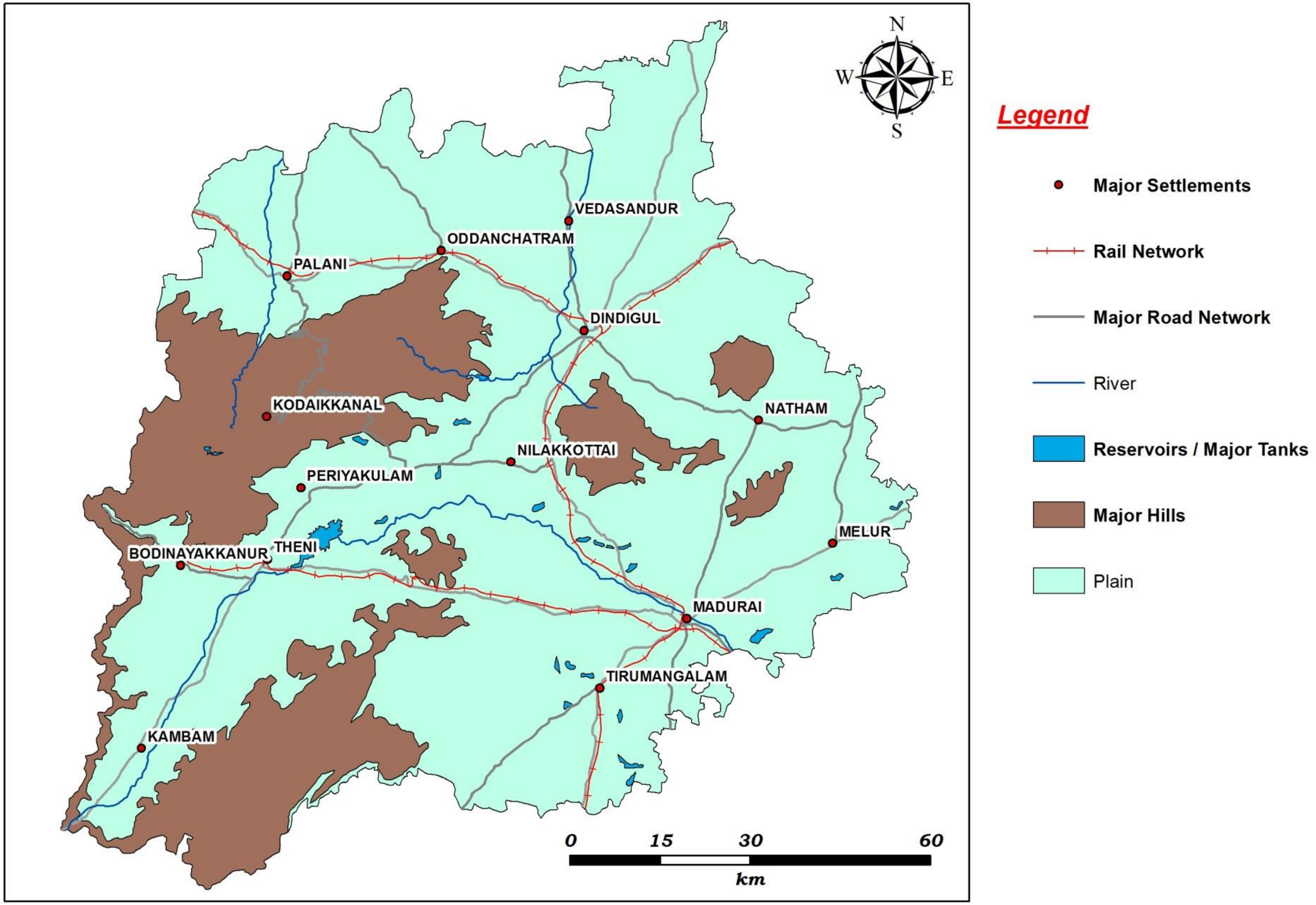
0 15 30
km

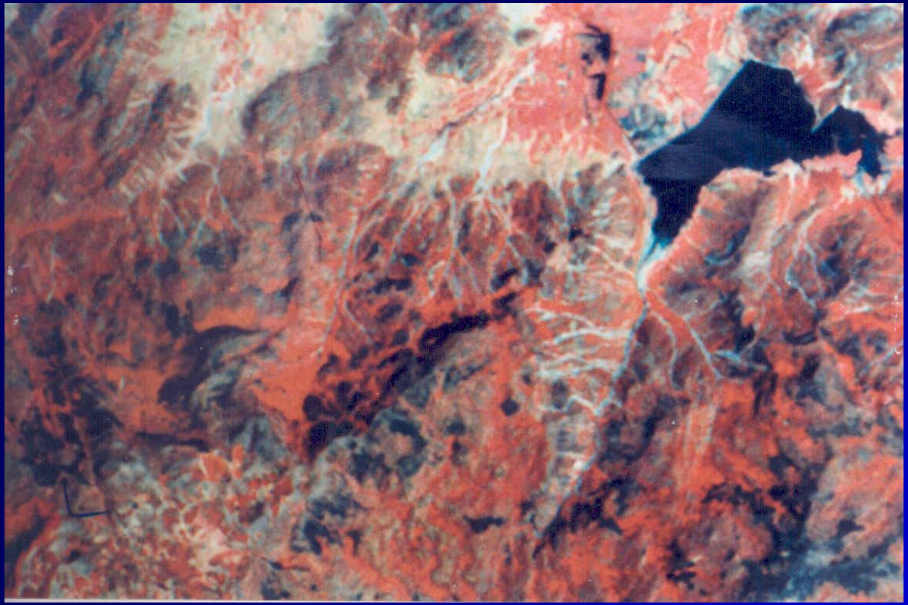
LEGEND

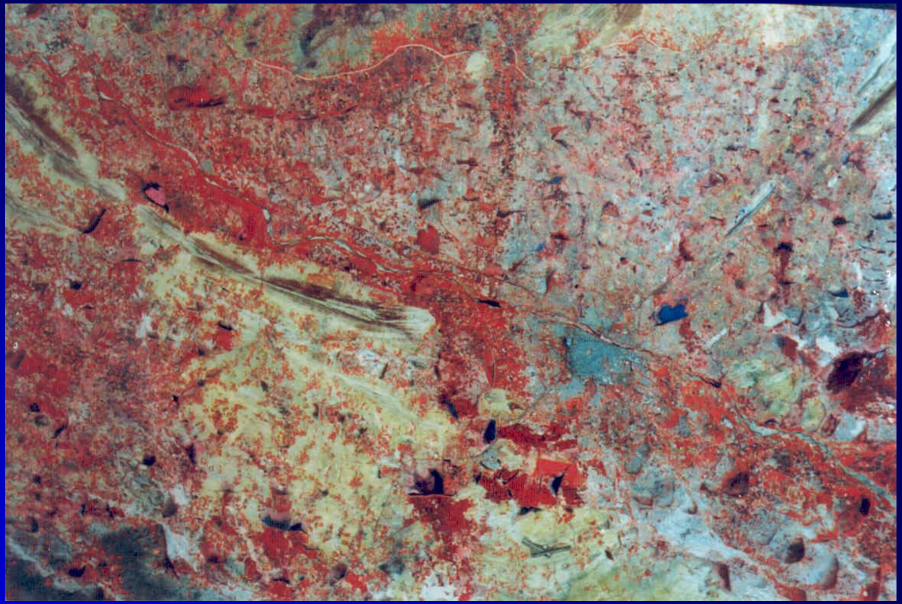
- SETTLEMENT
- 1 - DEFUNCT
- 1V - DEFUNCT + VEGETATED
- 2 - 80% SILTED
- 2V - 80% SILTED + VEGETATED
- 3 - 60 - 80% SILTED
- 3V - 60 - 80% SILTED + VEGETATED
- 4 - 40 - 60% SILTED
- 4V - 40 - 60% SILTED + VEGETATED
- 5 - 20 - 40 % SILTED
- 5V - 20 - 40% SILTED + VEGETATED
- 6 - < 20 % SILTED
- 6V - < 20 % SILTED + VEGETATED
- RIVER

STUDY – 5C

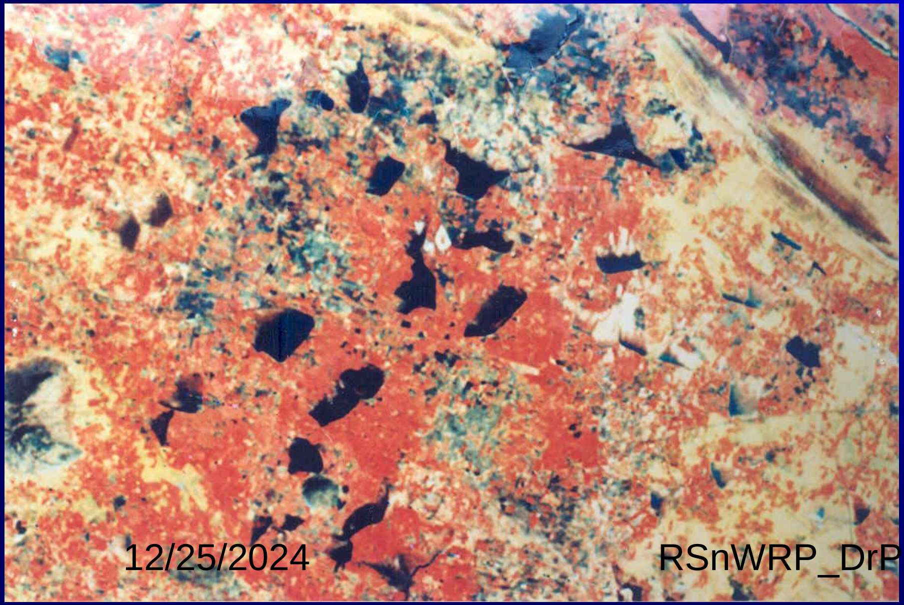
BASE MAP
Parts of Western Ghats, Tamil Nadu

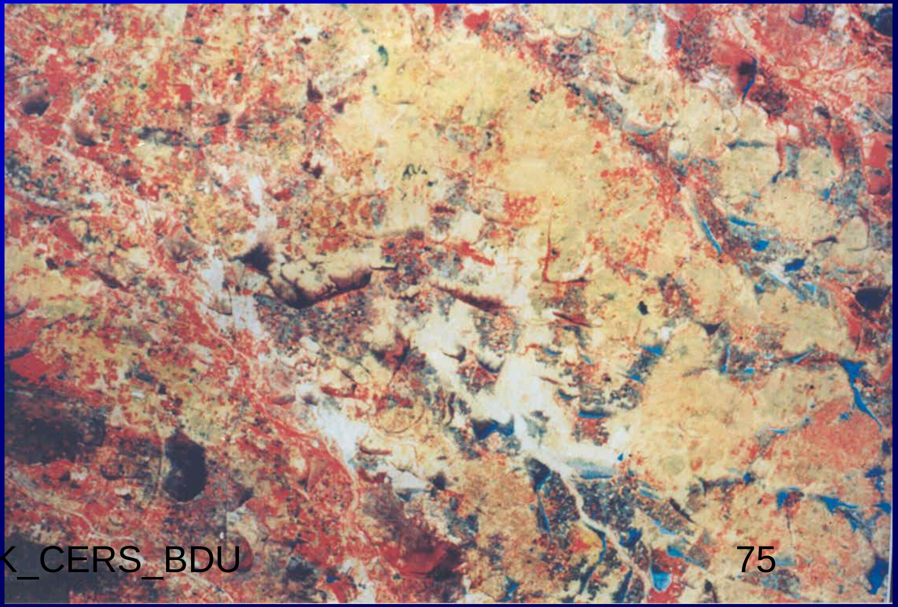




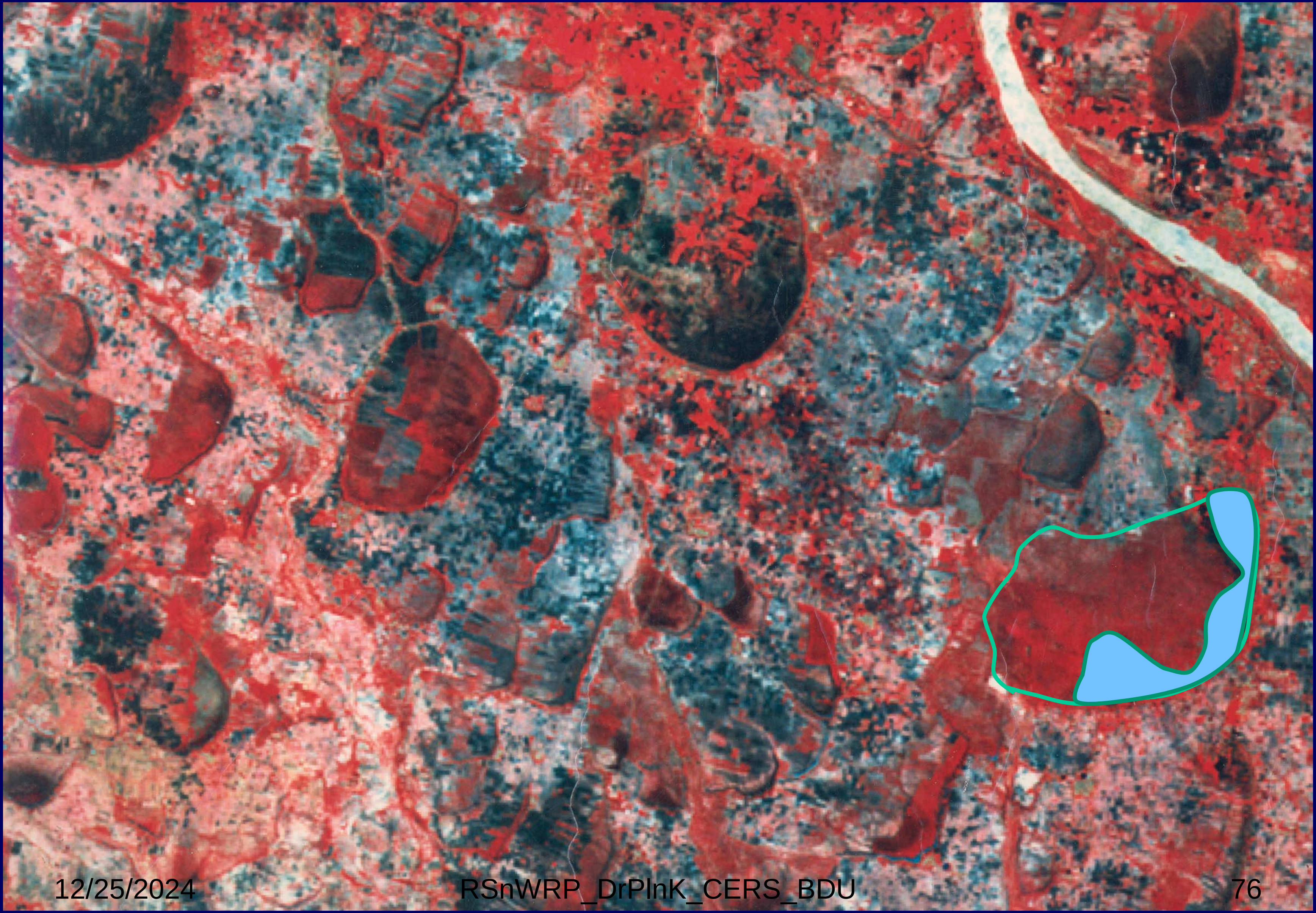


IRS satellite FCC images showing areas of soil erosion and silted water bodies

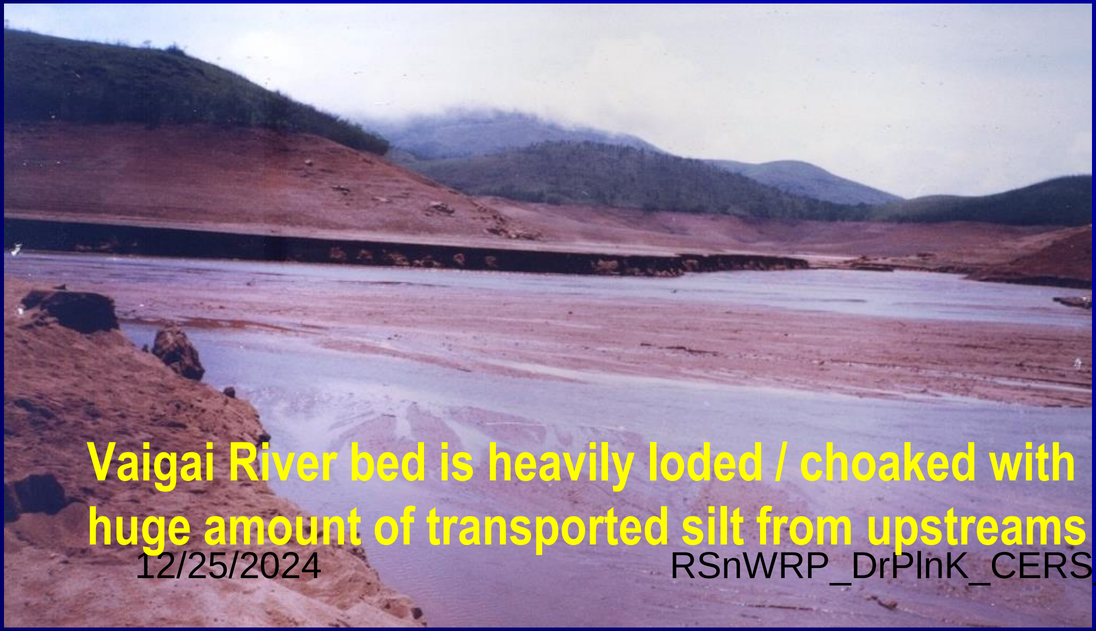




SILTATION OF SUPPLY CANALS AND TANKS

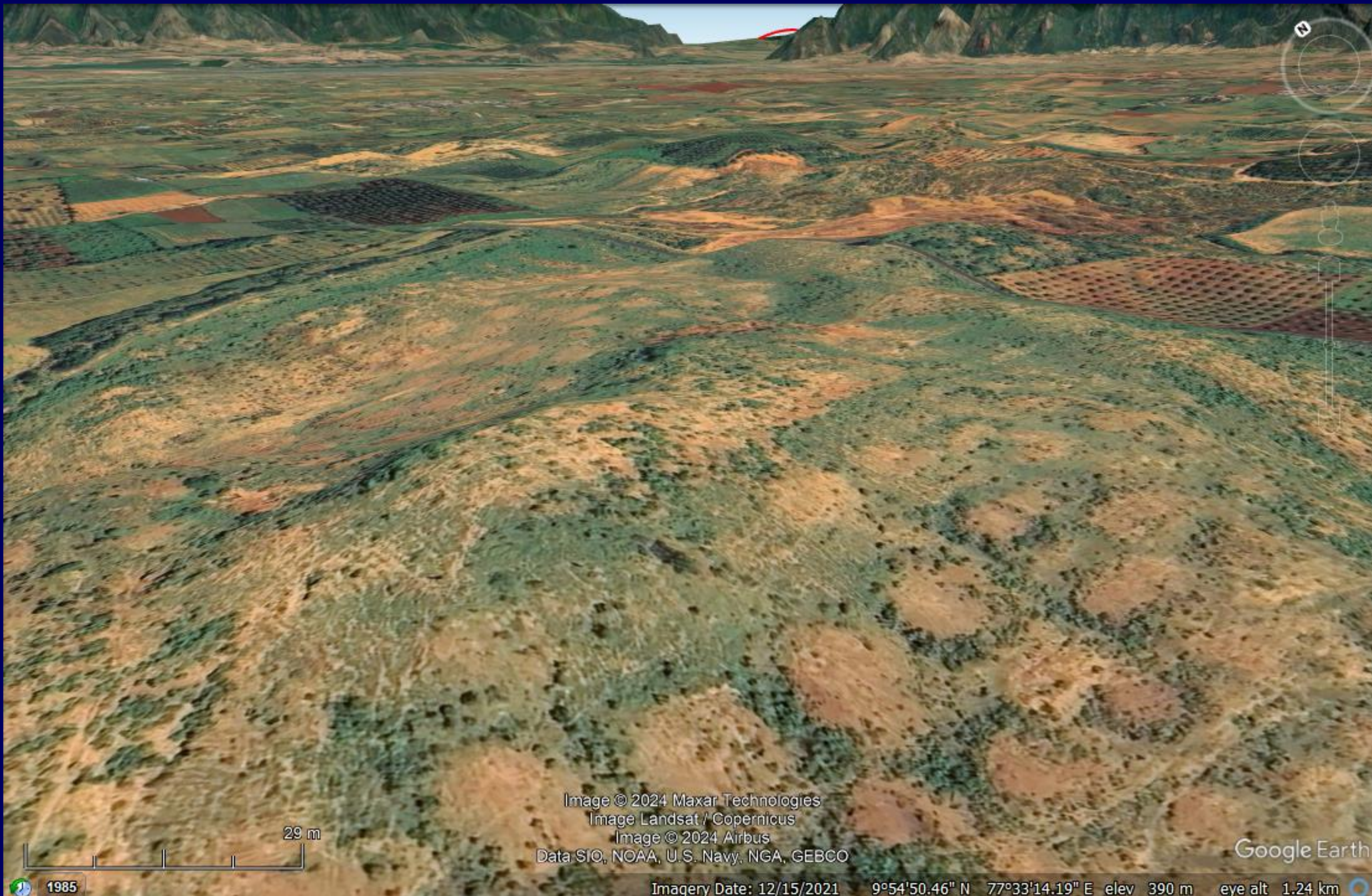


Bazada, Colluvial Fills, Piedmont zones, uplands in the catchment of Vaigai river are heavily eroded



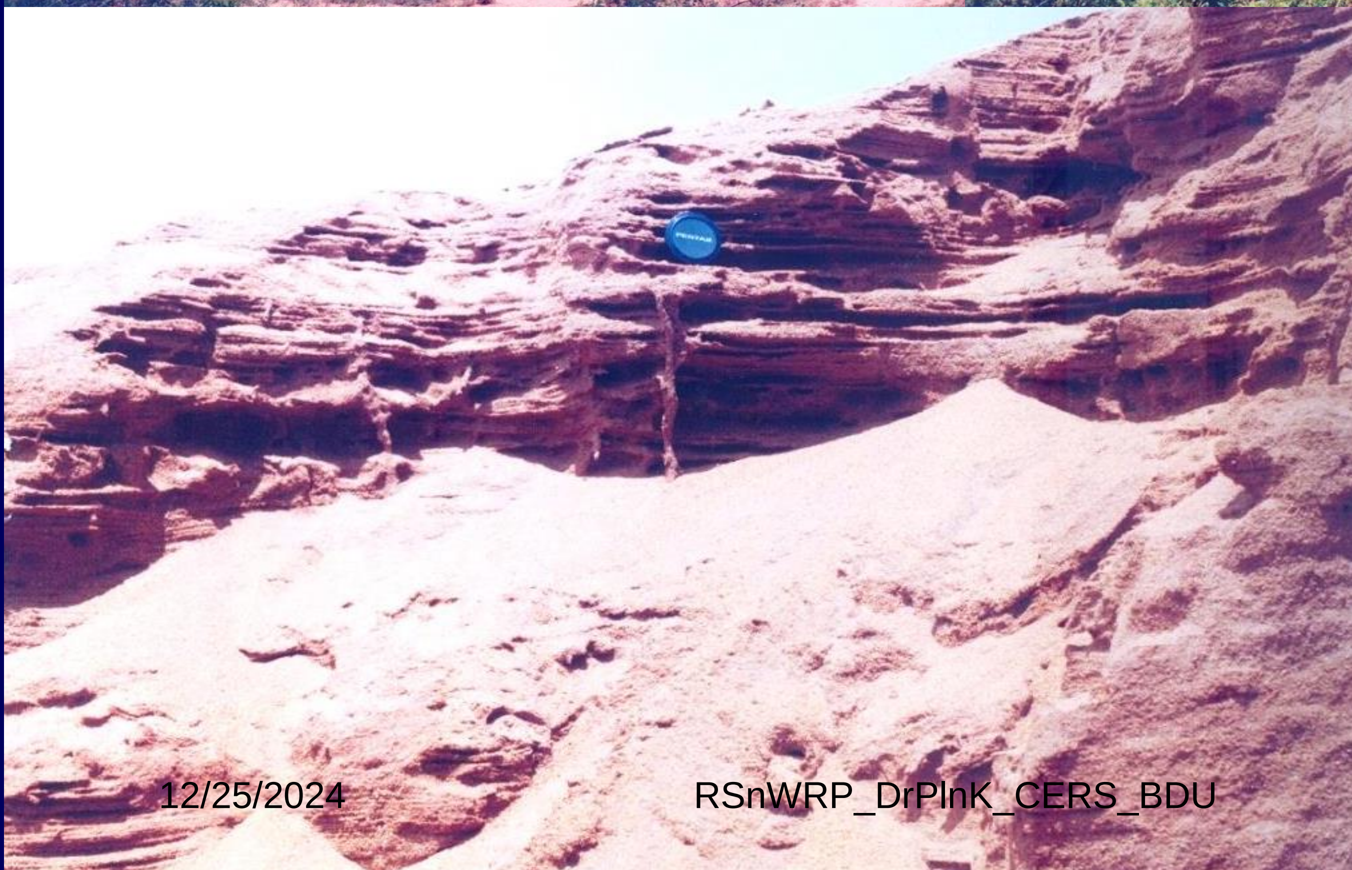
Vaigai River bed is heavily loded / choaked with huge amount of transported silt from upstreams

>5 km long & 0.5 km wide linear Sand dunes formed near Sitharpatti-Karakotampatti, Theni due to aeolian erosional and depositional activity

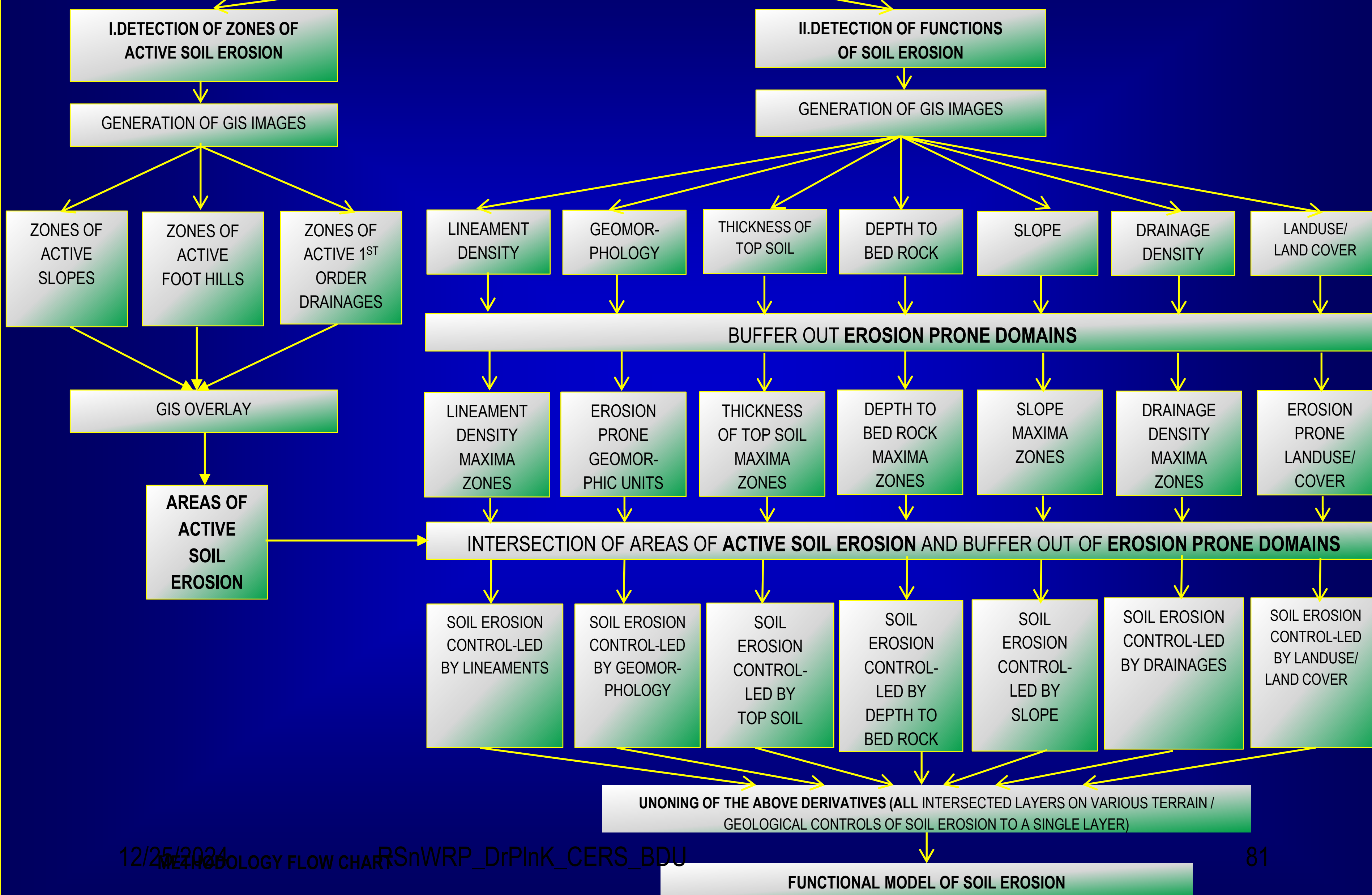


3D Terrain view of Sitharpatti, Theni Sand Dune (stabilized) oriented NE in GoogleEarth – Recent LANDSAT TCC image wrapped over SRTM DEM

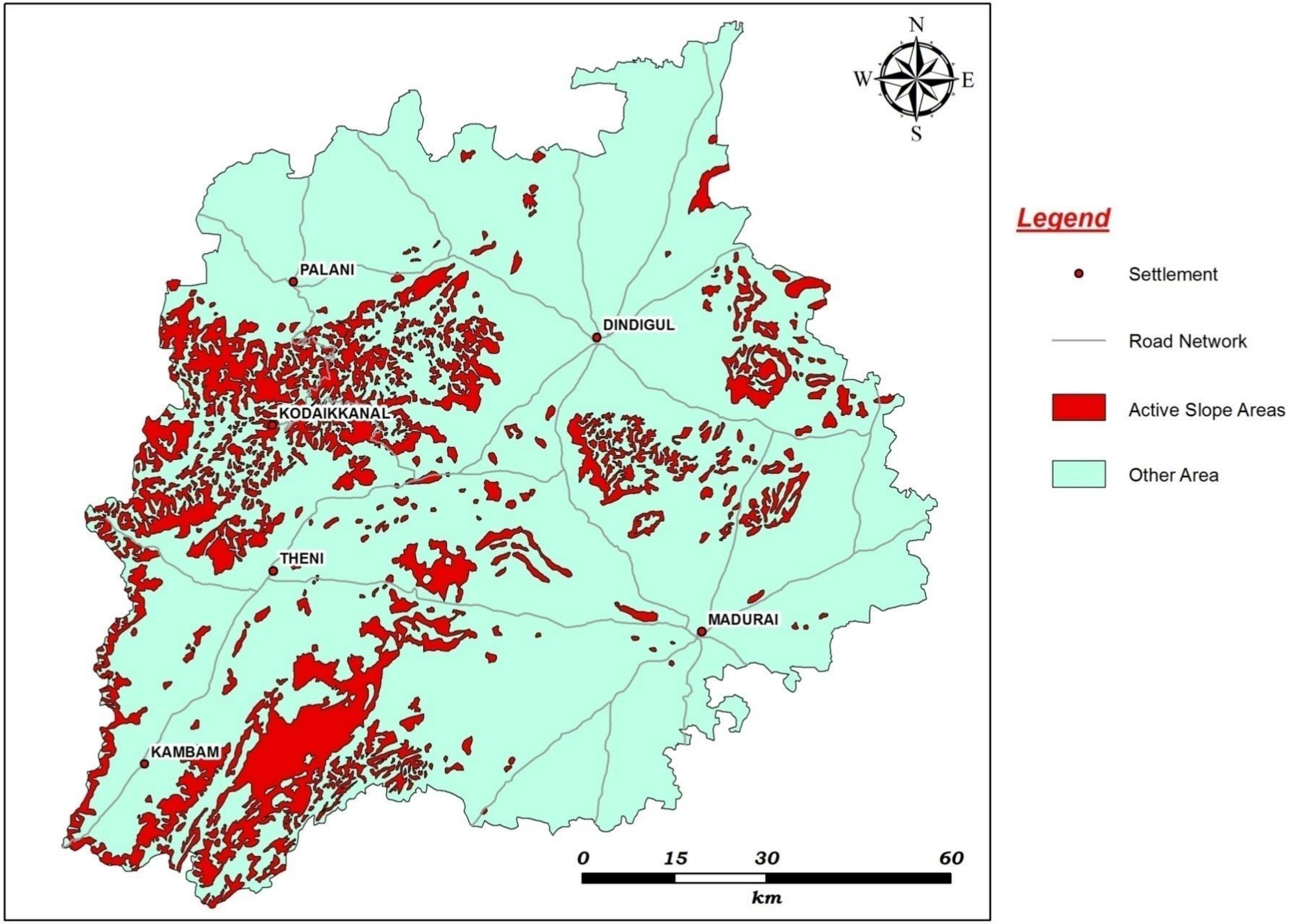
Field photographs showing the 5 km long 500m wide Sand dune formed near Sitharpatti-Karakotampatti, Theni



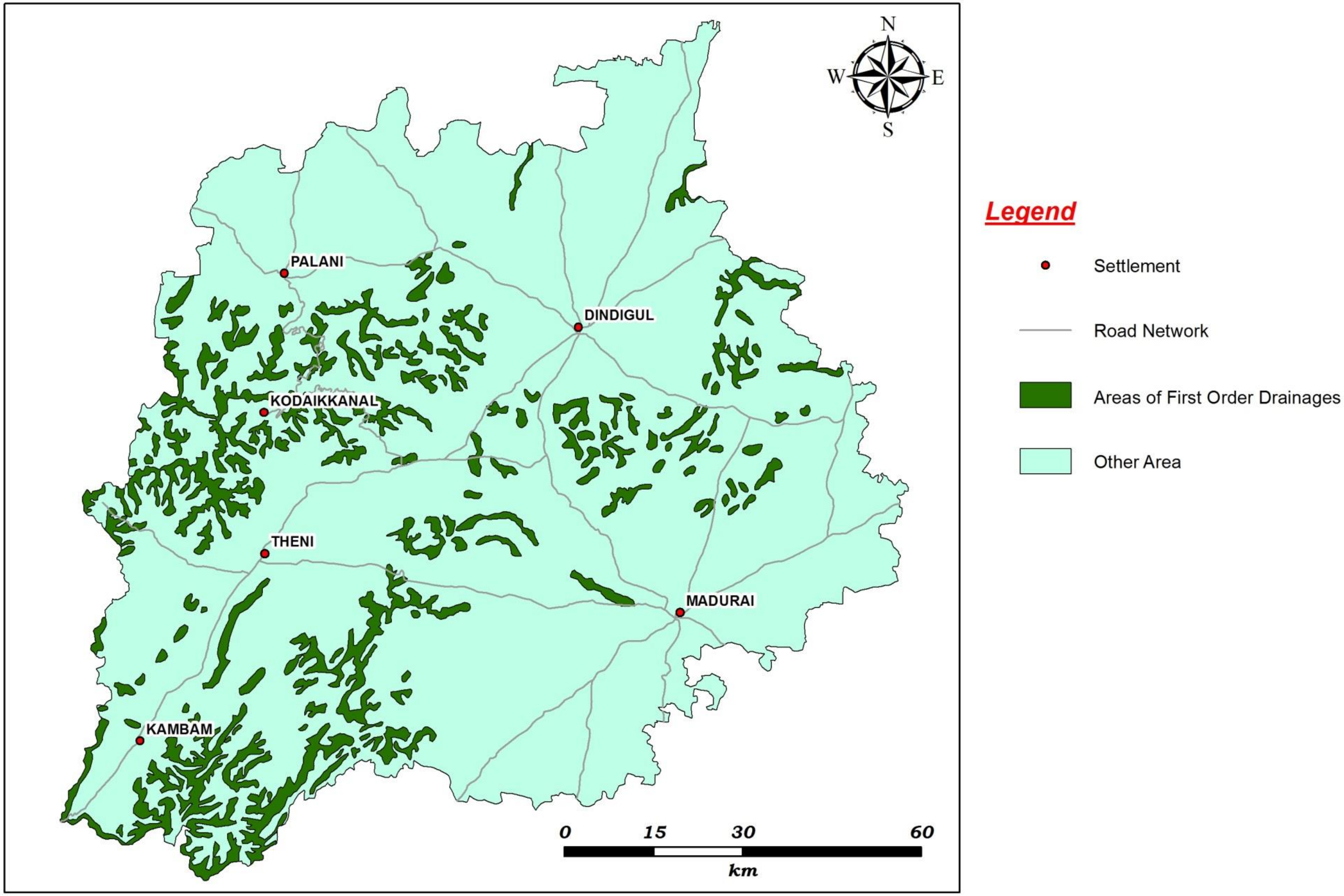
SOIL EROSION MAPPING & MITIGATION – TN, P&D Project “RENWE” (1995-1999)



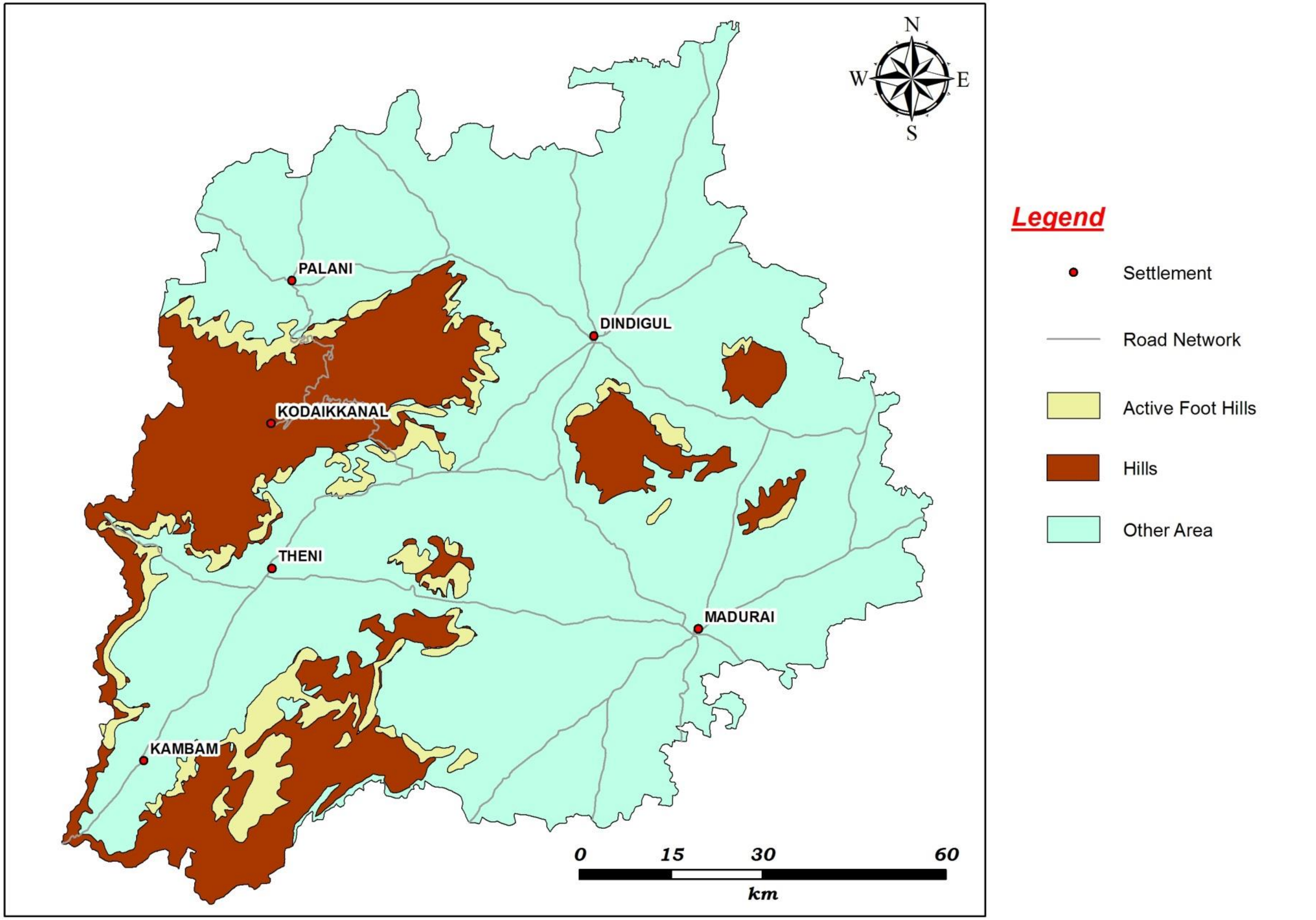
ACTIVE SLOPE AREAS



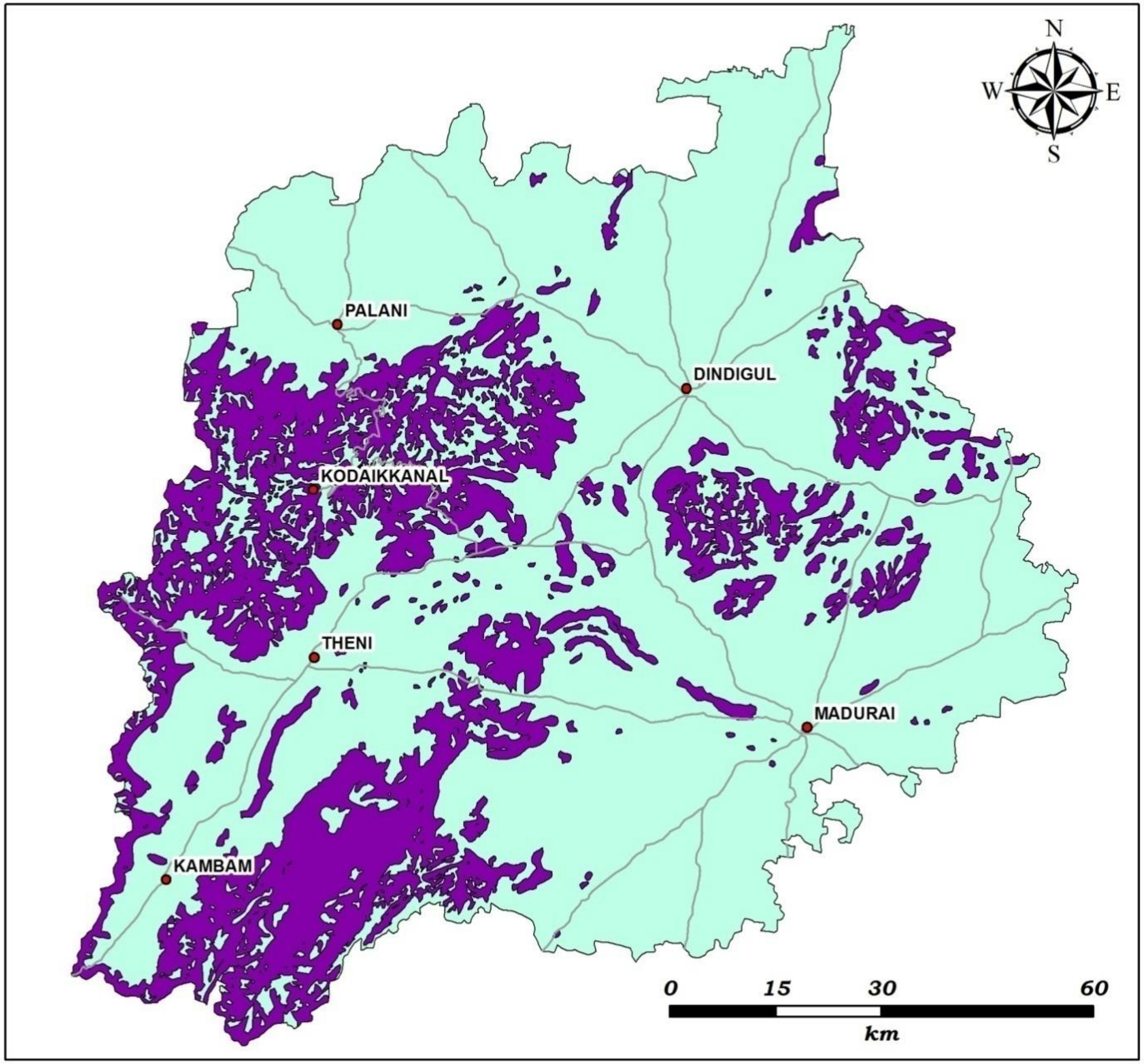
AREAS OF FIRST ORDER DRAINAGES



ACTIVE FOOT HILLS



AREAS OF ACTIVE SOIL EROSION

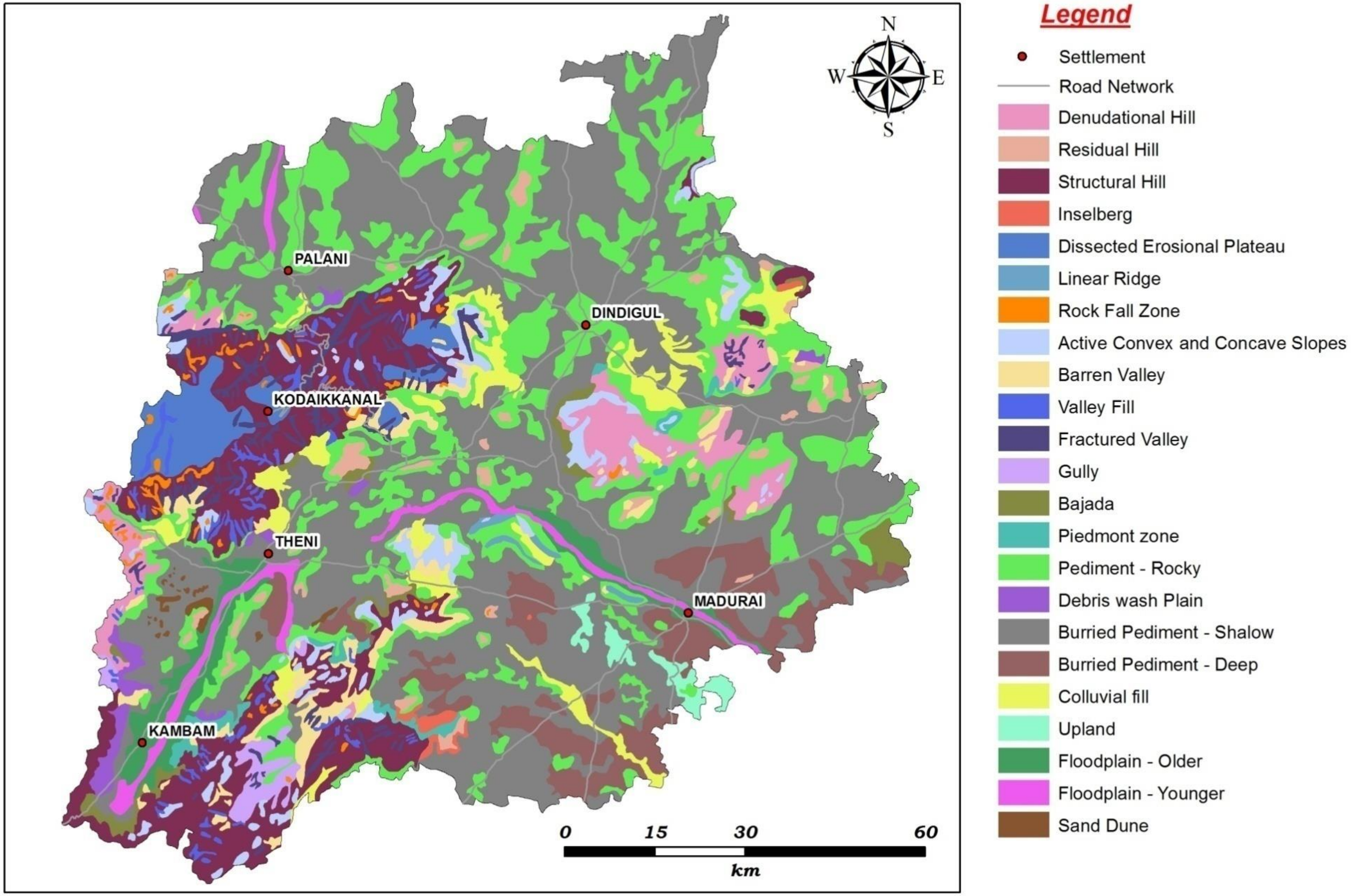


Legend

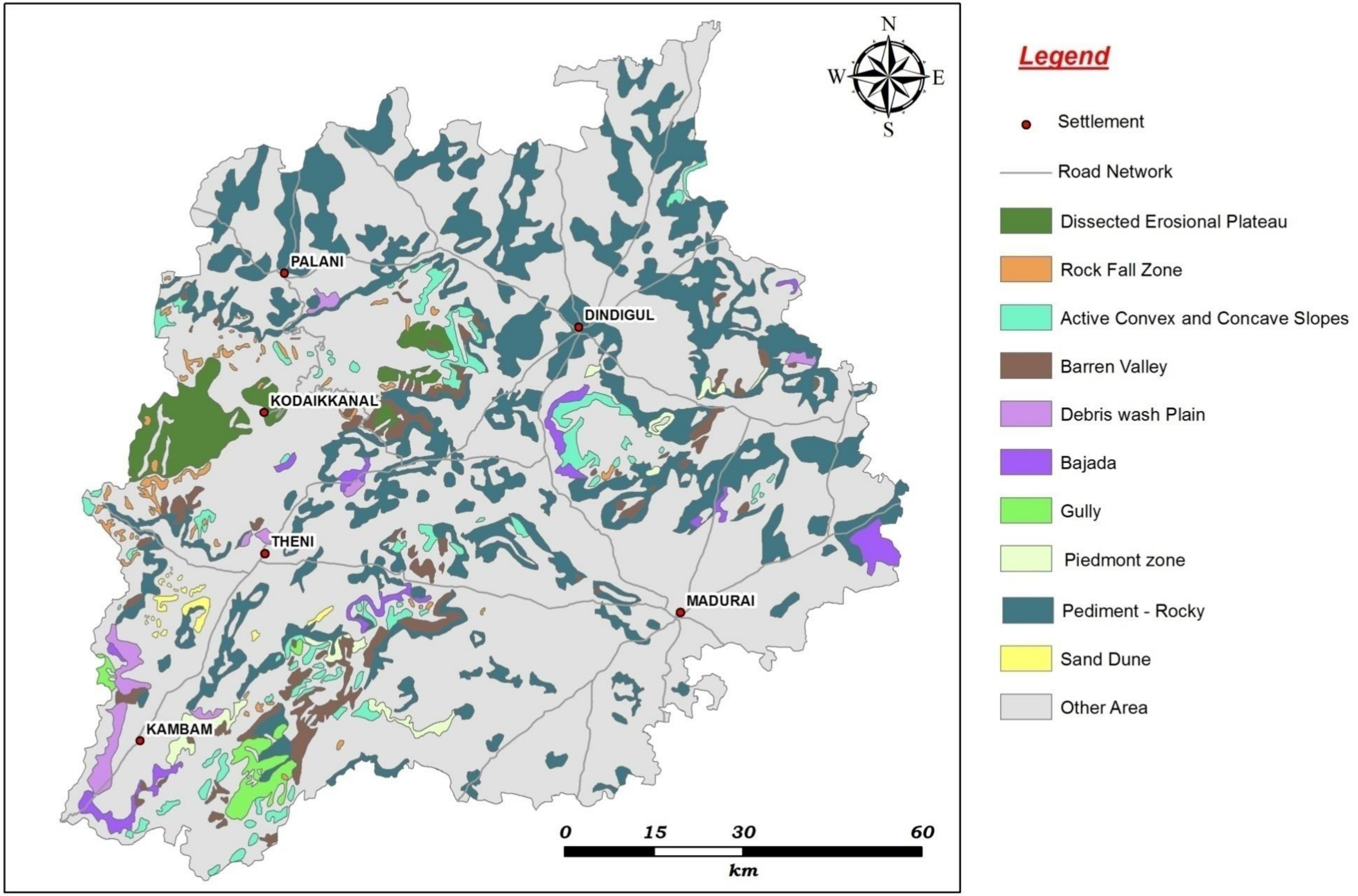
- Settlement
- Road Network
- Areas of Active Soil Erosion
- Other Area

(Combined Image of zones of
- Active Slopes
- Active Foot Hills and
- First Order Drainages)

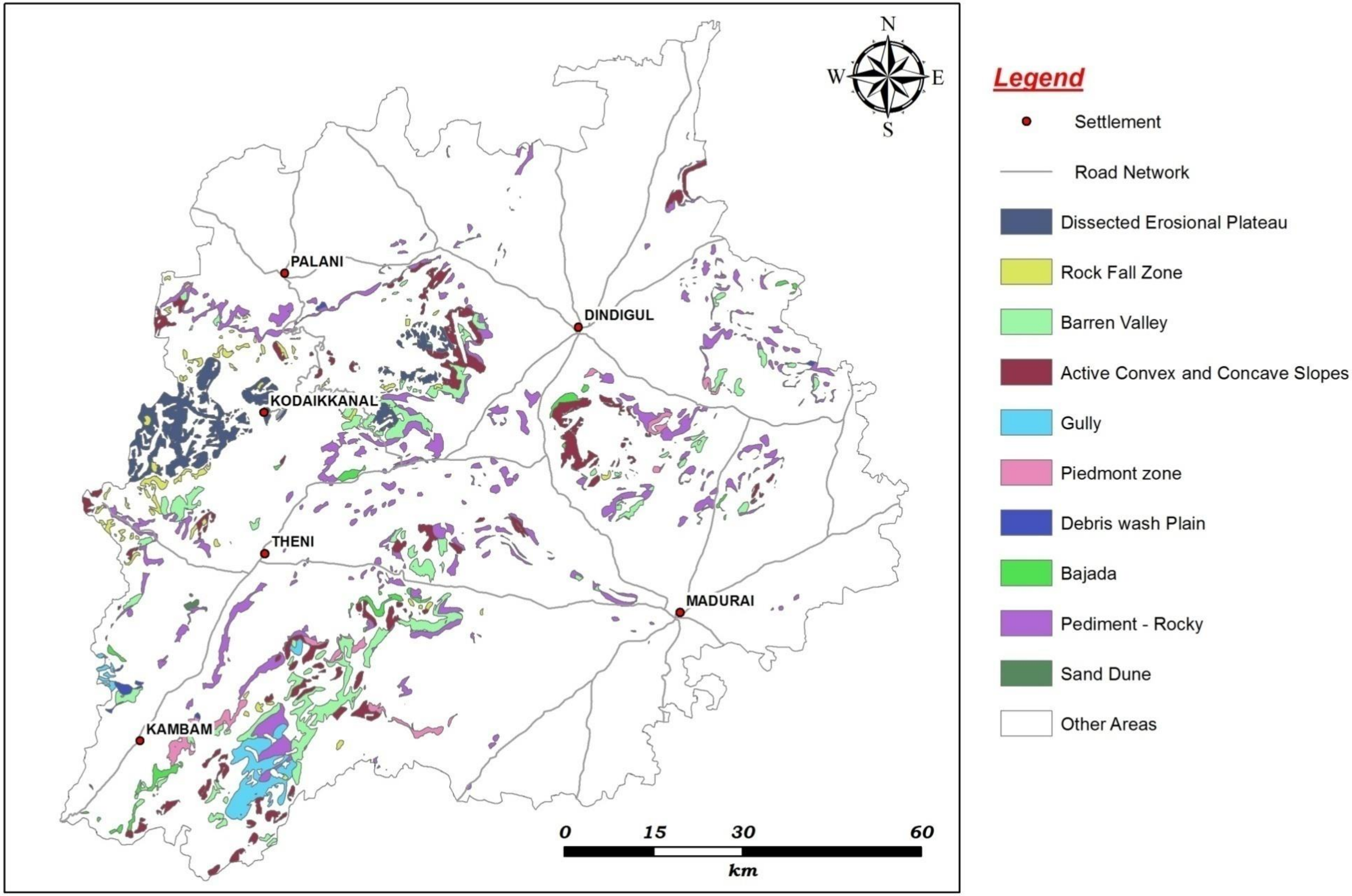
GEOMORPHOLOGY



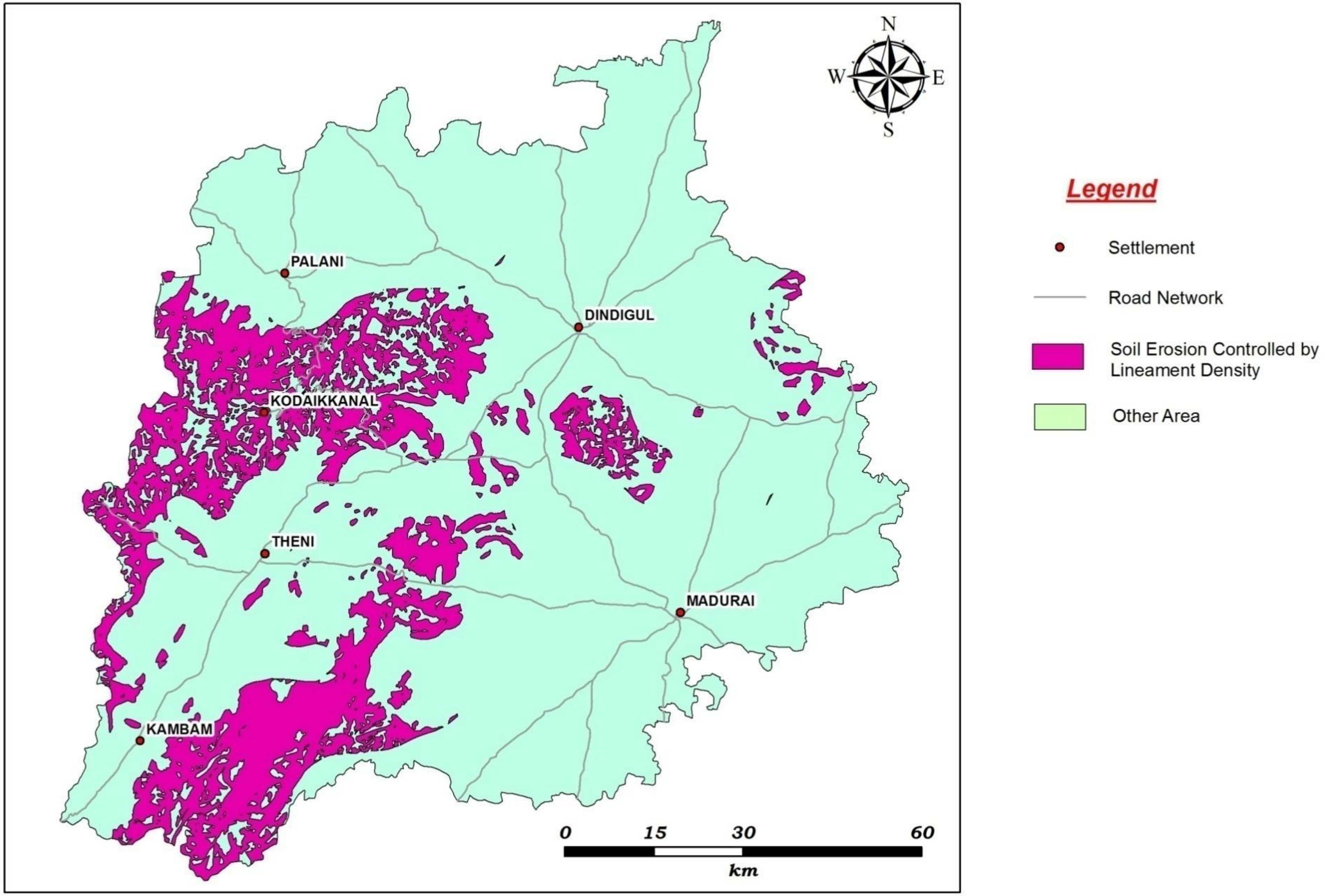
GEOMORPHOLOGY - EROSION PRONE



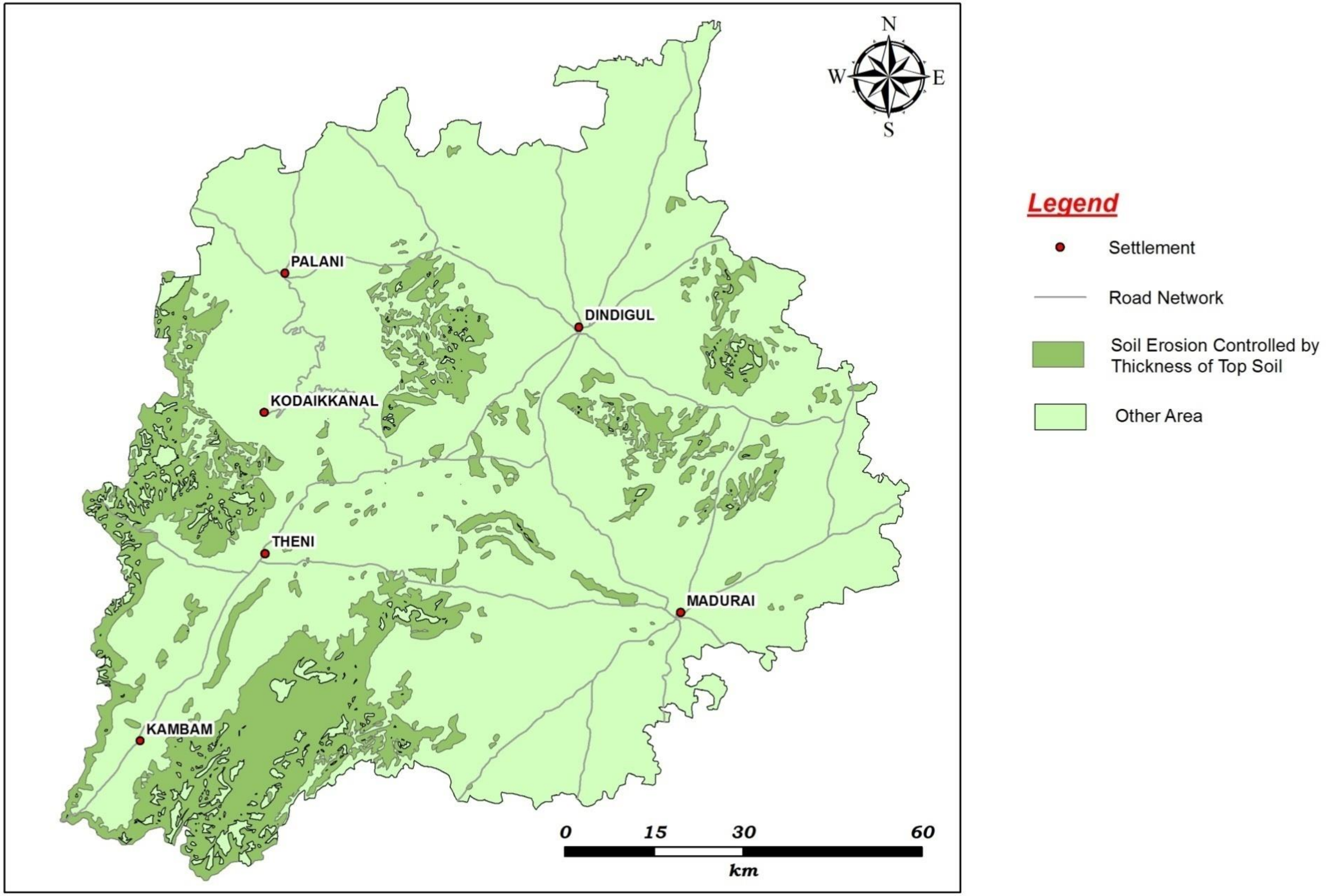
SOIL EROSION CONTROLLED BY GEOMORPHOLOGY



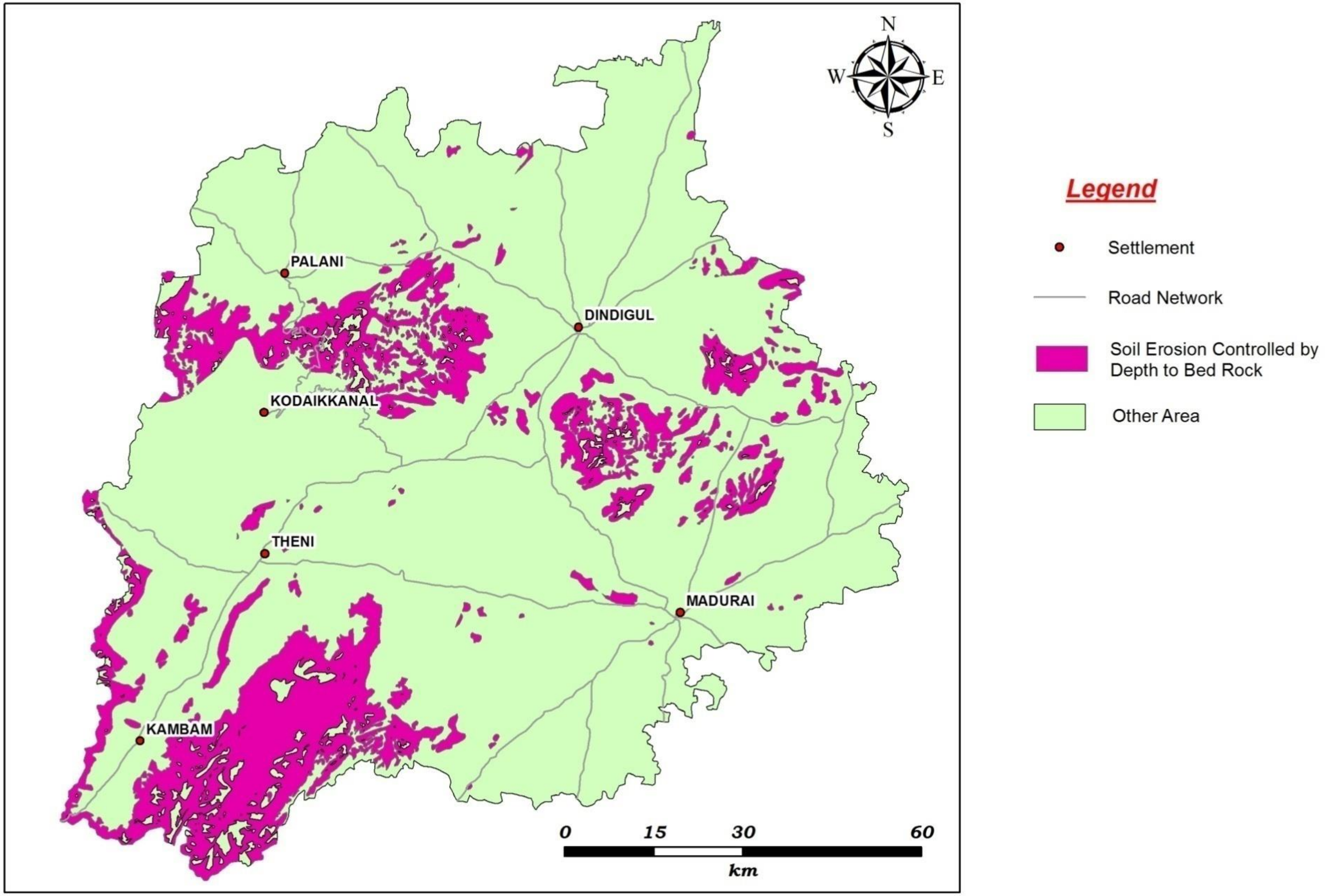
SOIL EROSION CONTROLLED BY LINEAMENT DENSITY



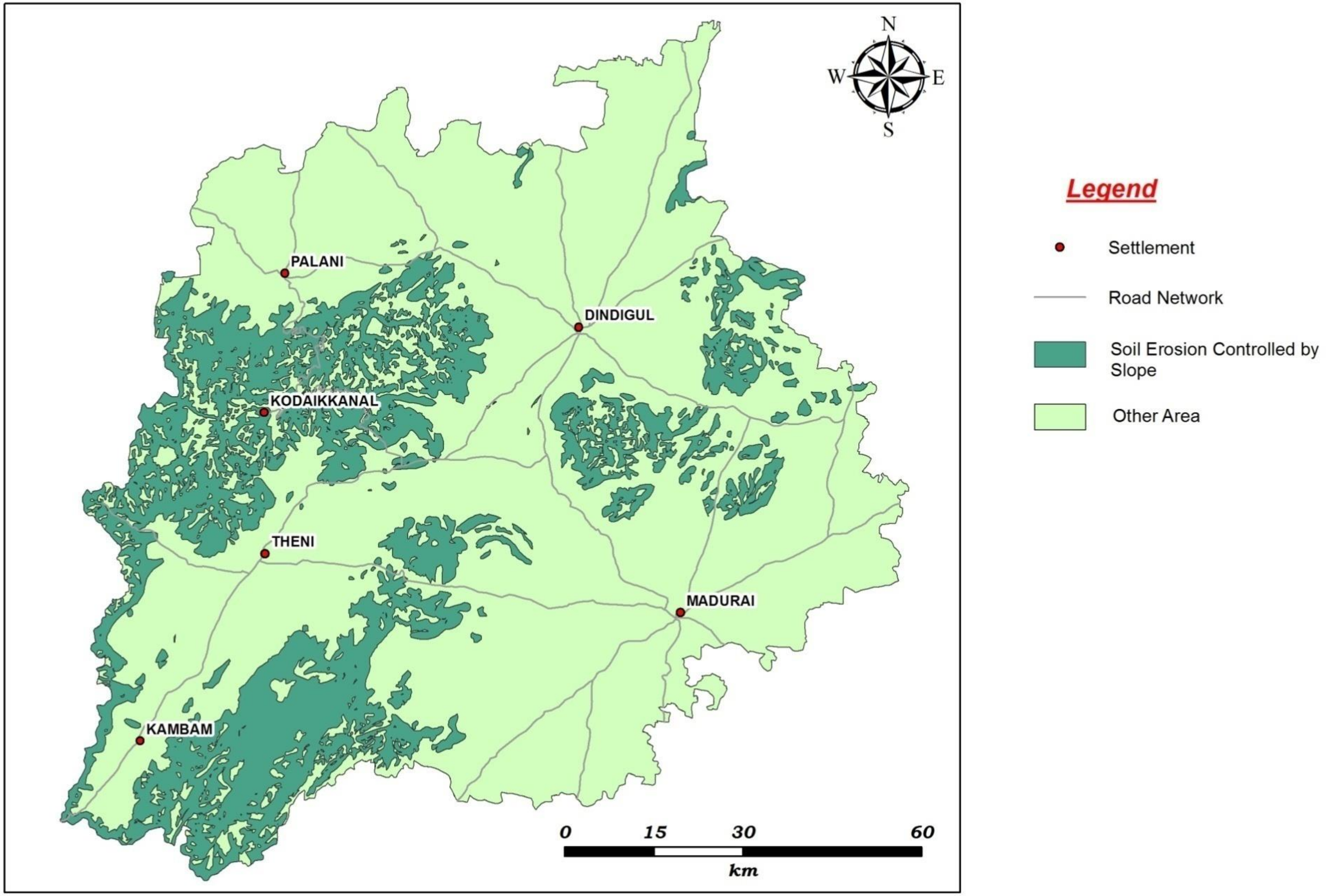
SOIL EROSION CONTROLLED BY THICKNESS OF TOP SOIL



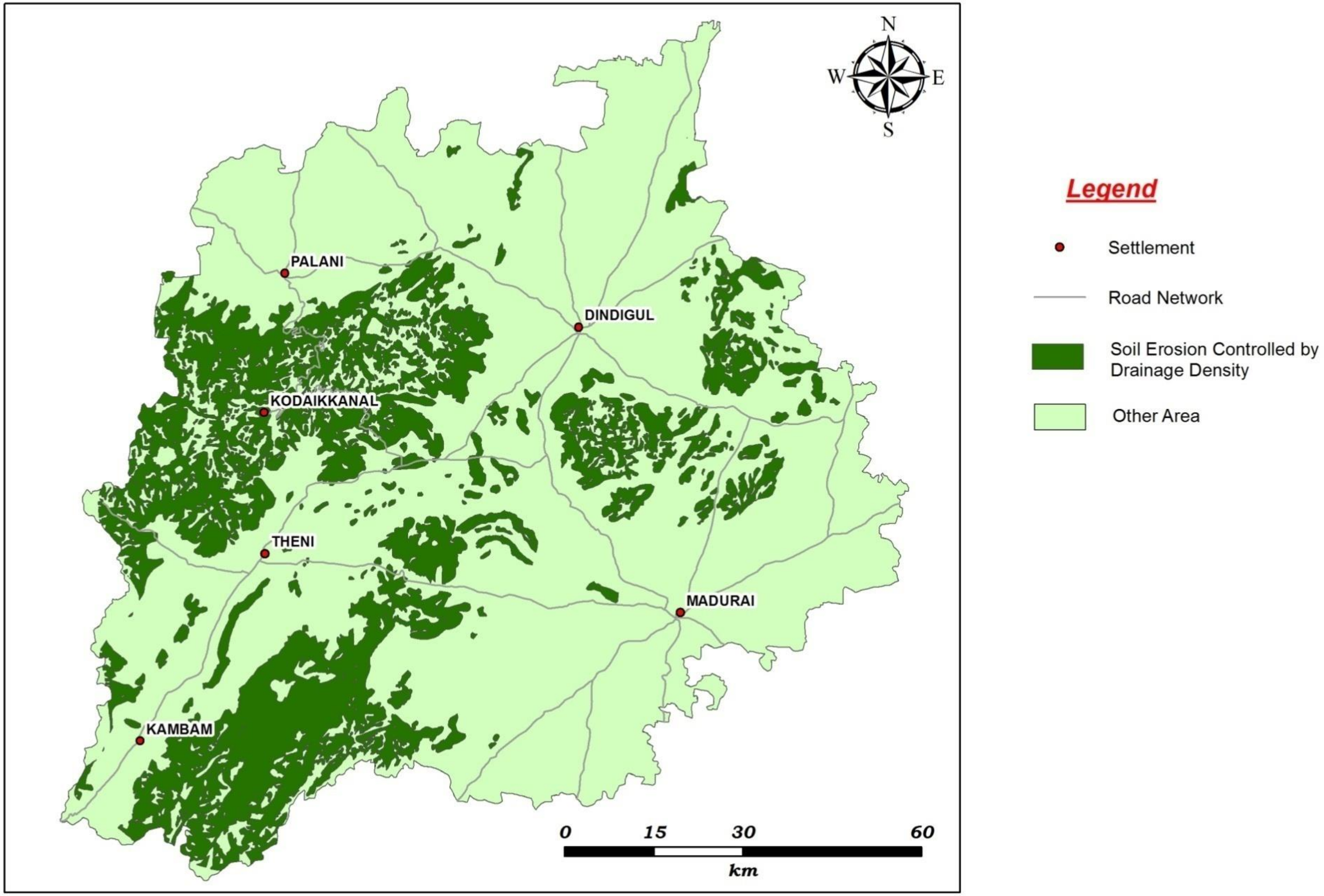
SOIL EROSION CONTROLLED BY DEPTH TO BED ROCK



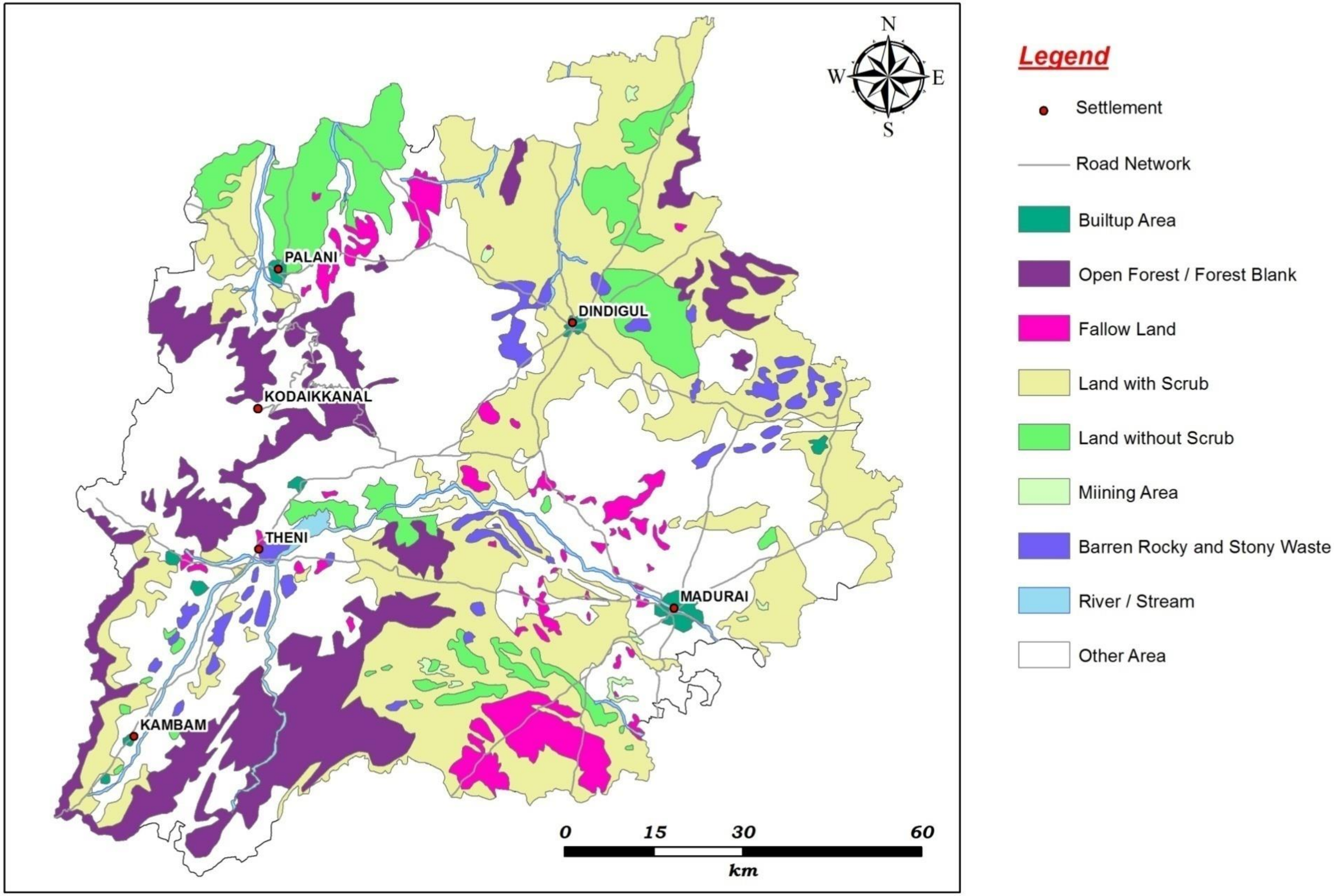
SOIL EROSION CONTROLLED BY SLOPE



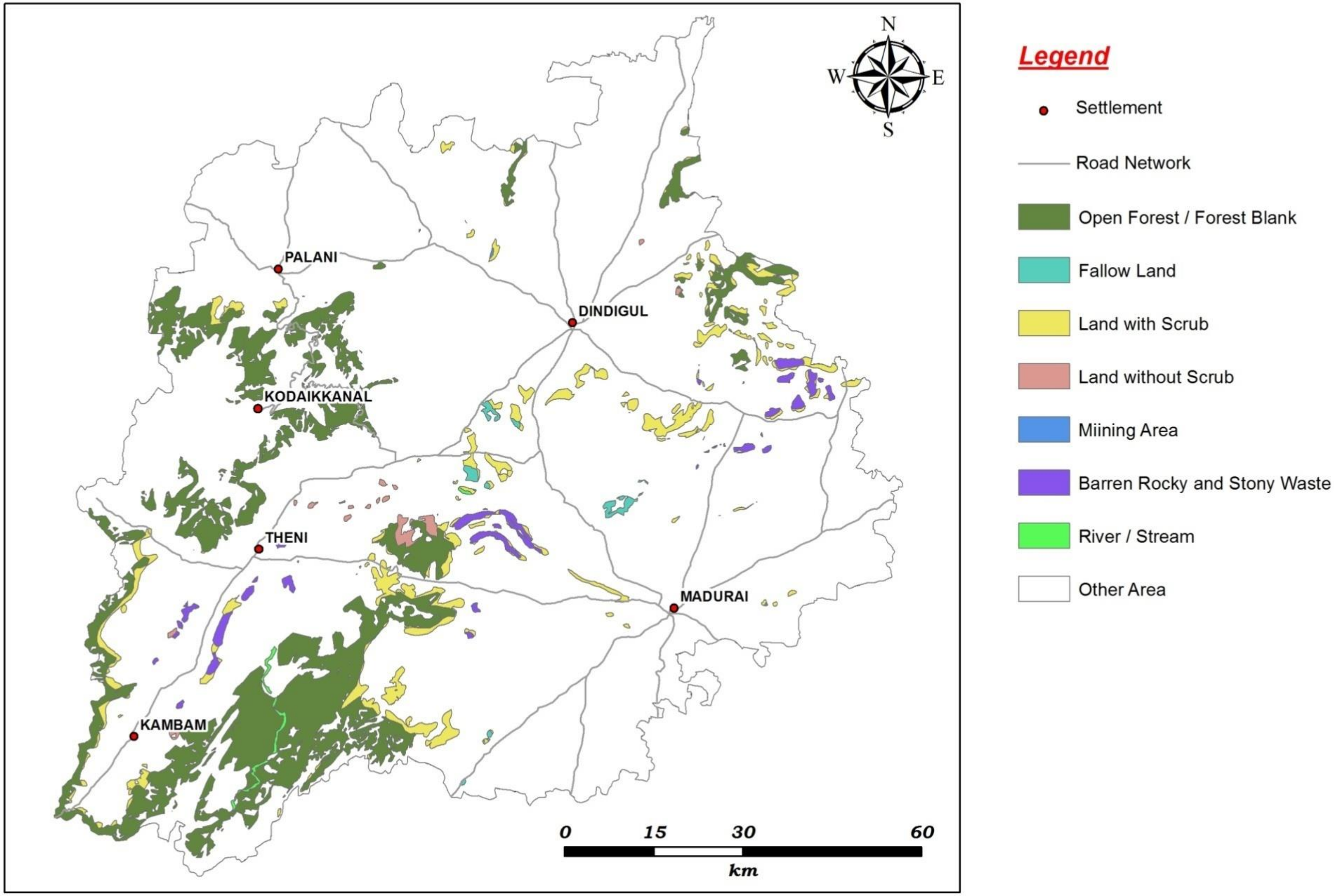
SOIL EROSION CONTROLLED BY DRAINAGE DENSITY



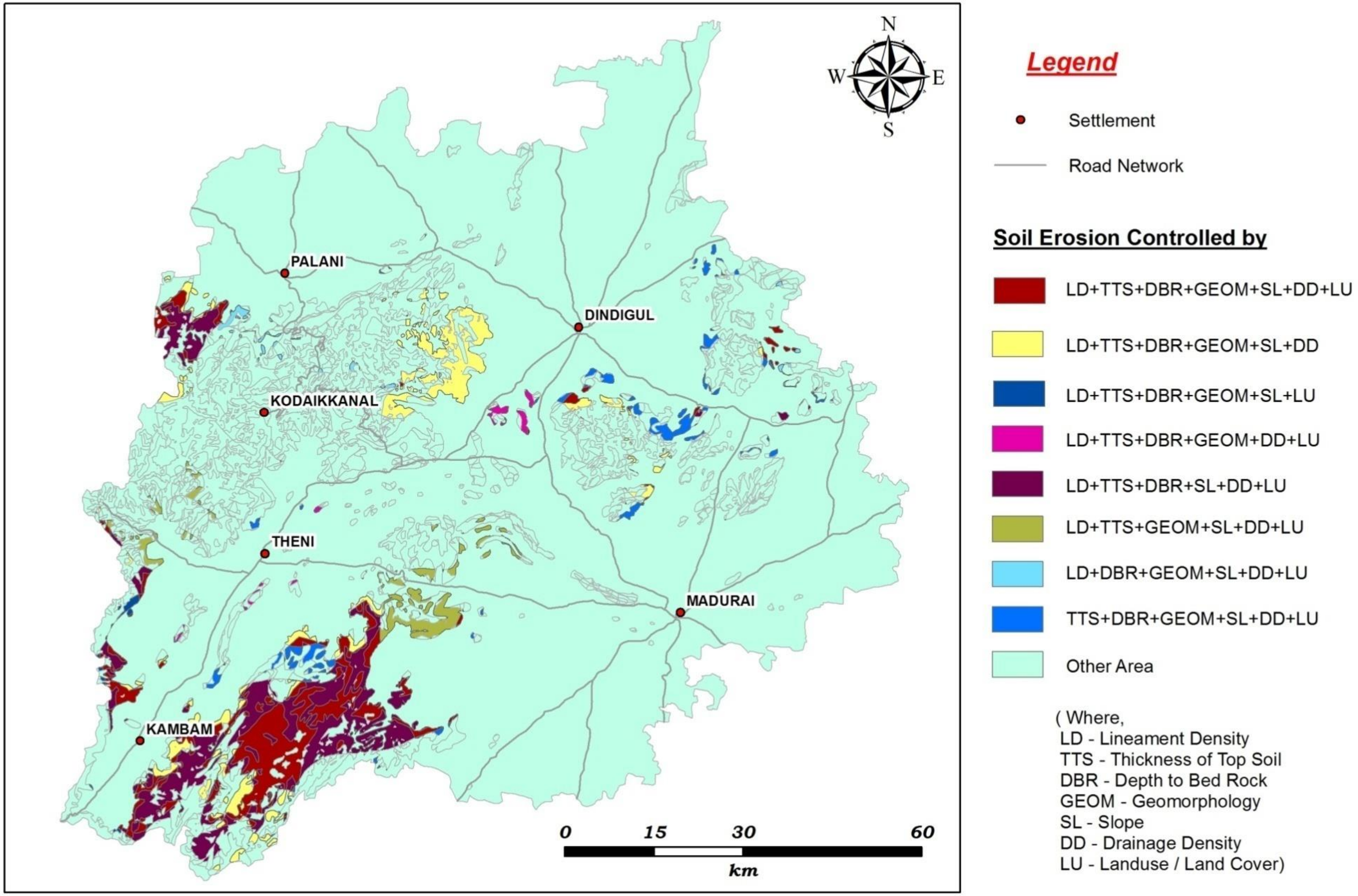
LANDUSE / LAND COVER - EROSION PRONE



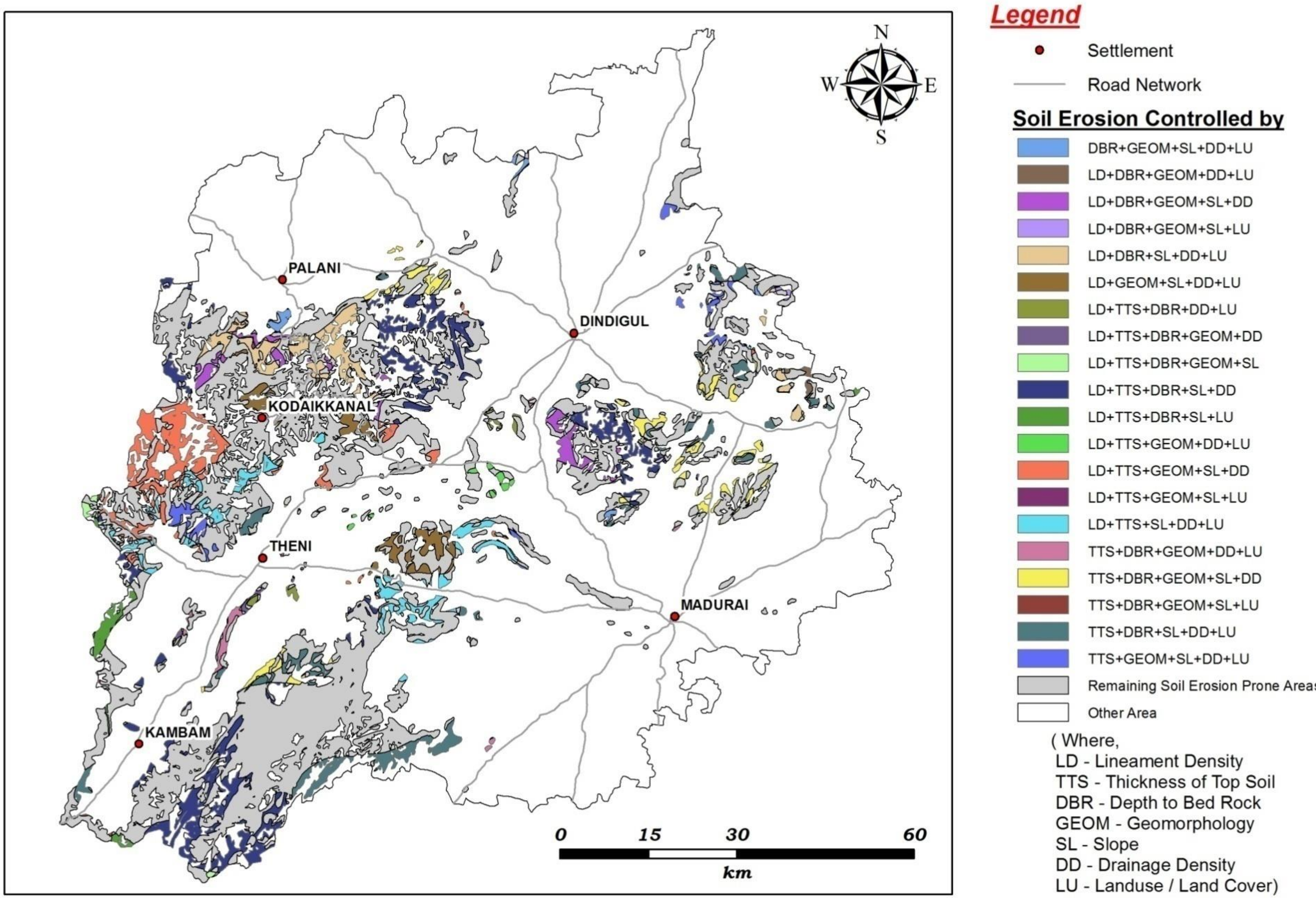
SOIL EROSION CONTROLLED BY LANDUSE / LAND COVER



FUNCTIONS OF SOIL EROSION (6 & 7 Parameters)



FUNCTIONS OF SOIL EROSION (5 PARAMETERS)



Remedial Measures

Areas of soil erosion controlled by		**Controlling Parameter based Remedial Measures**
1) Lineament density	□	**Gully Filled Vegetation**
2) Geomorphology	□	**Afforestation, Gully Plugging, Check Dams, Pasture development**
3) Thickness of top soil	□	**Afforestation, Geotextiling, Nailing**
4) Depth to bed rock	□	**Intensive Afforestation**
5) Slope	□	**Bench Cultivation**
6) Drainage density	□	**Gully Plucking, Check Dams**
7) Landuse/land cover	□	**Afforestation, etc.**

SOIL RESOURCES

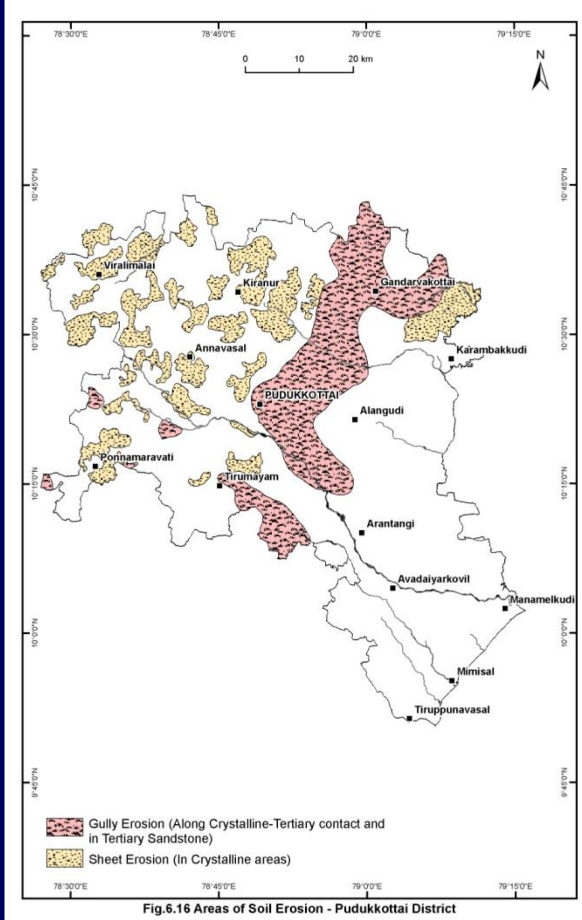


Fig.6.16 Areas of Soil Erosion - Pudukkottai District

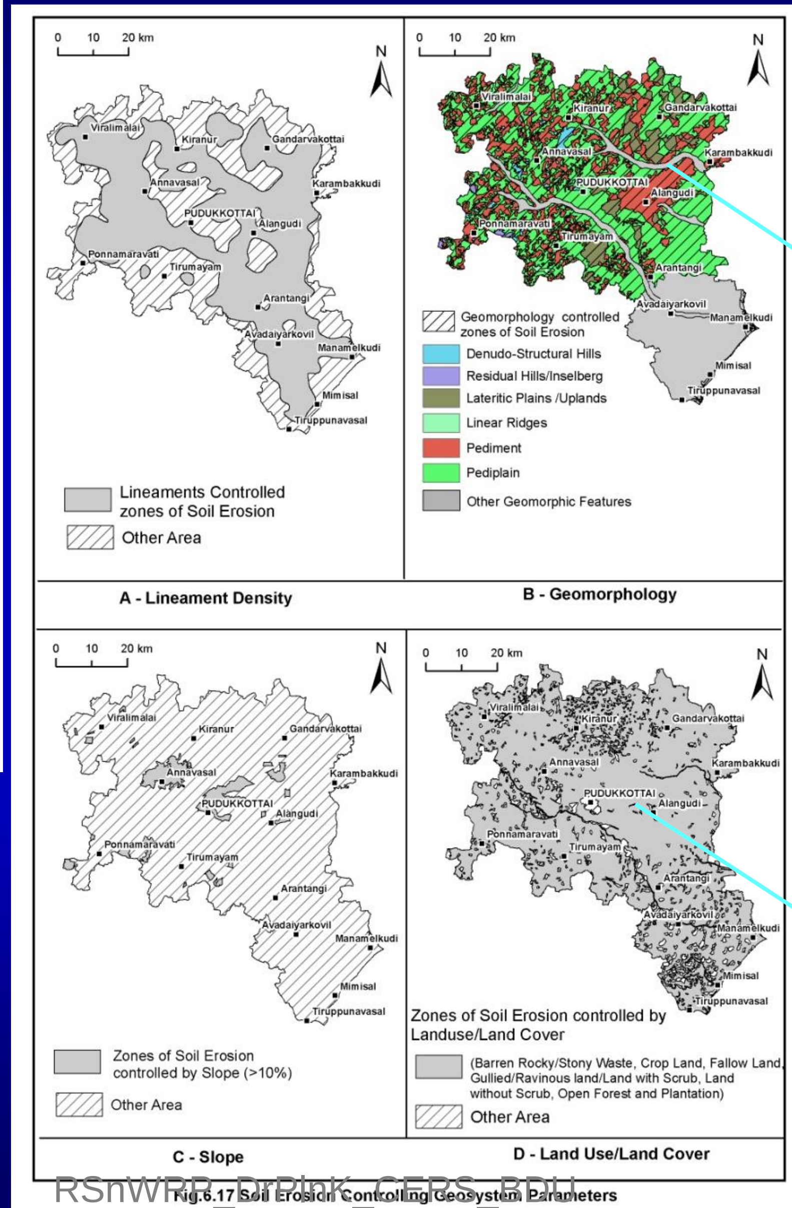


Fig.6.17 Soil Erosion Controlling Geosystem Parameters

STUDY - 5D

Soil erosion prone Geomorphic features

Soil erosion prone LU/LC

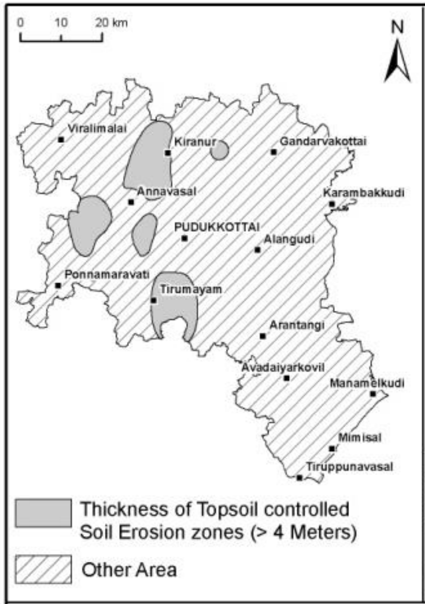


Fig.6.18 Thickness of Topsoil

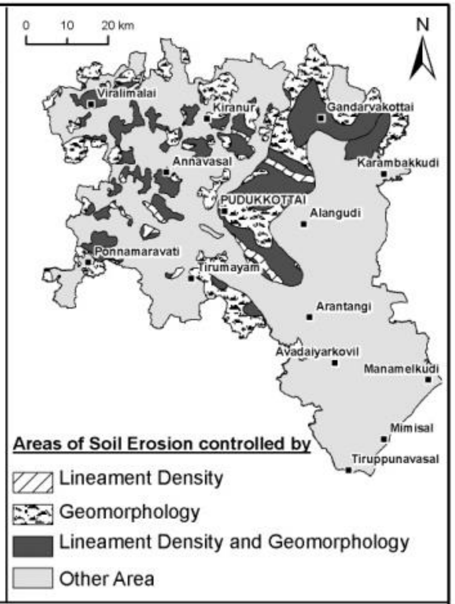


Fig.6.19 Level - I GIS Integration (Lineament Density Vs Geomorphology)

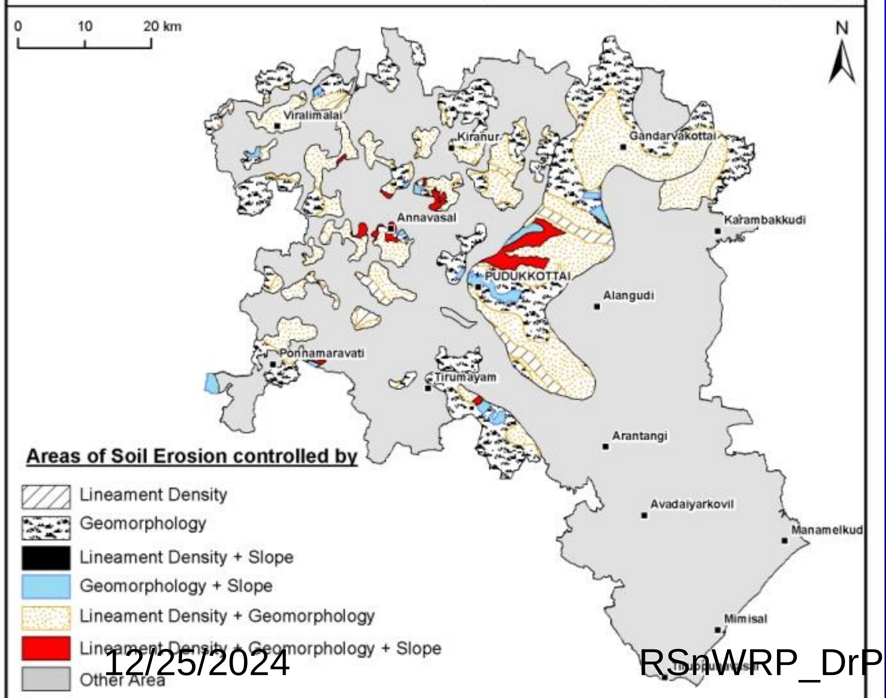


Fig.6.20 Level - II GIS Integration (Level - I + Slope)

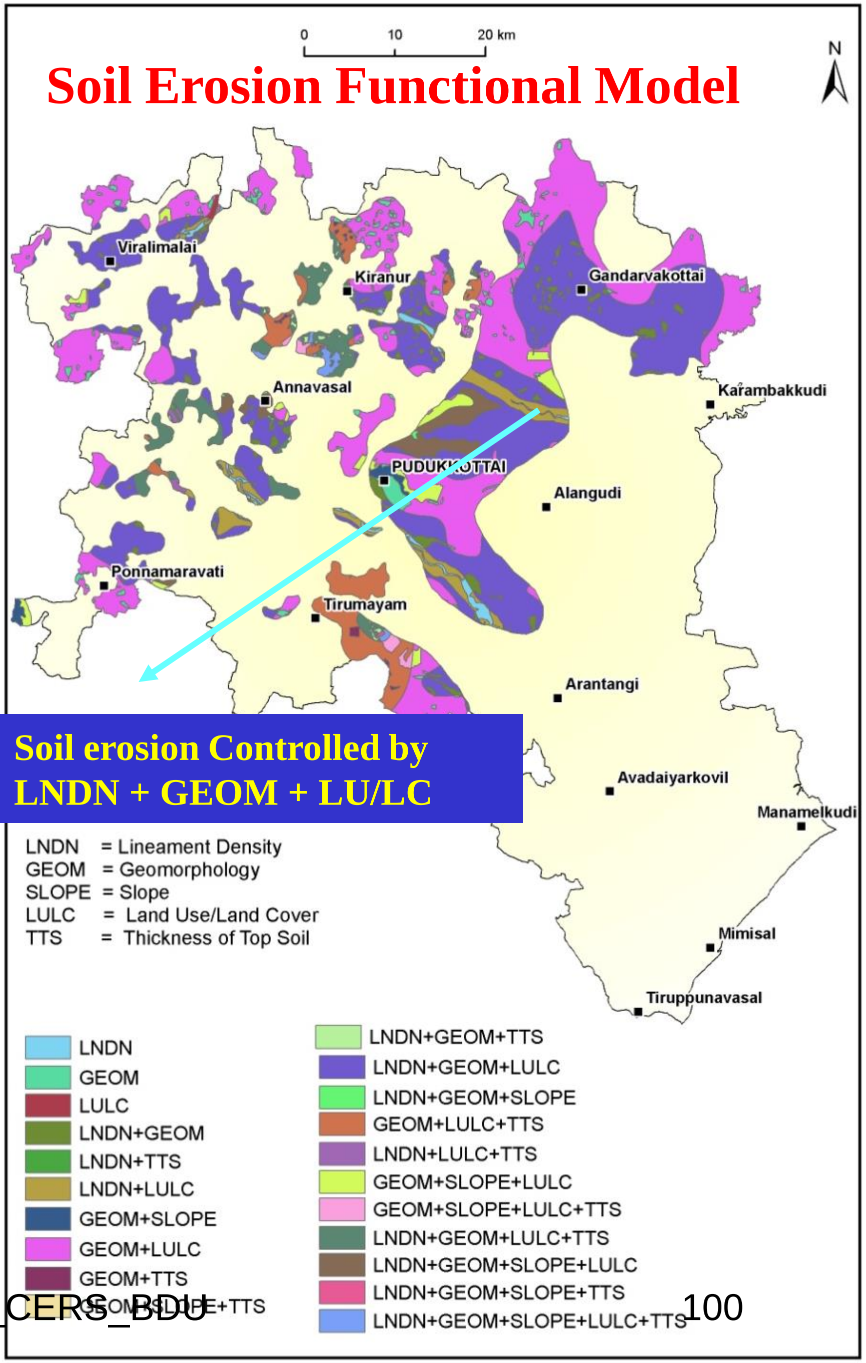


Fig.6.21 Soil Erosion Functional Model - Pudukkottai District

Sl. No.	Controlling Geo-system Parameters	Remedial Measures
1	Lineament Density - Erosion prone	Gully Plugging, Gully Filled Vegetation
2	Geomorphology - Erosion prone 2.1 Denudo-Structural hills	Afforestation, Contour bunding, Strip cropping
	2.2 Lateritic Plains/Uplands	Plantations, Dry land Irrigation, Horticulture
	2.3 Pediment/Pediplains	Agriculture, Horticulture, Mixed Plantation, etc
3	Slope - Erosion prone	Contour bunding, Bench Cultivation, Check Dam, Silt trapping
4	Landuse / Land Cover - Erosion prone 4.1 Land with scrub / without Scrub	Afforestation, Horticulture
	4.2 Fallow Land	Cultivation, Deep penetrating rooted Plants
	4.3 Gullied land / Ravinous land	Gully Plucking, Gully filed Vegetation
	4.4 Open Forest and Plantation	Intensive Afforestation
5	Thickness of Topsoil - Erosion prone	Afforestation, Geotextiling, Irrigation

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STUDY - 6

Inter-Watershed Transfer

Back

- After working out the surface water and groundwater potentials, natural and artificial recharges for an area, by comparing these values, it is very important to suggest for transfer of water from surplus / excess watersheds to deficit watersheds with suitable and pragmatic strategies. This is a societal relevant and beneficial plan known as Inter-watershed water transfer to tackle both flood and drought problems as did by our fore-fathers.

- A case study was performed in Ayyar Basin located in central part of Tamil Nadu between Kollimalai and Pachchaimalai hills. The watershed wise: 1. aerial extent of rechargeable formations, 2. volume of rechargeable formations, 3. total thickness of unsaturated zone (Water level below ground level), 4. volume of rechargeable formations available for recharge, 5. volume of allowable recharge, were worked out.

- To workout the volume of rechargeable formations, the aerial extent of rechargeable formations was multiplied with the depth to bedrock data. The water level data was multiplied with the area of artificially rechargeable formations to arrive the <u>volume of rechargeable formations</u>(column 7) available for recharge.

- As the area exposes mostly Gneisses, the storage coefficient of 0.23 or 23 % was taken as allowable storage. The data arrived at column 7 was multiplied with 0.23 to arrive the <u>volume of allowable recharge</u> (column 8)

- The total water potential available as run-off was less than the volume of allowable recharge (column 8) the said watershed was declared as <u>deficit watershed</u>. Instead, if the run-off was more than volume of allowable recharge, then it was declared as water <u>surplus watershed</u>.

ANNEXURE - II

INTER WATERSHED TRANSFER

1 SL.No	2 WATER-SHED No	3 SURFACE WATER POTENTIAL	4 AREA OF ARTFICIAL RECHARGEABLE FORMATIONS IN MM^2	5 VOLUME OF RECHARGEABLE FORMATIONS IN MCM	6 THICKNESS OF UNSATU-RATED ZONE IN M	7 VOLUME OF RECHARGEABLE FORMATIONS AVAILABLE FOR RECHARGE IN MCM	8 VOLUME OF ALLOWABLE RECHARGE IN MCM (Storage coefficient)	9 REMARKS
1	1	5.590	58.834	2353.360	9.00	529.506	121.786	DEFICIT
2	2	58.990	24.613	246.130	8.50	209.211	48.119	SURPLUS
3	3	40.690	48.353	1160.472	4.90	236.930	54.494	DEFICIT
4	4	19.520	39.254	863.588	8.50	333.659	76.742	DEFICIT
5	5	56.810	20.481	491.544	7.50	153.608	35.330	SURPLUS
6	6	15.400	26.575	797.250	9.00	239.175	55.010	DEFICIT
7	7	46.060	71.908	2588.688	11.50	826.942	190.197	DEFICIT
8	8	4.280	22.798	1094.304	8.50	193.783	44.570	DEFICIT
9	9	9.400	24.909	647.634	10.00	249.090	57.291	DEFICIT
10	10	27.000	39.173	783.460	8.00	313.384	72.078	DEFICIT
11	11	22.900	4.233	186.252	11.00	46.563	10.709	SURPLUS
12	12	41.030	68.298	1434.258	11.50	785.427	180.648	DEFICIT
13	13	8.380	15.186	425.208	12.00	182.232	41.913	DEFICIT
14	14	38.230	15.074	361.776	14.00	211.036	48.538	DEFICIT
15	15	4.050	28.877	721.925	12.00	346.524	79.701	DEFICIT
16	16	3.860	12.925	361.900	9.50	122.788	28.241	DEFICIT
17	17	73.640	43.443	868.860	9.00	390.987	89.927	DEFICIT
18	18	65.130	51.270	1230.480	10.00	512.700	117.921	DEFICIT
19	19	70.220	39.181	940.344	9.00	352.629	81.105	DEFICIT
20	20	38.260	12.398	347.144	10.00	123.980	28.515	SURPLUS

ANNEXURE - II (Contd...)

INTER WATERSHED TRANSFER

1 SL.No	2 WATER-SHED No	3 SURFACE WATER POTENTIAL	4 AREA OF ARTFICIAL RECHARGEABLE FORMATIONS IN MM^2	5 VOLUME OF RECHARGEABLE FORMATIONS IN MCM	6 THICKNESS OF UNSATU-RATED ZONE IN M	7 VOLUME OF RECHARGEABLE FORMATIONS AVAILABLE FOR RECHARGE IN MCM	8 VOLUME OF ALLOWABLE RECHARGE IN MCM (Storage coefficient)	9 REMARKS
21	21	15.970	52.453	839.248	10.50	550.757	126.674	DEFICIT
22	22	13.600	44.320	975.040	11.00	487.520	112.130	DEFICIT
23	23	36.900	81.835	2618.720	10.50	859.268	197.632	DEFICIT
24	24	30.700	30.375	364.500	11.00	334.125	76.849	DEFICIT
25	25	11.900	27.099	541.980	12.50	338.738	77.910	DEFICIT
26	26	27.890	81.835	1964.040	8.50	695.598	159.988	DEFICIT
27	27	7.400	58.848	1647.660	9.00	529.605	121.809	DEFICIT
28	28	3.700	2.163	69.216	7.00	15.141	3.482	SURPLUS
29	29	6.400	50.991	1733.694	7.50	382.433	87.960	DEFICIT
30	30	9.700	3.908	132.872	6.50	25.402	5.842	SURPLUS
31	31	12.500	59.989	2159.604	9.50	569.896	131.076	DEFICIT
32	32	57.700	30.963	743.112	11.50	356.075	81.897	DEFICIT
33	33	29.600	5.325	127.800	9.50	50.588	11.635	SURPLUS

STUDY - 7

FLOOD WATER HARVESTING

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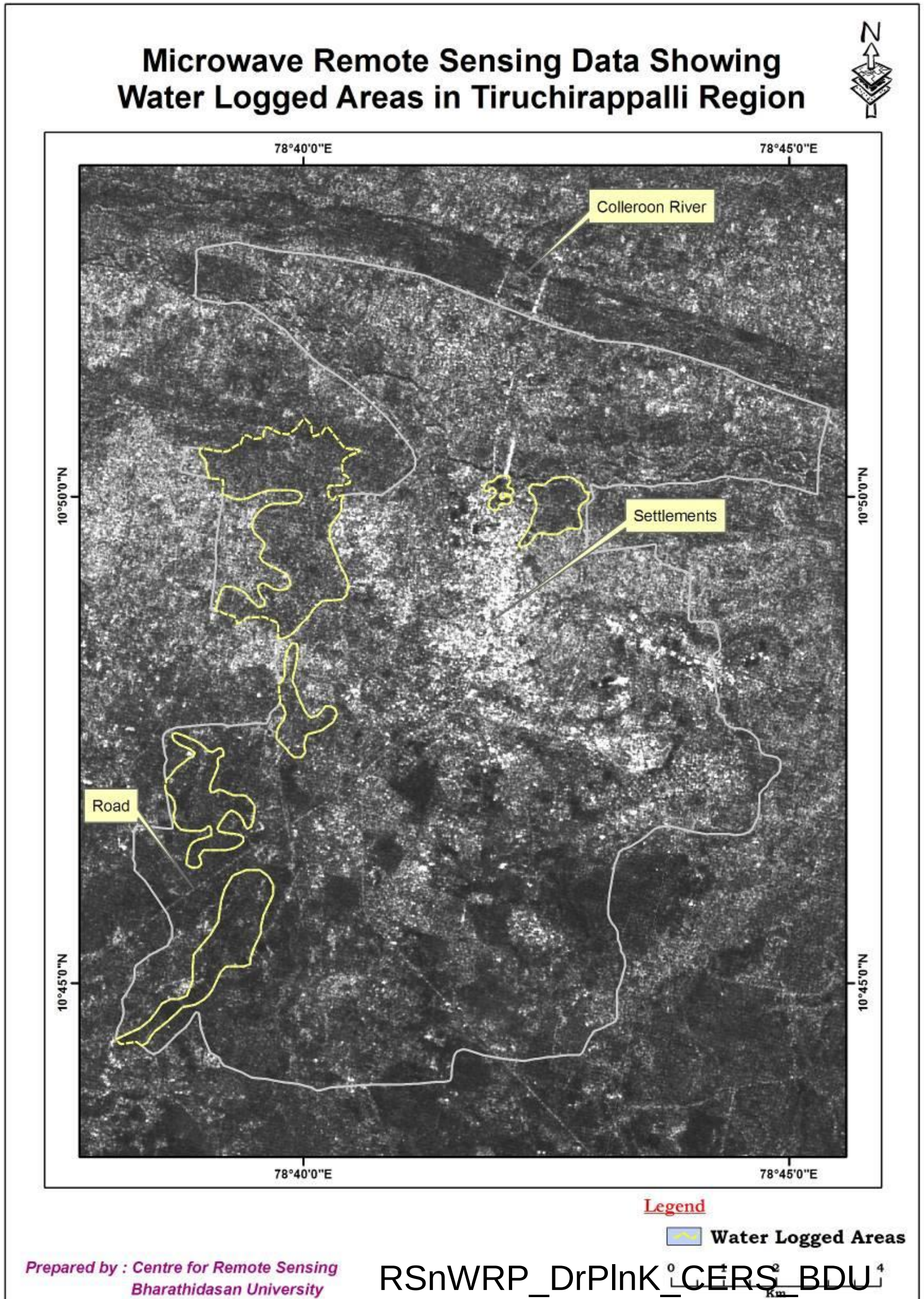
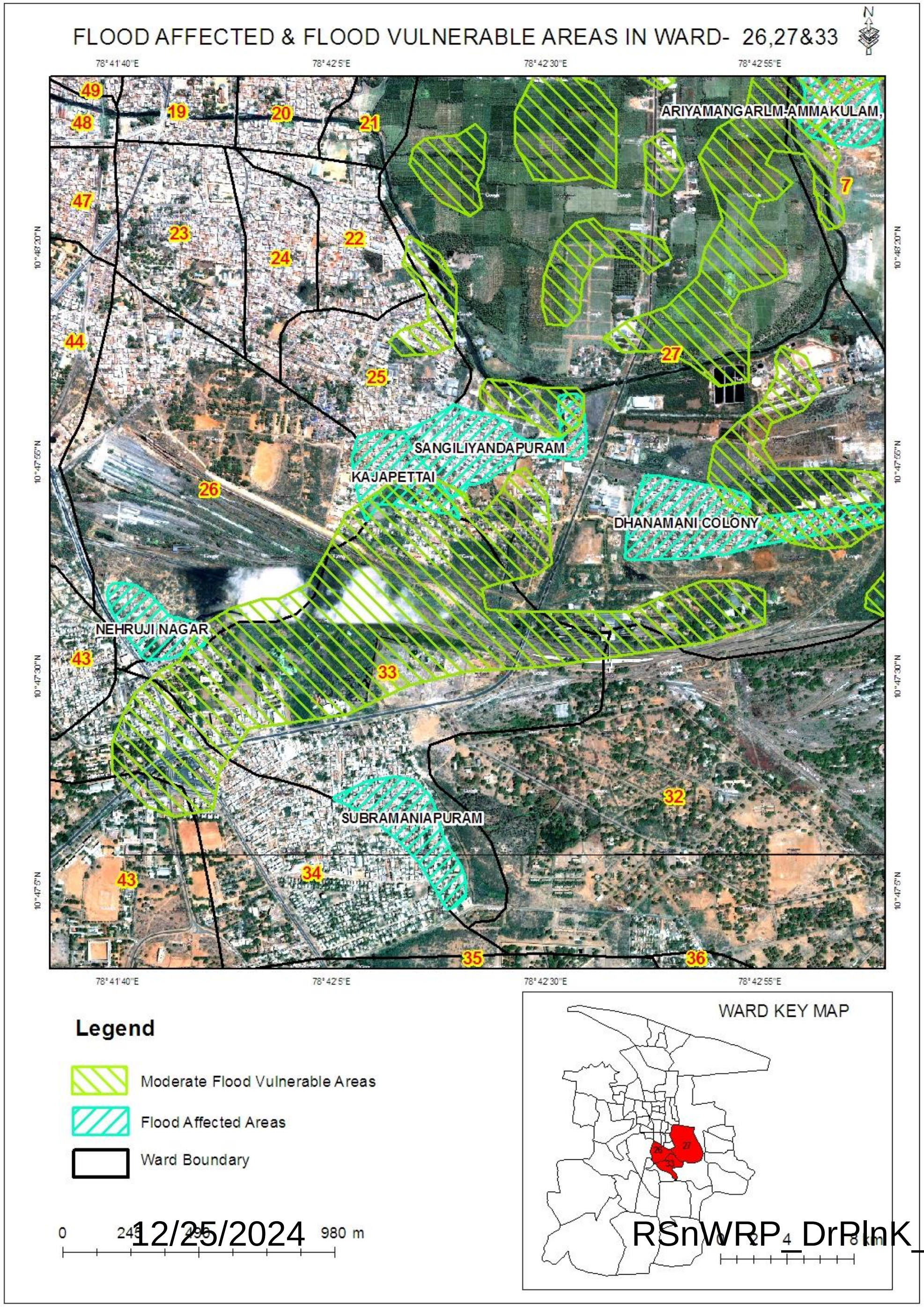
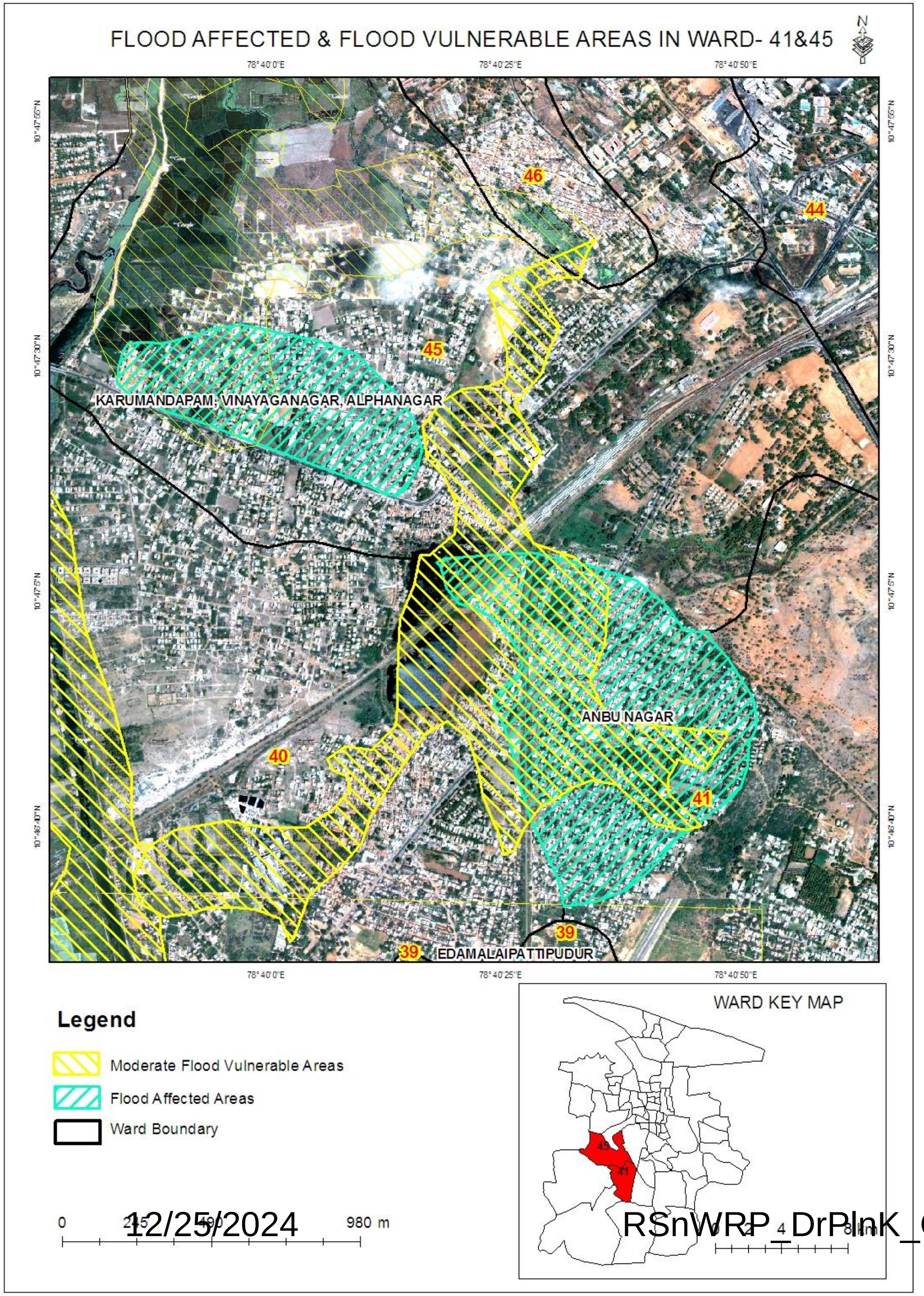

Microwave Remote Sensing Data Showing
Water Logged Areas in Tiruchirappalli Region
N
78°40'0"E
78°45'0"E
10°50'0"N
10°45'0"N
Colleroon River
Settlements
Road
Legend
Water Logged Areas
Prepared by : Centre for Remote Sensing
Bharathidasan University
Km

STUDY – 7A



Flood vulnerable areas and affected areas in Wards 26, 27&33, Tiruchirappalli Corporation

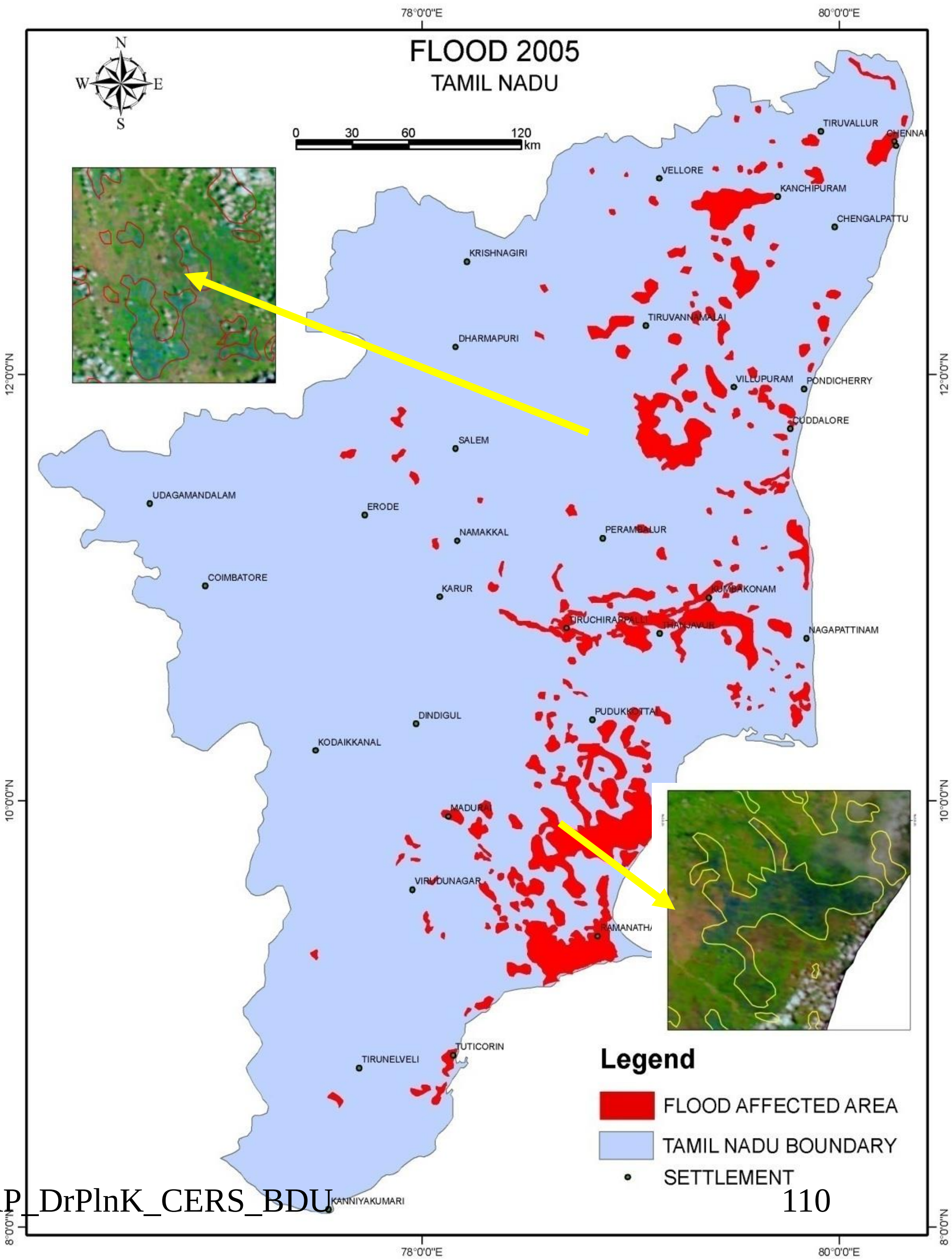


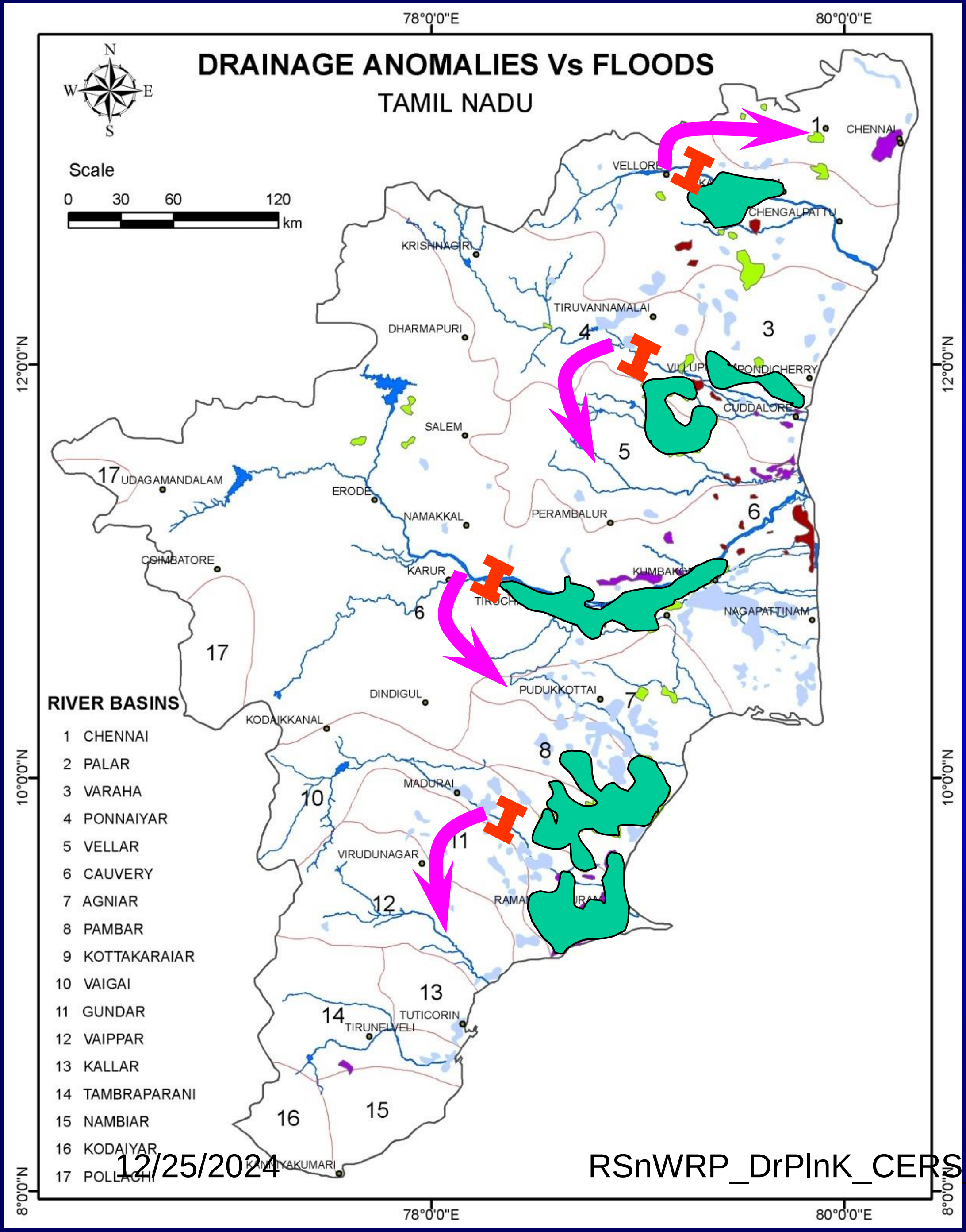
Flood vulnerable areas and affected areas in Ward 41&45, Tiruchirappalli Corporation

STUDY - 7B

Flooded areas in Tamil Nadu during Dec.2005

- Mapped using MODIS temporal data + Microwave data + Flood polygons from media (Radio, TV, internet) and authorized reports…



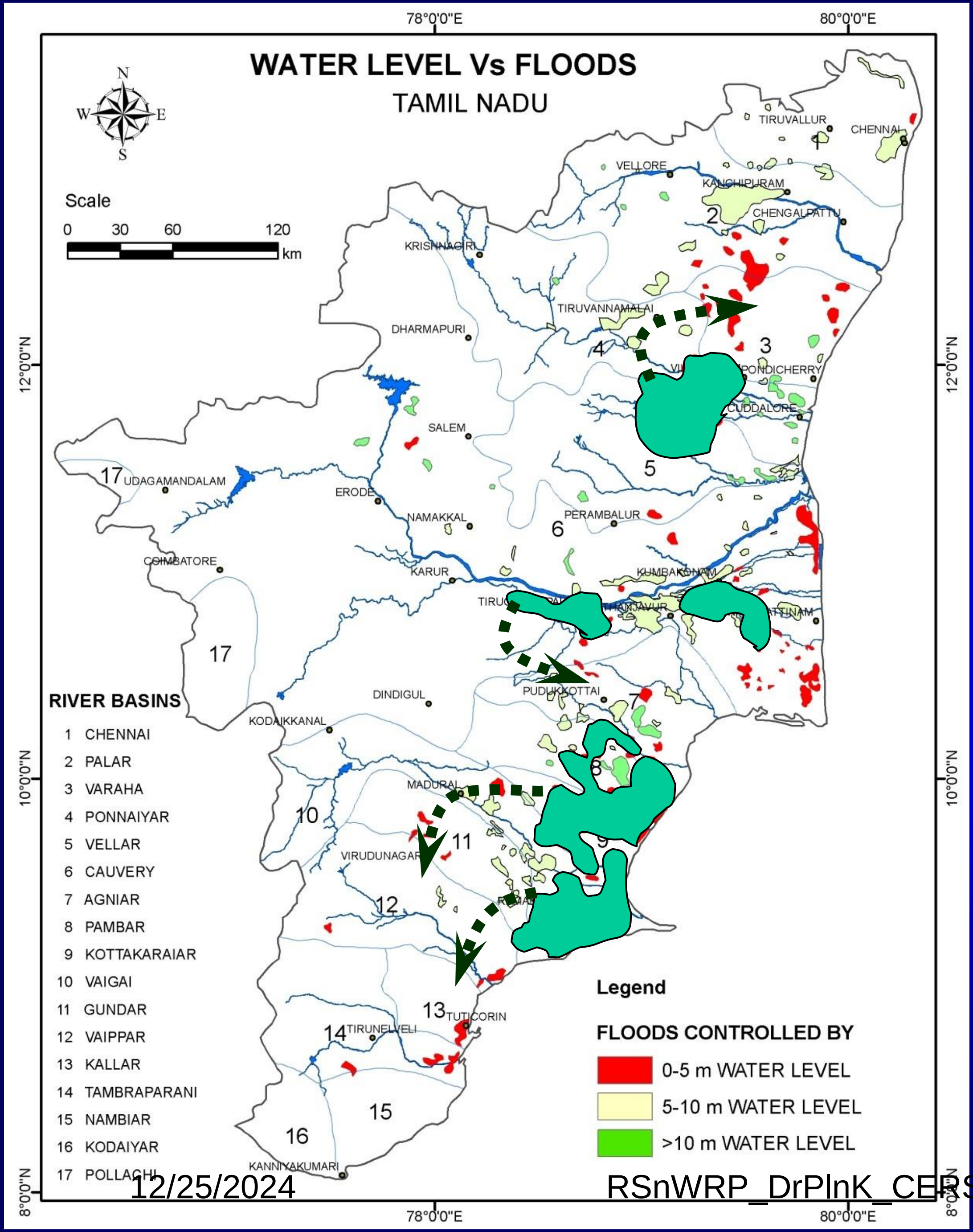


FLOOD CONTROLLED BY DRAINAGE ANOMALIES

- ❖ Eyed Drainages
- ❖ Rectilinear drainages
- ❖ Fault/Lineament controlled drainages, etc.

➥ **Check dam in upper reaches**

➥ **Transfer to Other basins**

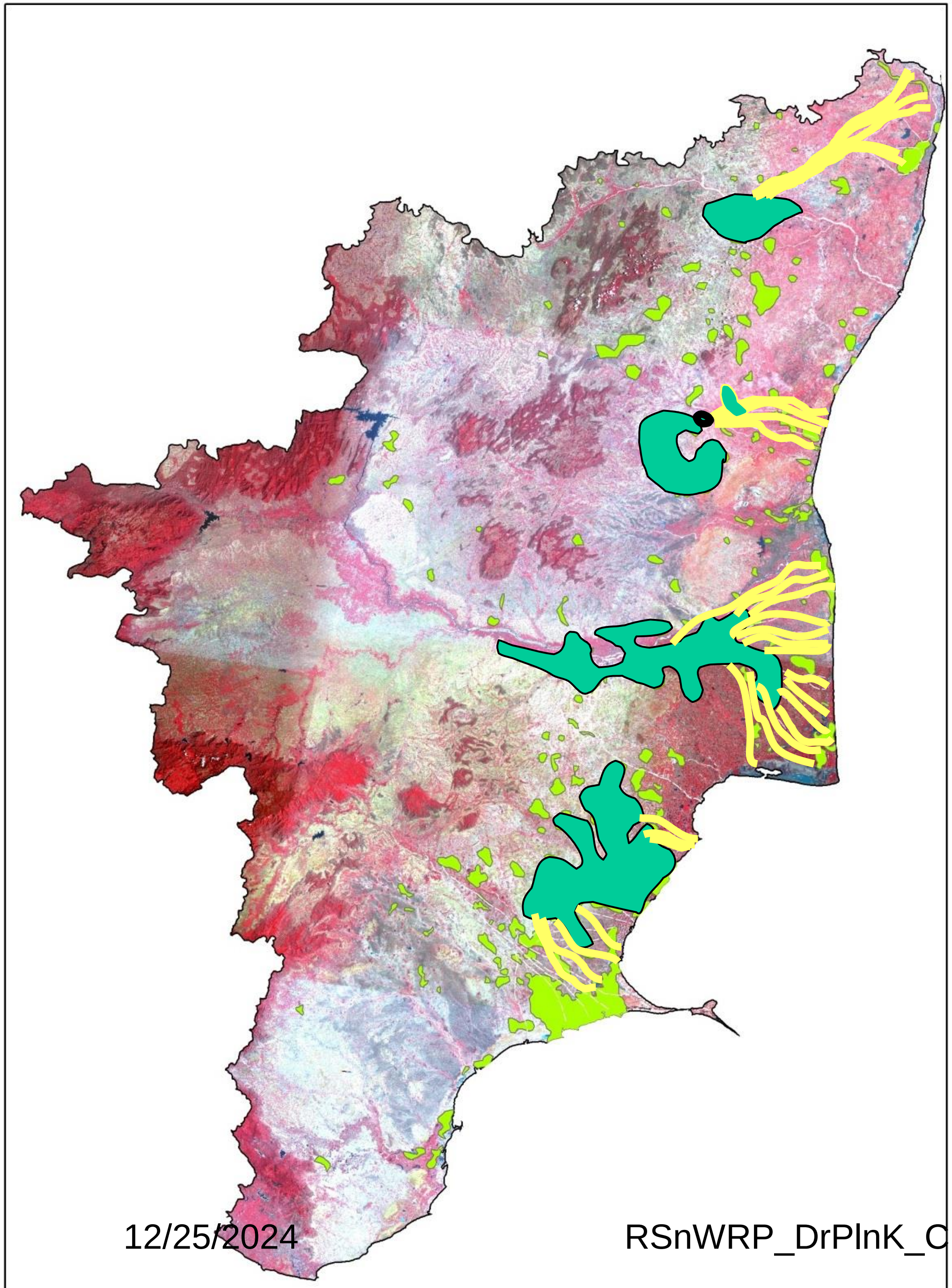


FLOOD CONTROLLED BY

WATER LEVEL

Areas of Shallow GWLs are flooded

- **Depress the water level**
- **Transfer to other basin**



FLOOD WATER HARVESTING

DIVERSION OF FLOOD THROUGH BURIED RIVERS / PALAEOCHANNELS

Transfer of excess flood water to the desilted and bund/dam strengthened reservoirs, tanks, lakes and harvested & ploughed agricultural lands located in the adjacent water deficit (Grey / Black) watersheds through any of the naturally favourable routes.

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STUDY - 8

GIS BASED DRAINAGE MORPHOMETRIC ANALYSES & RUNOFF ESTIMATION

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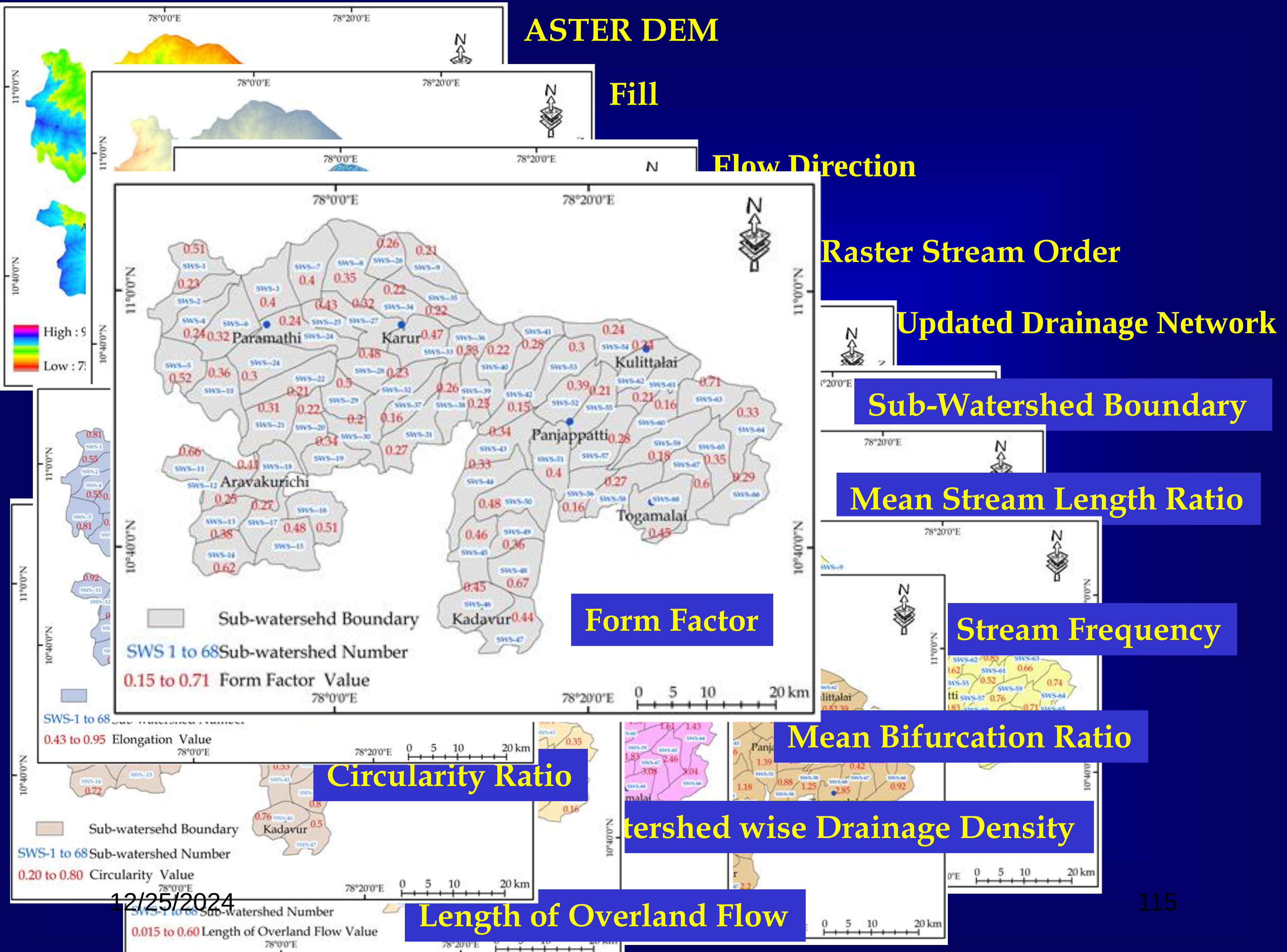
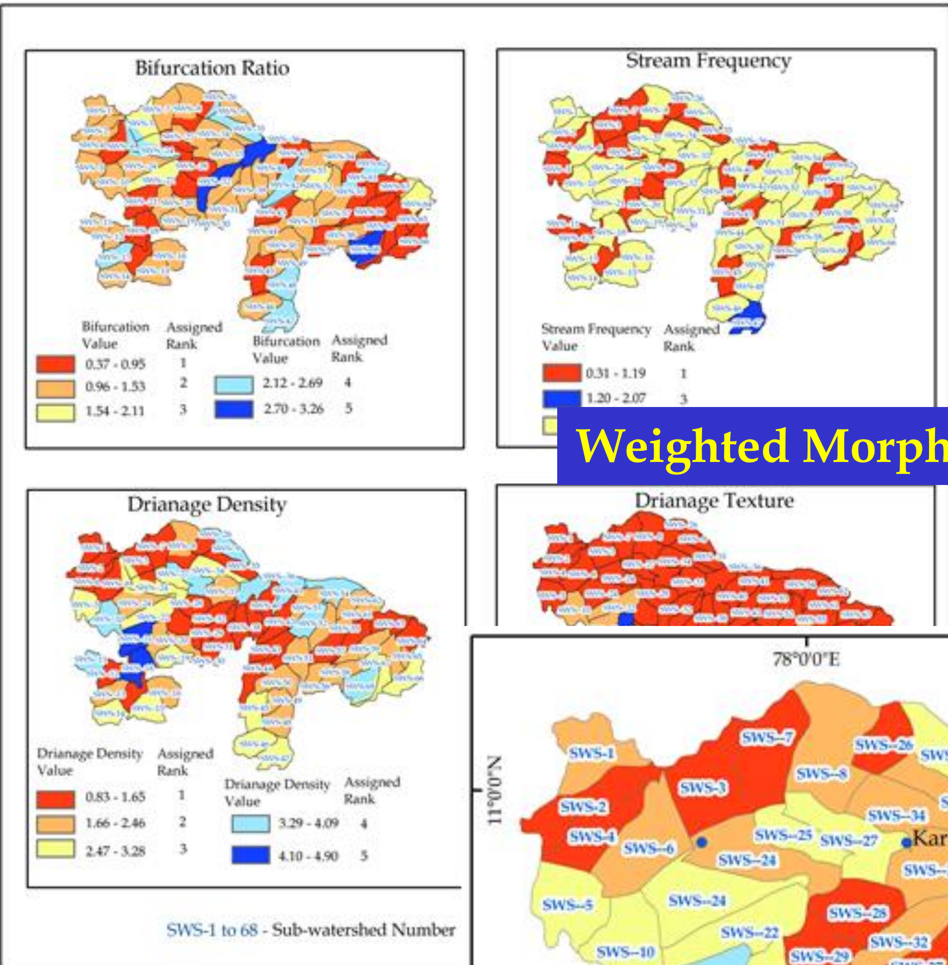
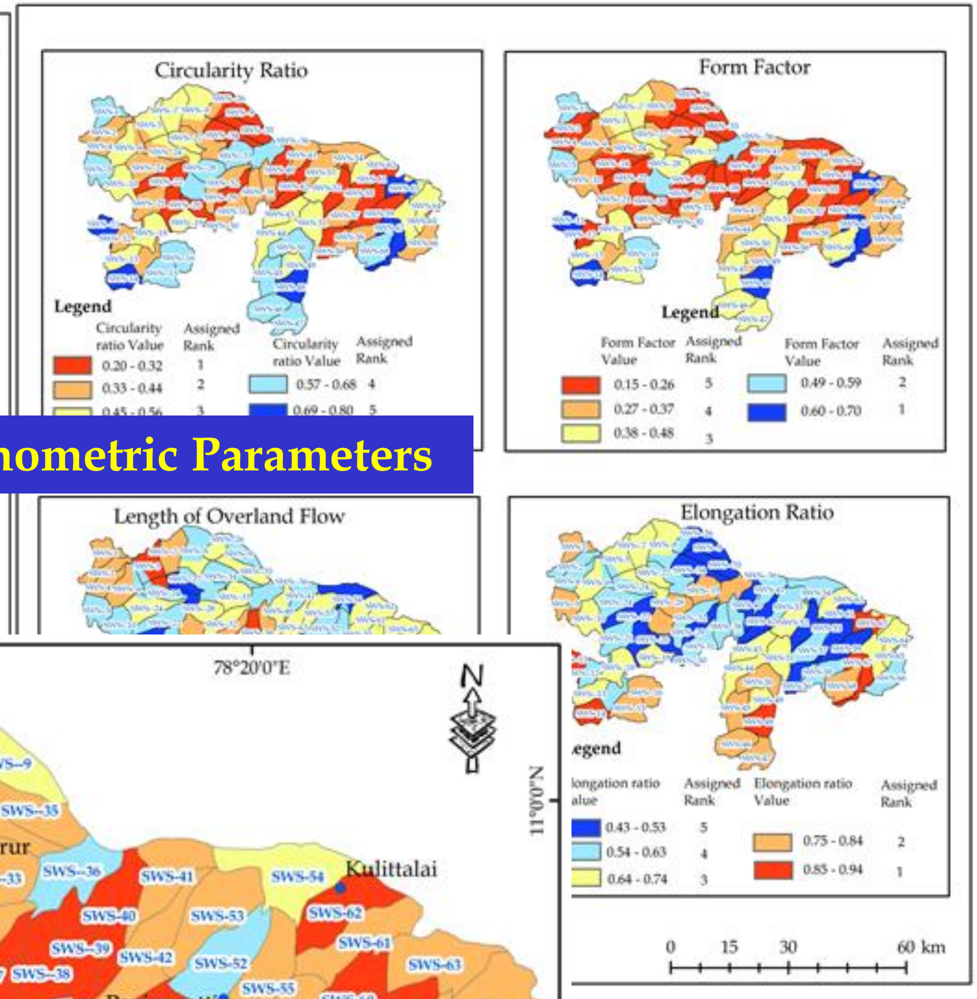
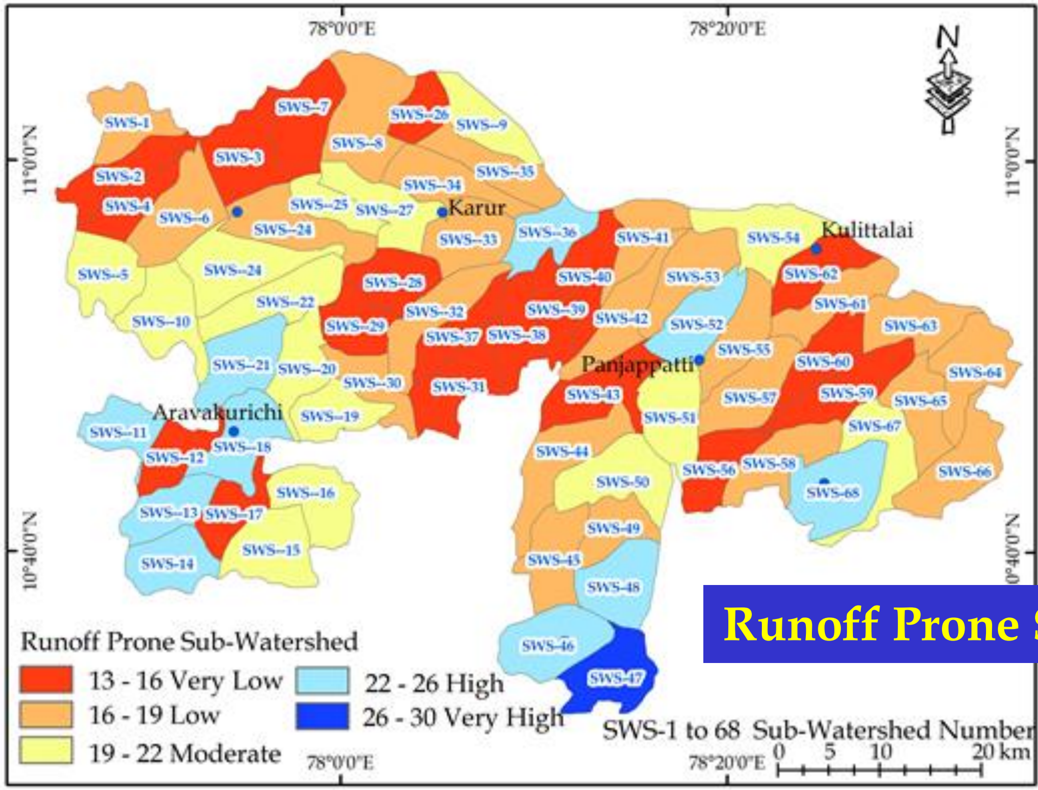

ASTER DEM
Fill
Flow Direction
Raster Stream Order
Updated Drainage Network
Sub-Watershed Boundary
Mean Stream Length Ratio
Form Factor
Stream Frequency
Mean Bifurcation Ratio
tershed wise Drainage Density
Circularity Ratio
Length of Overland Flow
78°0'0"E
78°20'0"E
11°0'0"N
10°40'0"N
Paramathi
Karur
Kulittalai
Panjappatti
Aravakurichi
Togamalai
Kadavur
Sub-watersehd Boundary
SWS 1 to 68 Sub-watershed Number
0.15 to 0.71 Form Factor Value
0 5 10 20 km
SWS-1 to 68
0.43 to 0.95 Elongation Value
Sub-watersehd Boundary
SWS-1 to 68 Sub-watershed Number
0.20 to 0.80 Circularity Value
0.015 to 0.60 Length of Overland Flow Value





Weighted Morphometric Parameters



Runoff Prone Sub-watersheds

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