Role of Technology (Remote Sensing & GIS) in Water Conservation

State workshop on
WATER CONSERVATION AND WASTEWATER RECYCLE/REUSE IN RAJASTHAN – ISSUES AND CHALLENGES
February 07, 2013

Rohit Goyal

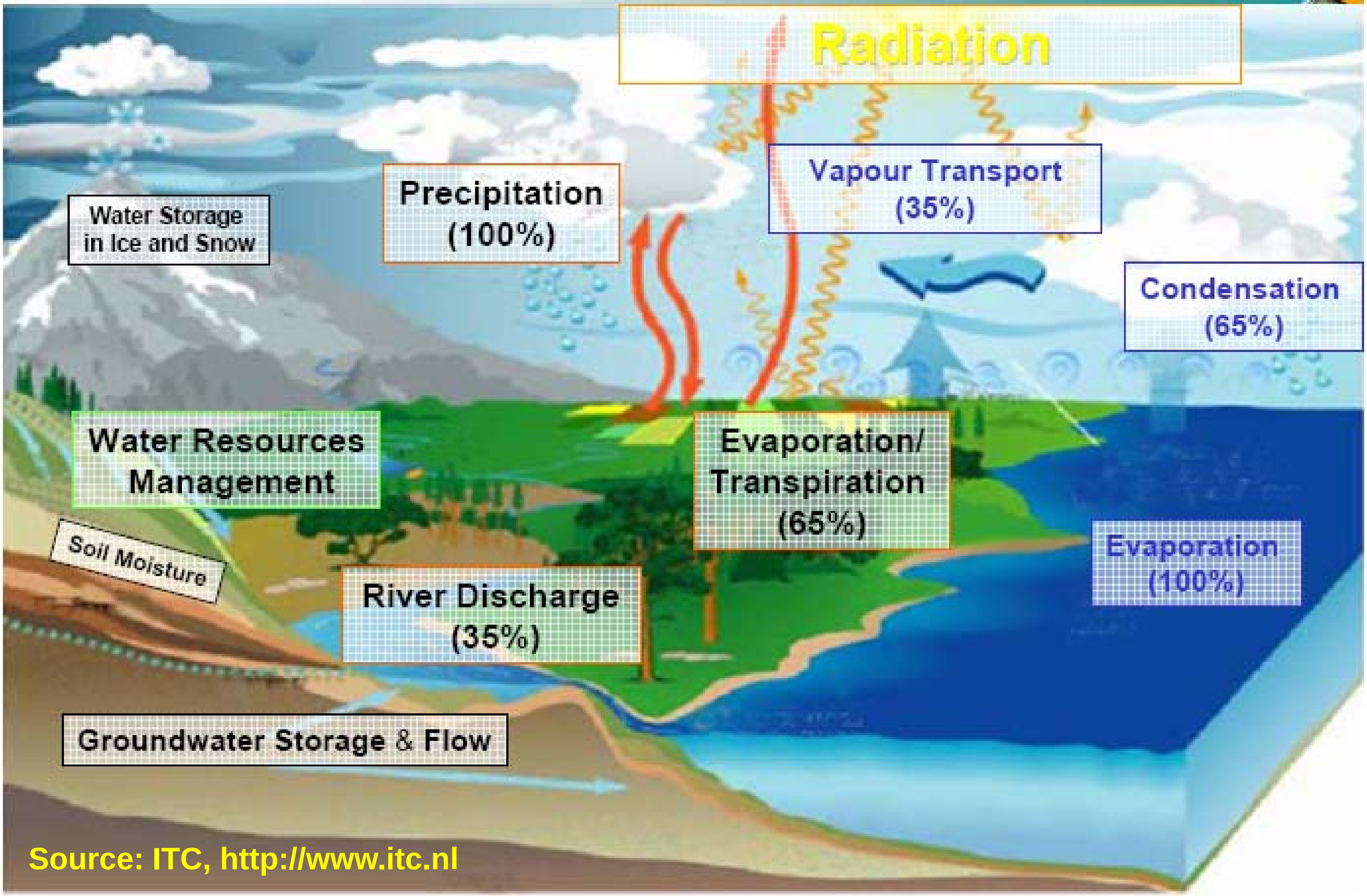
Professor & Dean Academic
Department of Civil Engineering
Malaviya National Institute of Technology
Jaipur 302 017

E-Mail: rgoyal_jp@yahoo.com

Overview

- India Occupies 2% of the earth surface area but 16% of its population.
- India receives only 4% of average runoff in it's river as compared to world.
- Livelihood of about 70% depends on agriculture.
- 25% of GDP is derived from agriculture, which depends upon
  - **Water Resources**
  - **Land**

Earth Observation of Water Cycle



Rajasthan, A Water Deficit State

- Approximately **10% Area**
- **5% Population**
- Only **1% utilizable water resources**
- Ground water
  - Available 11.15 BCM
  - Withdrawal 11.83 BCM (104 %)
- 100 Year Av. Rainfall for the state 531.0 mm
  - Eastern Districts (22) 688.68
  - Western Districts (10) 318.68

How to “manage” resources?

- Skidmore *et al.* (1997) argued that in order to effectively “manage” resources, three elements must be present
  - Information about natural resources
  - Clear policies on how the resource may be managed (eg, Acts of Government, policy papers, administrative procedures)
  - Participation of everyone (including local people)

Data/Information Needs

- In order to optimally utilize it's land and sparse water resources, data/information is needed on parameters such as
  - Rainfall
  - Availability of surface water resources
  - Groundwater resources
  - Landuse-landcover maps
  - Elevations, slopes,
  - Land surface temperatures, evapotranspiration (ET)
  - Biomass etc.
- Not only information is needed, Tools are required to properly analyze such information for planning purposes.

Remote Sensing Data

- Remote sensing data is a versatile data which not only directly provides much of the useful data/information
  - but may also be used to infer a lot of other unavailable data.
- In the literature Remote Sensing data has been used for information such as
  - Soil erosion (Jain et al., 2005)
  - Water stress detection (Colaizzi et al., 2003)
  - Soil moisture (Scott et al., 2003, Shih and Jordan, 1993)
  - Water resource management (Bastiaanssen et al., 2005, Dymond et al., 2004) etc.

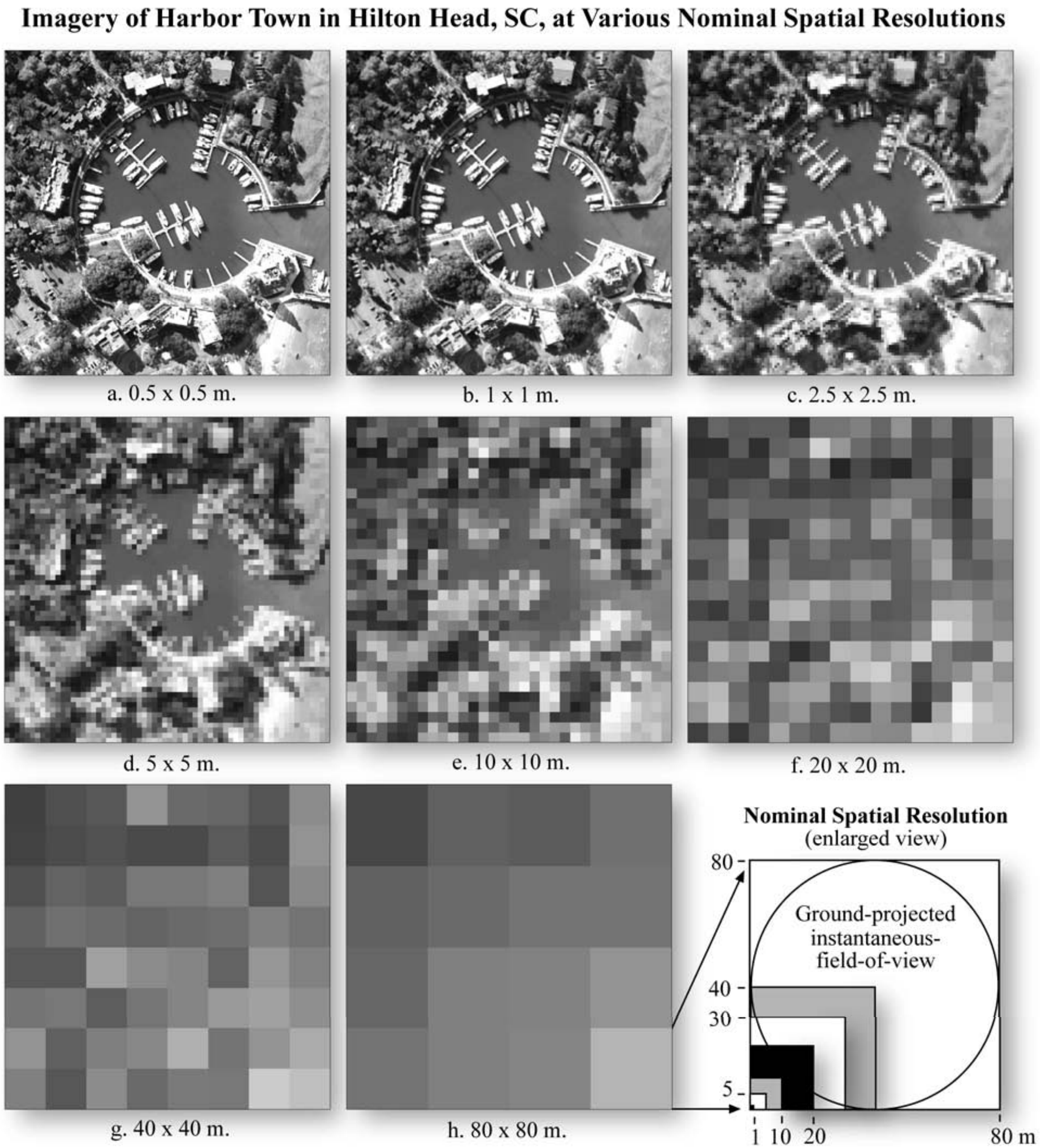
Geographic Information System

- Along with Remote Sensing, Geographic Information System (GIS) is a tool which allows us to effectively manage, analyze such data in quick and efficient manner
  - Hydrological modeling (Ikweiri and Jin, 2004, Droogers and Bastiaanssen, 2002)
  - Mathematical modeling of watershed hydrology (Singh and Woolhiser, 2002)
  - Watershed conservation (Biswas et al., 2002) etc.

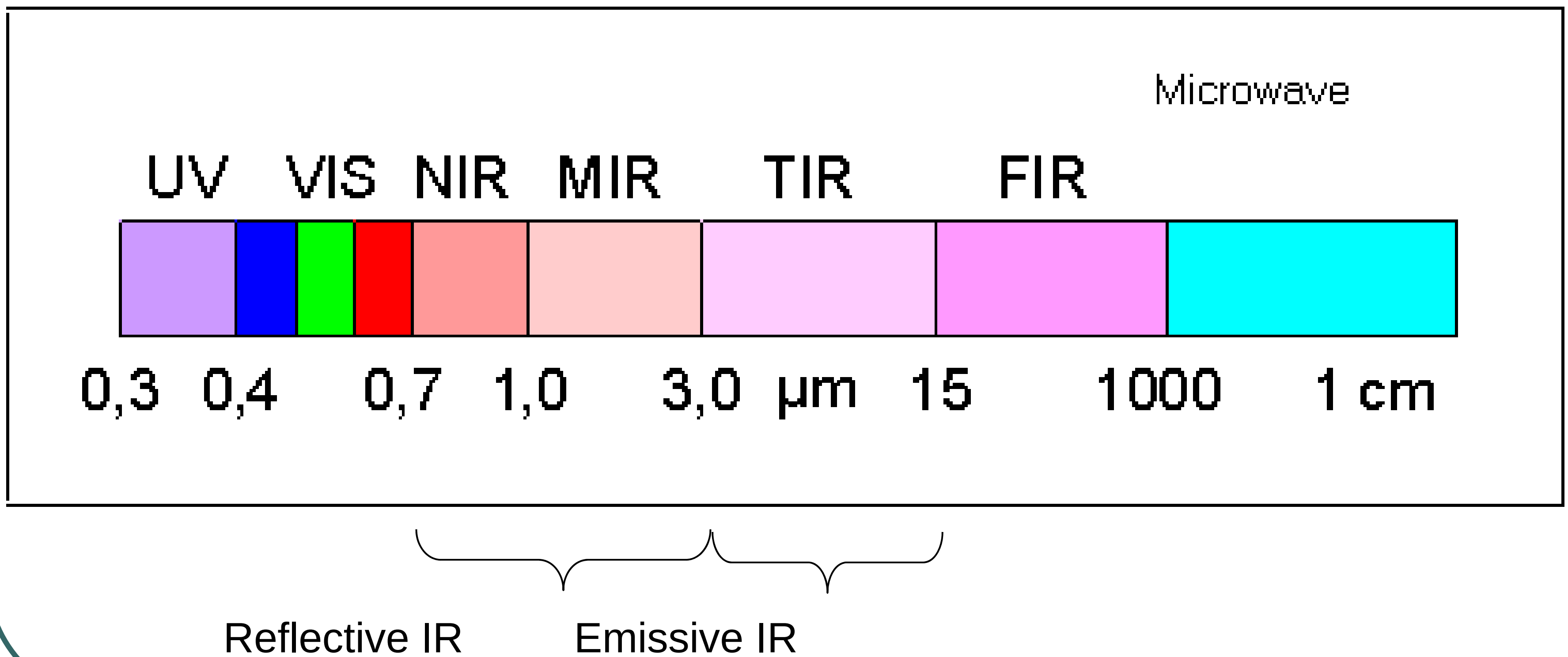
Advantage of RS Data

- Remote sensing data is available in multitude of ways such as
  - Multi-stage: Providing different spatial resolution so that we can work at local, regional and global levels
  - Multi-spectral: Data is available in multiple bands hence providing more information
  - Multi-temporal: Repetitive coverage and so providing a opportunity to observe dynamic processes.
  - Multi-angle: Coverage of same area from different angle, providing different perspective and so different analysis capabilities.

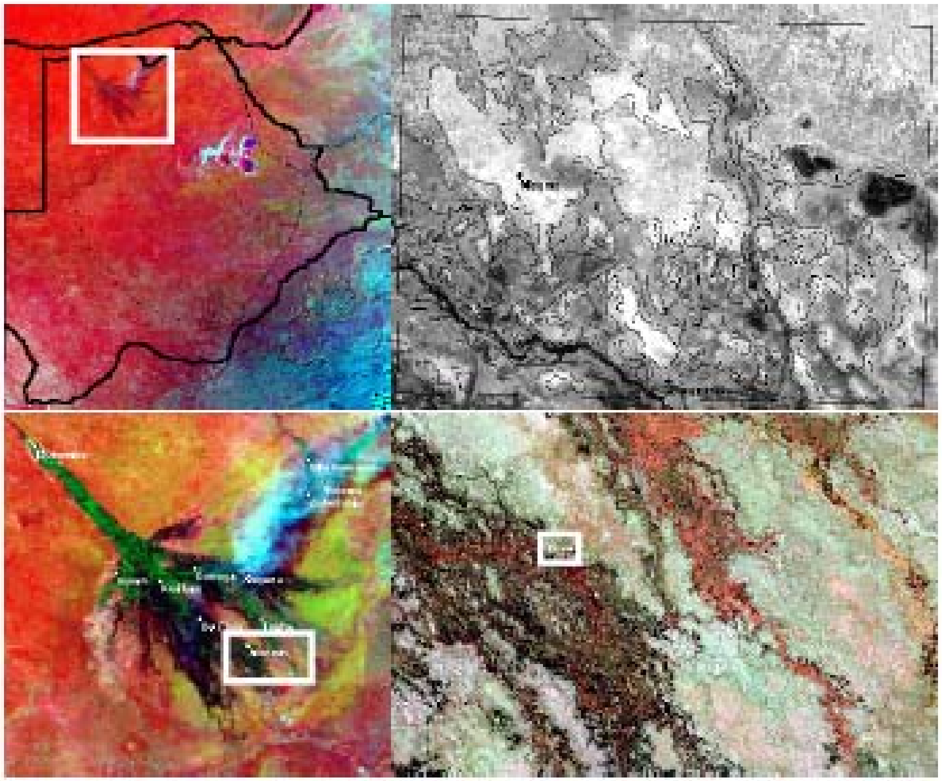
Spatial Resolution



EMR Spectrum for RS



Integrated River Basin and Water Management



Okavango delta, Botswana

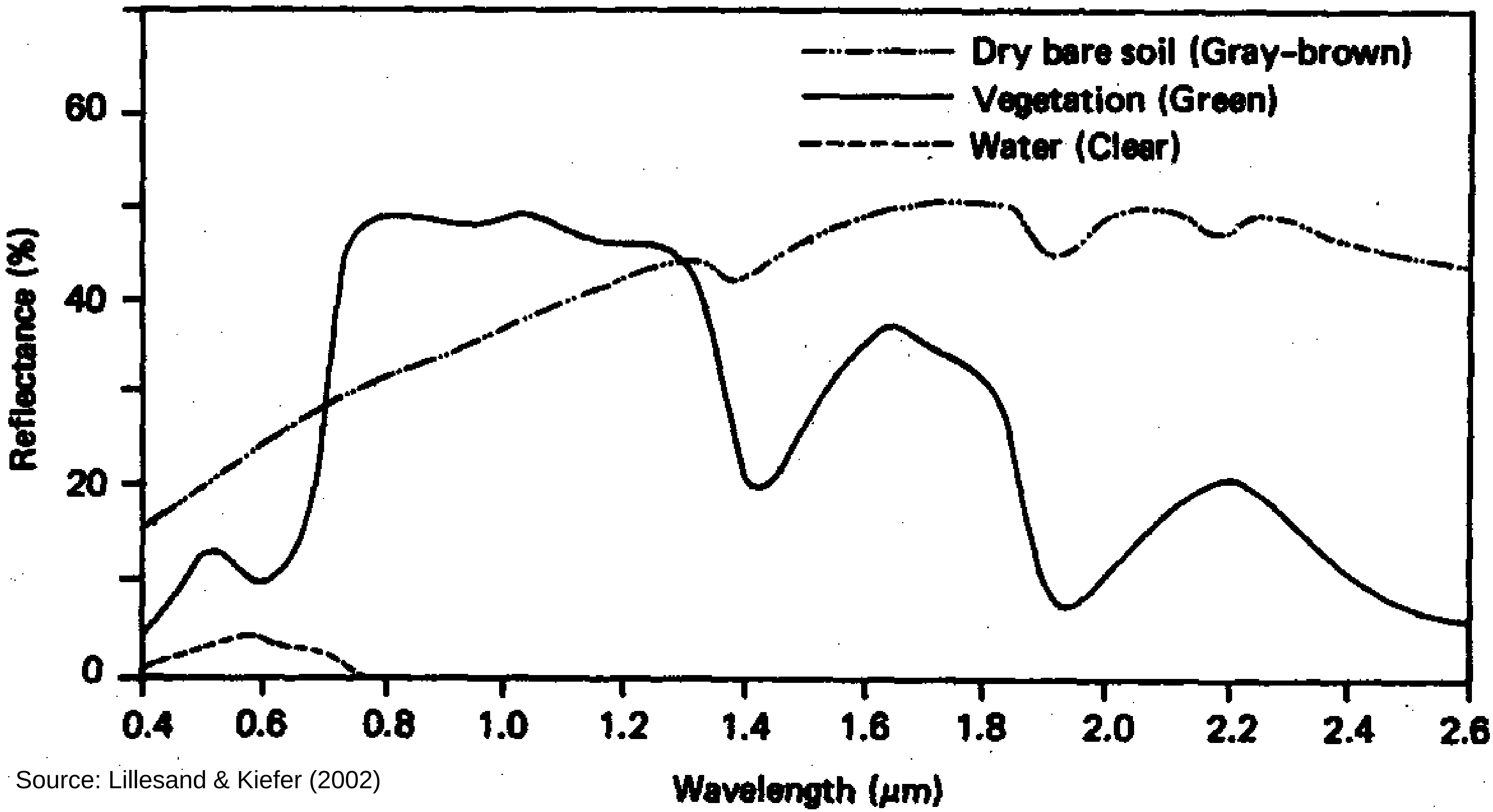
- Earth Observation methods for mapping and spatial analysis of water resources
- Remote sensing & GIS for quantifying hydrological processes in time and space
- Integrate geo information in water resources management

ITC

Source: ITC, http://www.itc.nl

(Mannaerts et al.)

SRC of Water, Soil and Vegetation



Source: Lillesand & Kiefer (2002)

Remote Sensing Data

- With the launch of different satellites by India, US and other nations, remote sensing data is now available with
  - Different resolutions
    - Coarser resolution is required for regional planning and finer for local planning
  - Different formats suitable for varying applications
  - Different bands providing truly multi-spectral capabilities
  - Continuous basis with repetition as low as 1, 2 days to 15-20 days
  - Freely available for download from Internet

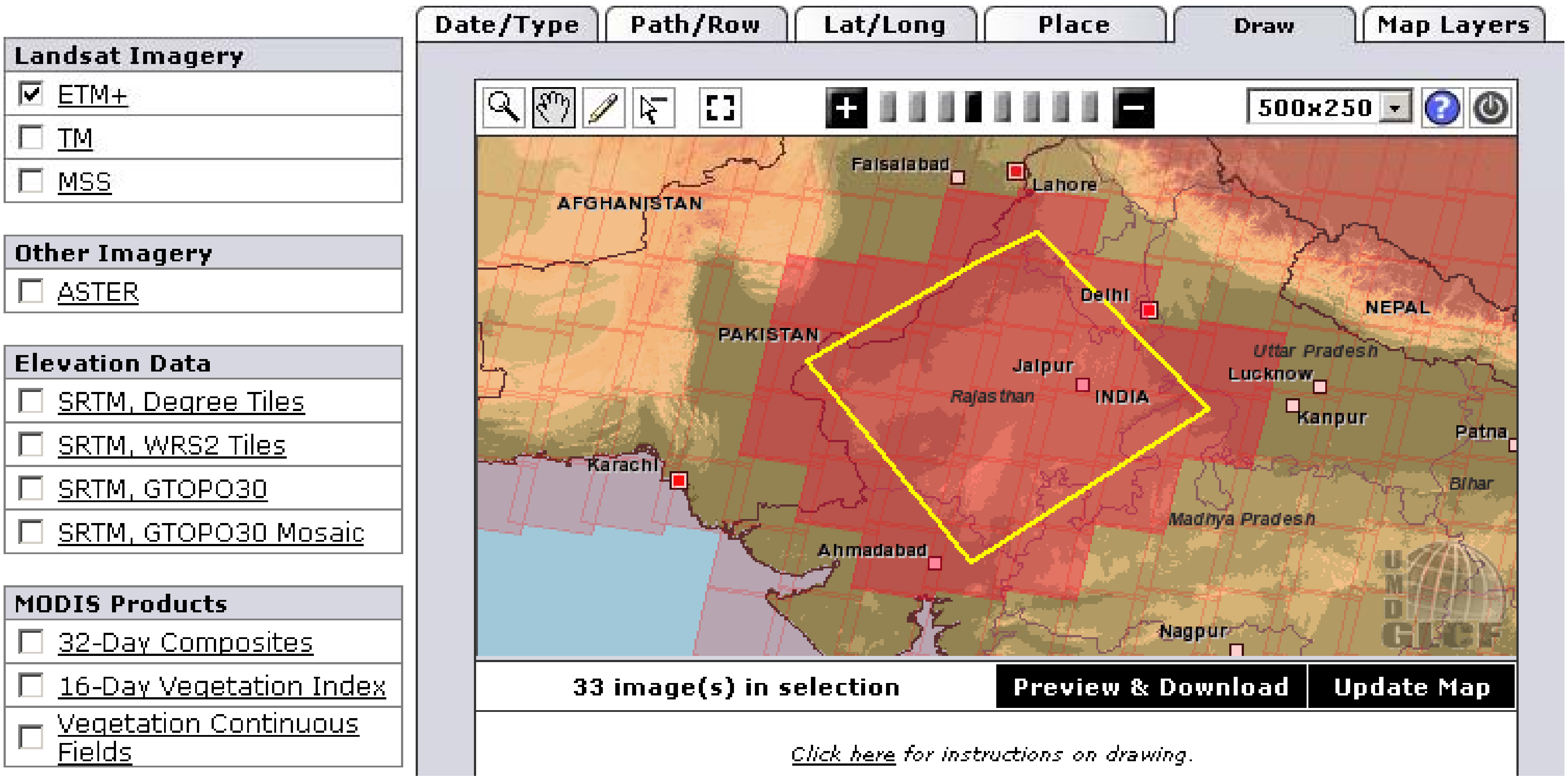
Satellite Systems

- Following Series of Satellites are continuously monitoring earth since as early as 1970
  - **Landsat Series** (Landsat 1-7) with sensors such as ETM+, TM, MSS, RBV, 1972 onwards
  - **Spot Series** (Spot 1-5) with sensors HRG, HRS, HRVIR, Vegetation-I, HRV, 1986 onwards
  - **IRS** (IRS 1A-1D, P5, P6 etc.) with sensors Pan, LISS IV, LISS III, AWiFS, WiFS etc., 1988 onwards

Free LANDSAT Data

- Limited old LANDSAT data is now available free of cost and can be download from Internet through the web site of Global Land Cover Facility (GLFC)
  - URL: http://glcf.umiacs.umd.edu
- For any given area in Rajasthan state typically three imageries are available
  - MSS data of around 1975-80
  - TM data of 1985-90
  - ETM+ data of 1995-2000.

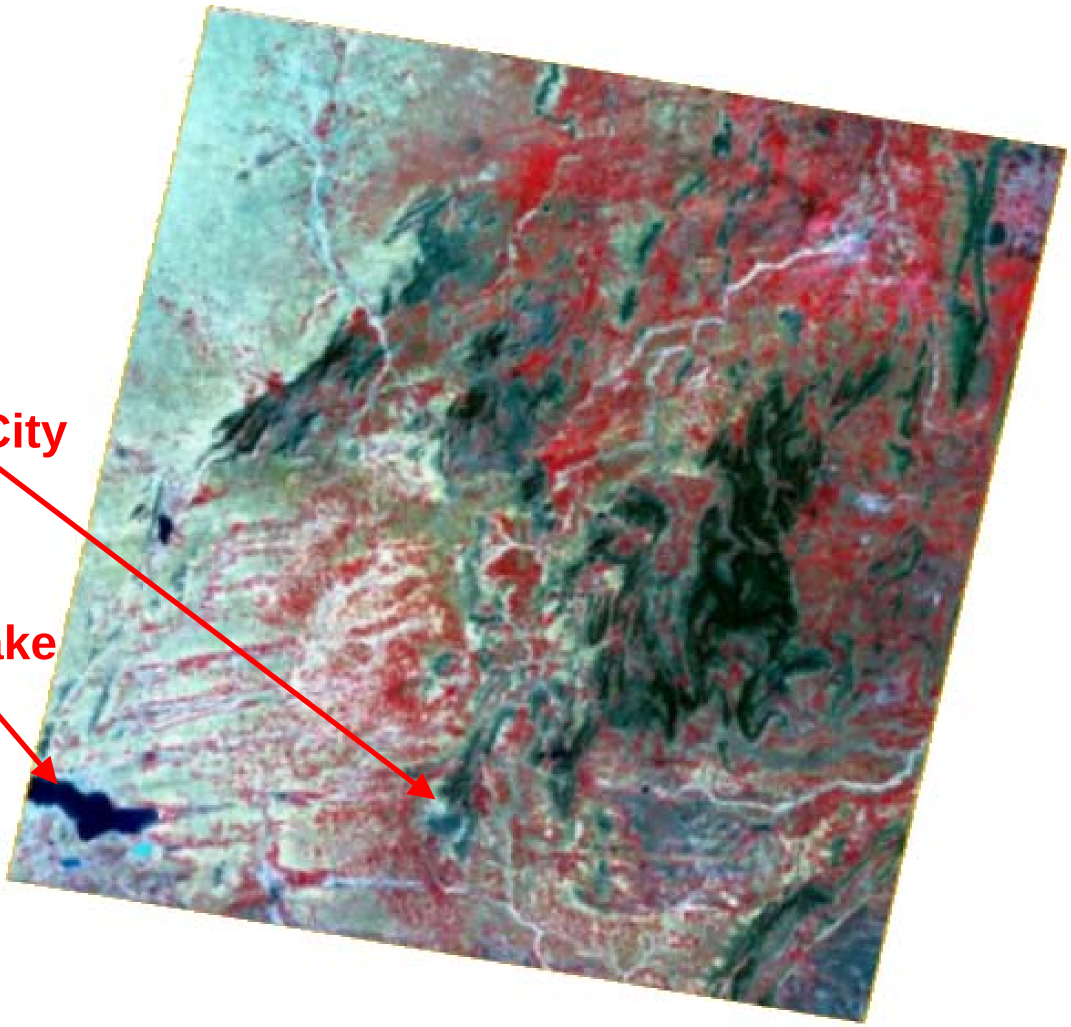
GLFC Web Site



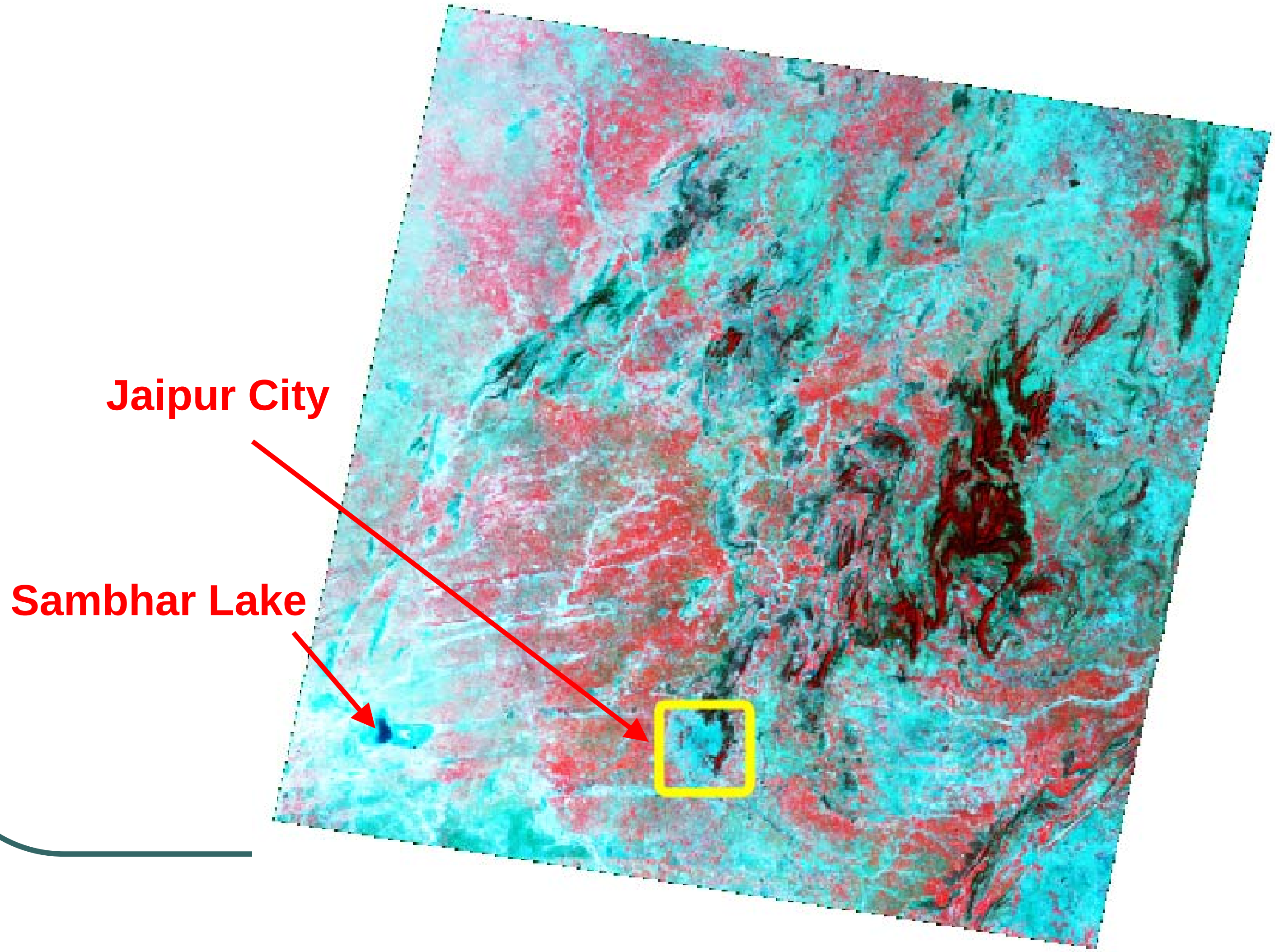
LANDSAT Images of Jaipur District

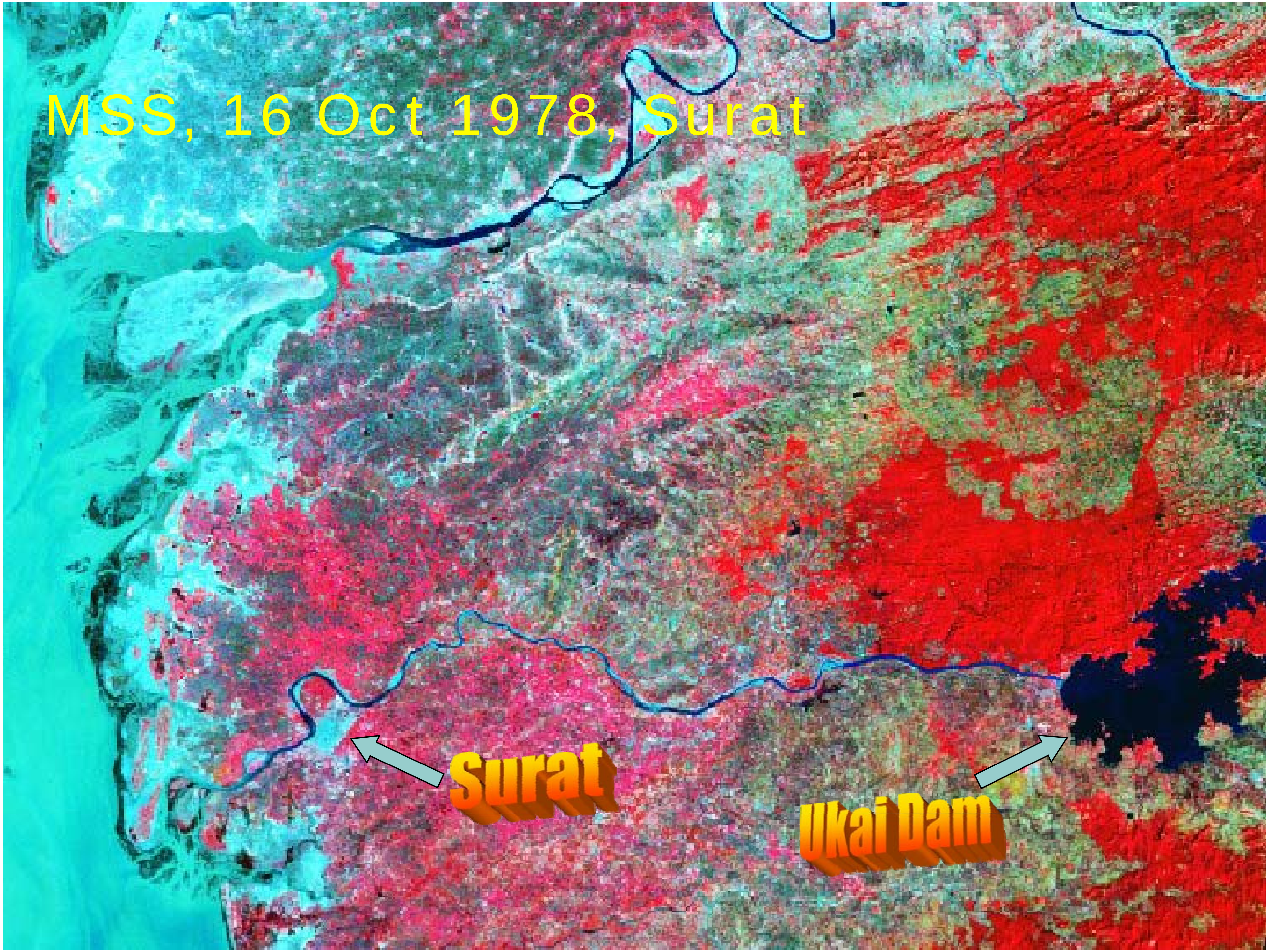
S. No.	ID	Sensor	Acquisition Date	Size, MB	Location
1.	020-876	MSS	02-03-1975	64	North of Jaipur District
2.	020-877	MSS	02-03-1975	64	South of Jaipur District
3.	028-671	TM	09-10-1989	395	North of Jaipur District
4.	028-672	TM	09-10-1989	396	South of Jaipur District
5.	038-858	ETM+	13-09-2000	656	North of Jaipur District
6.	038-859	ETM+	13-09-2000	656	South of Jaipur District

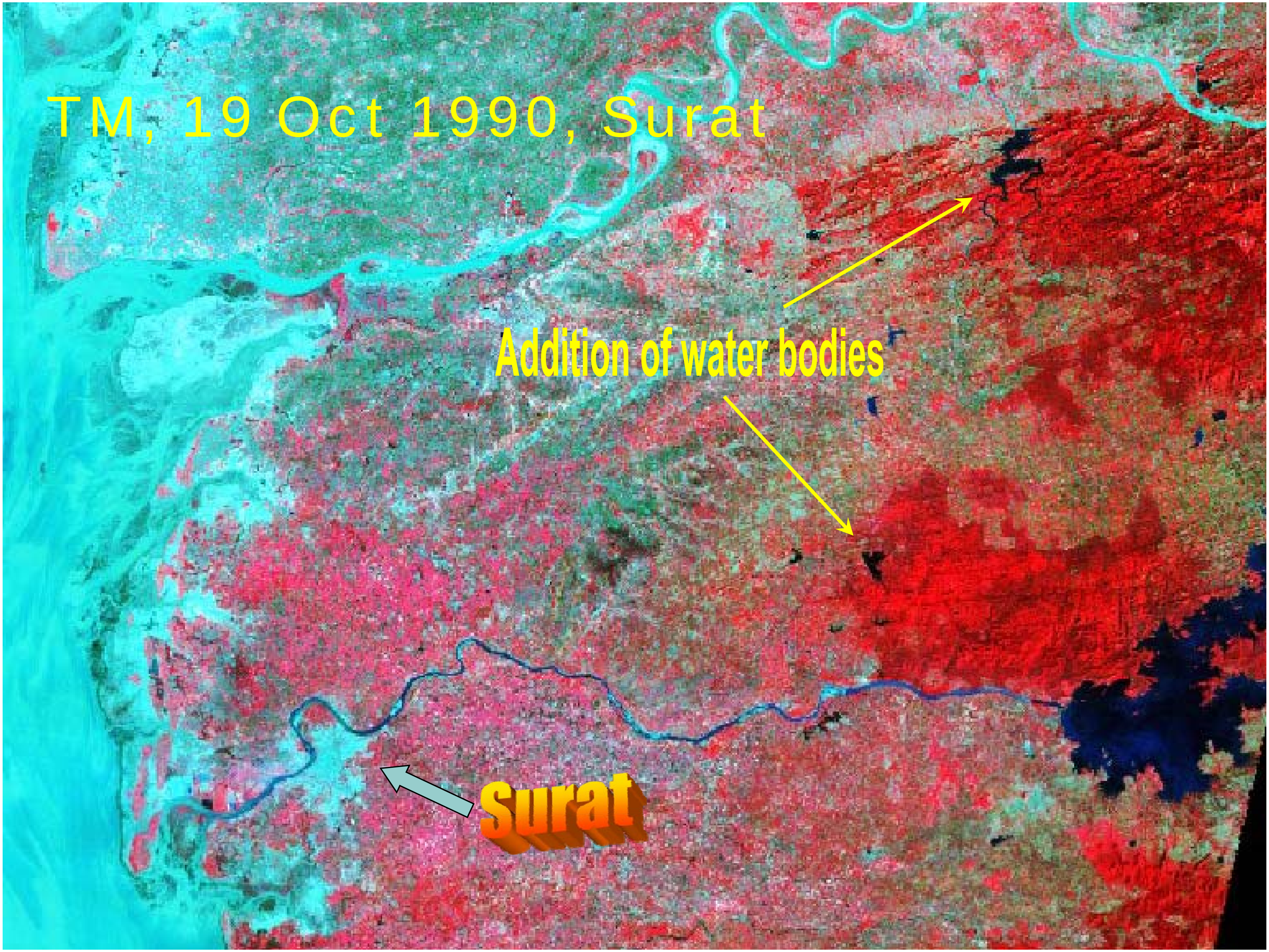
MSS, 1975 Images of North Part of Jaipur District

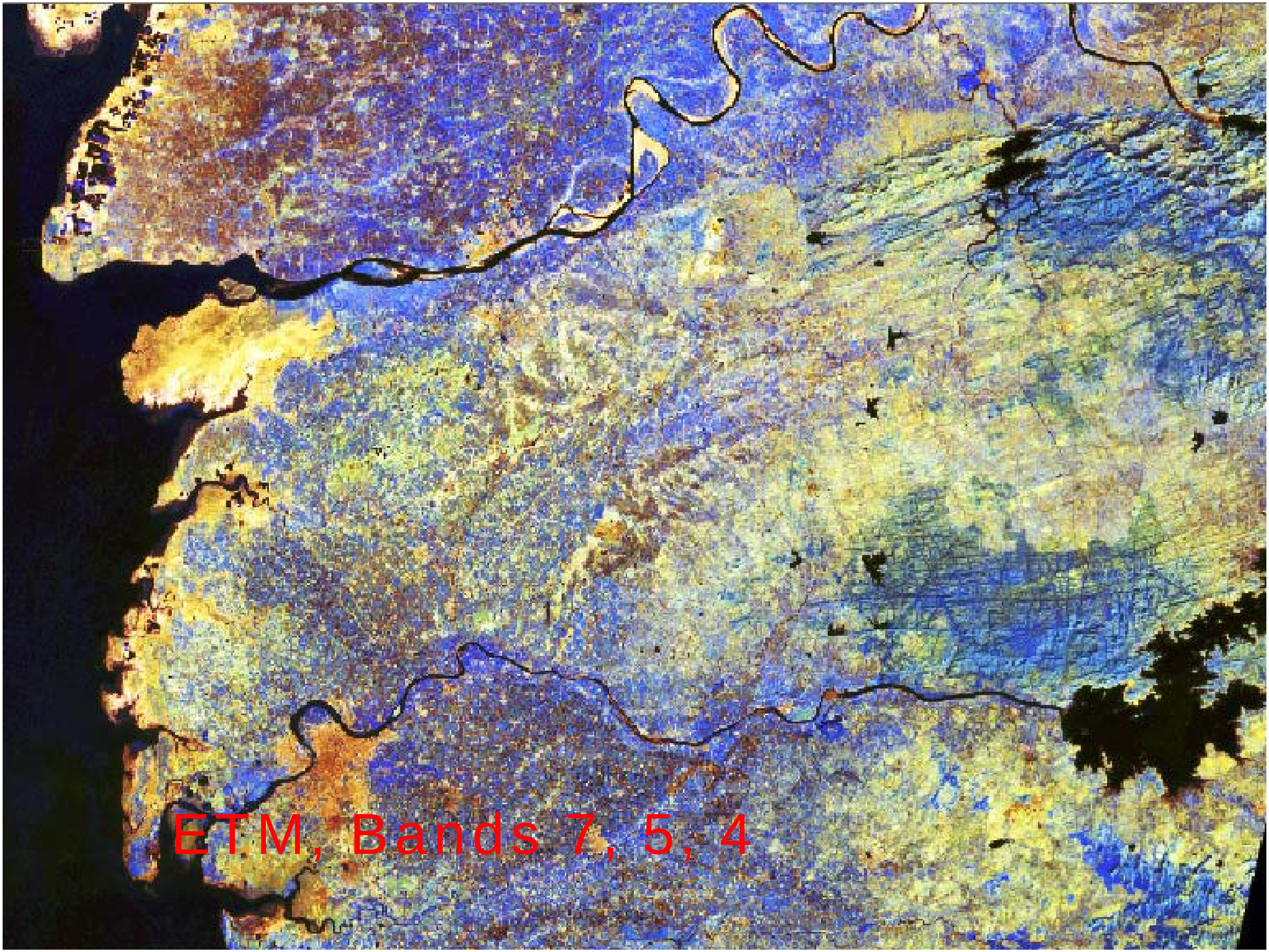


ETM+ 2000 Image

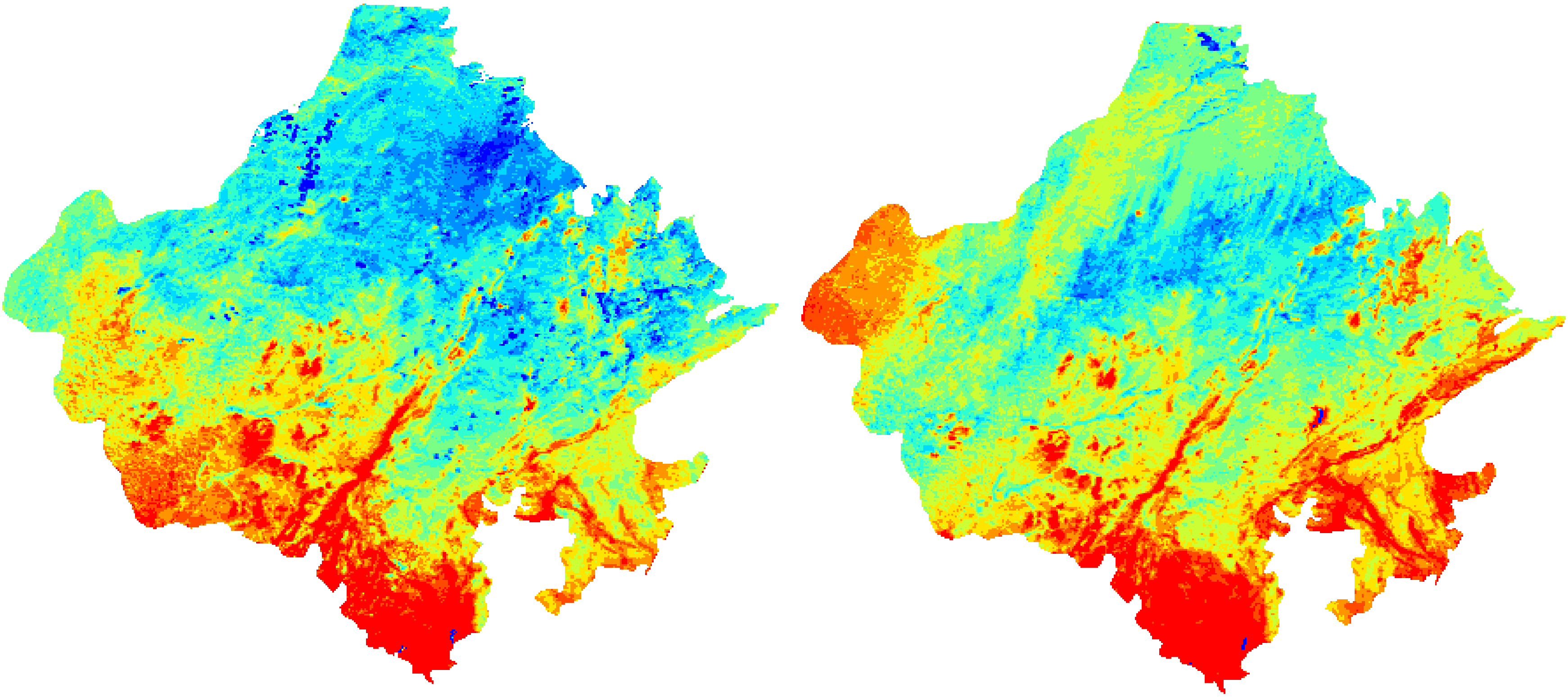



MSS, 16 Oct 1978, Surat
Surat
Ukai Dam

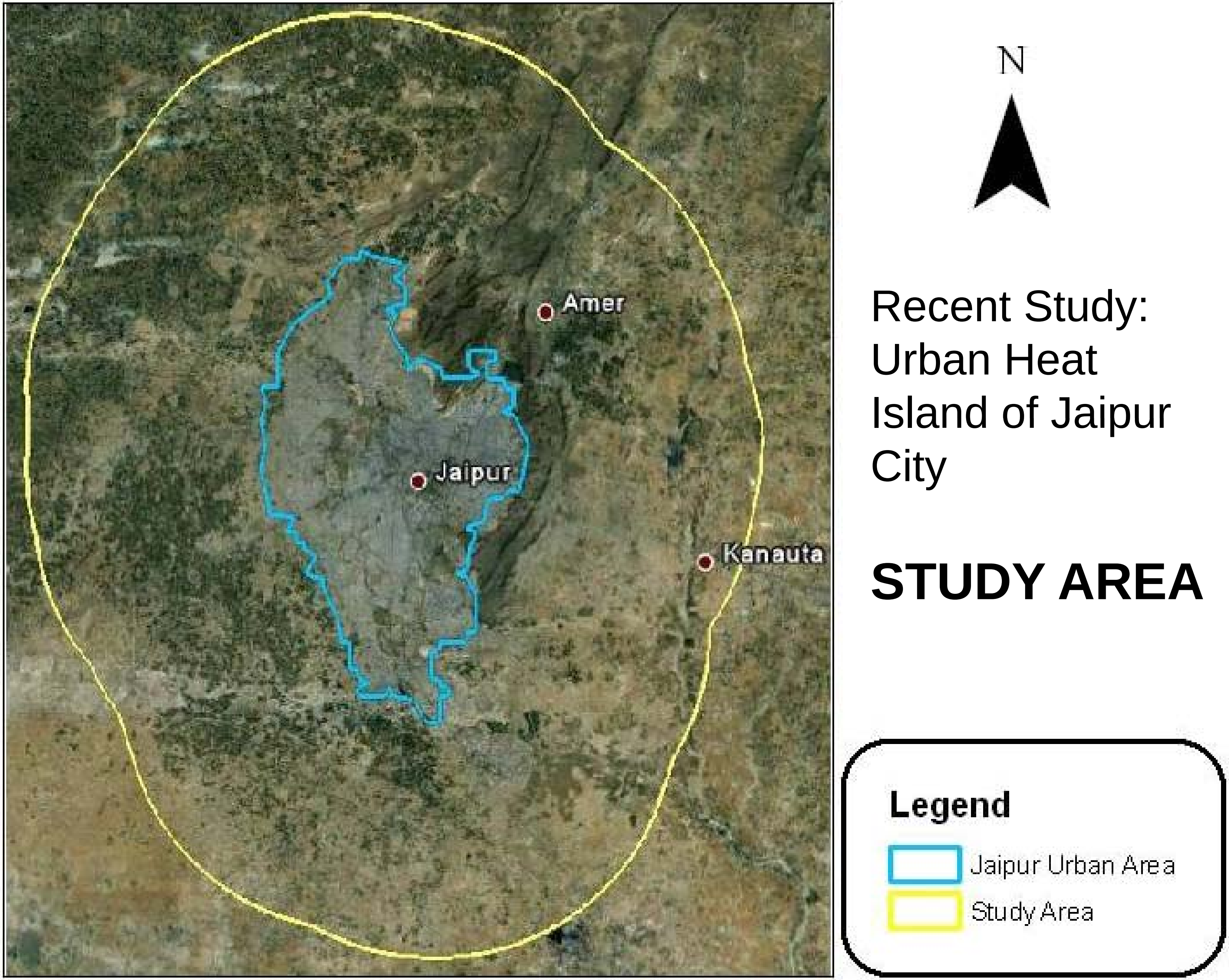

TM, 19 Oct 1990, Surat
Addition of water bodies
Surat


ETM, Bands 7, 5, 4

MODIS 8-Days LST of Rajasthan State of 8th Jan



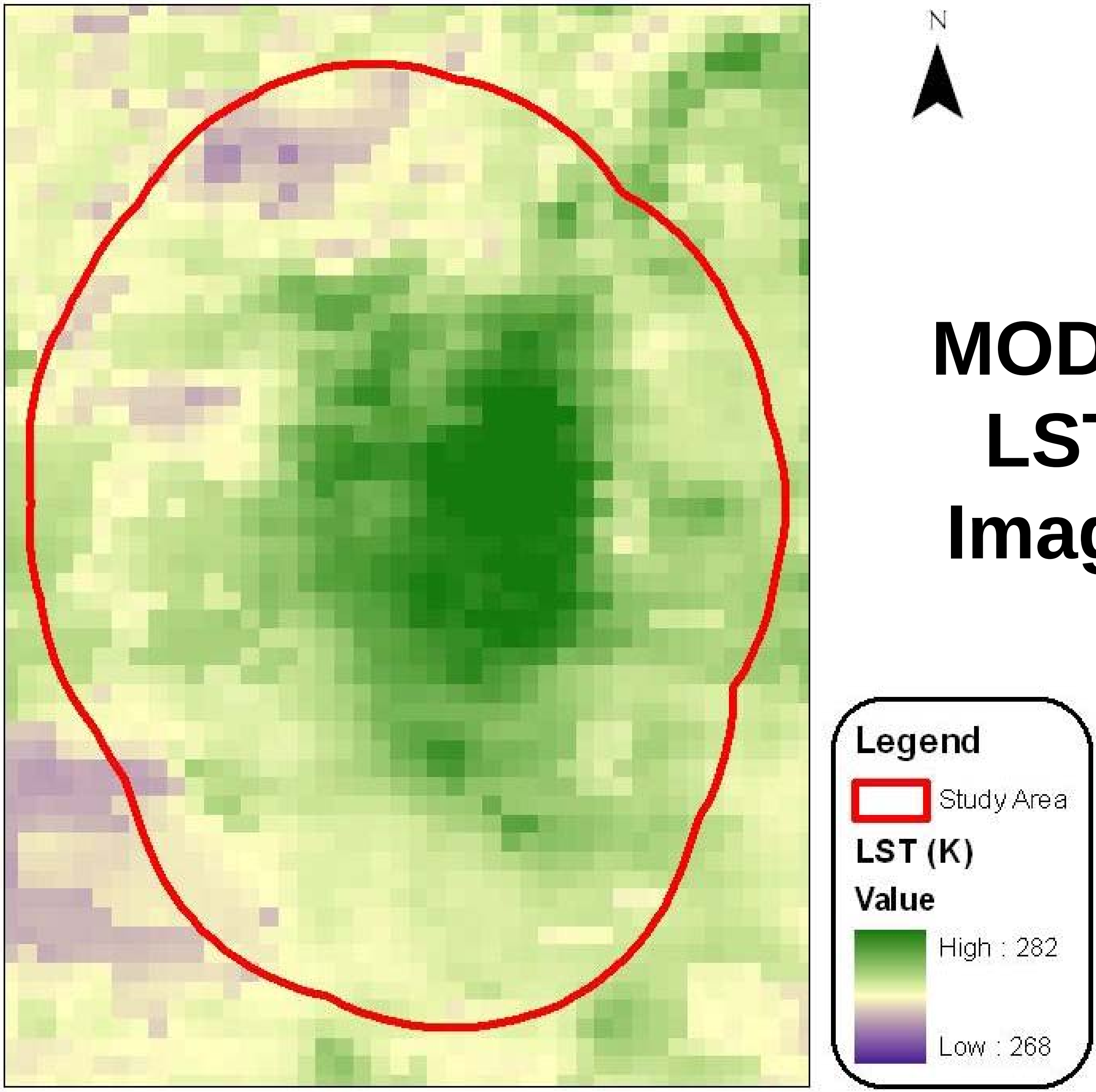
Land Surface Temperature



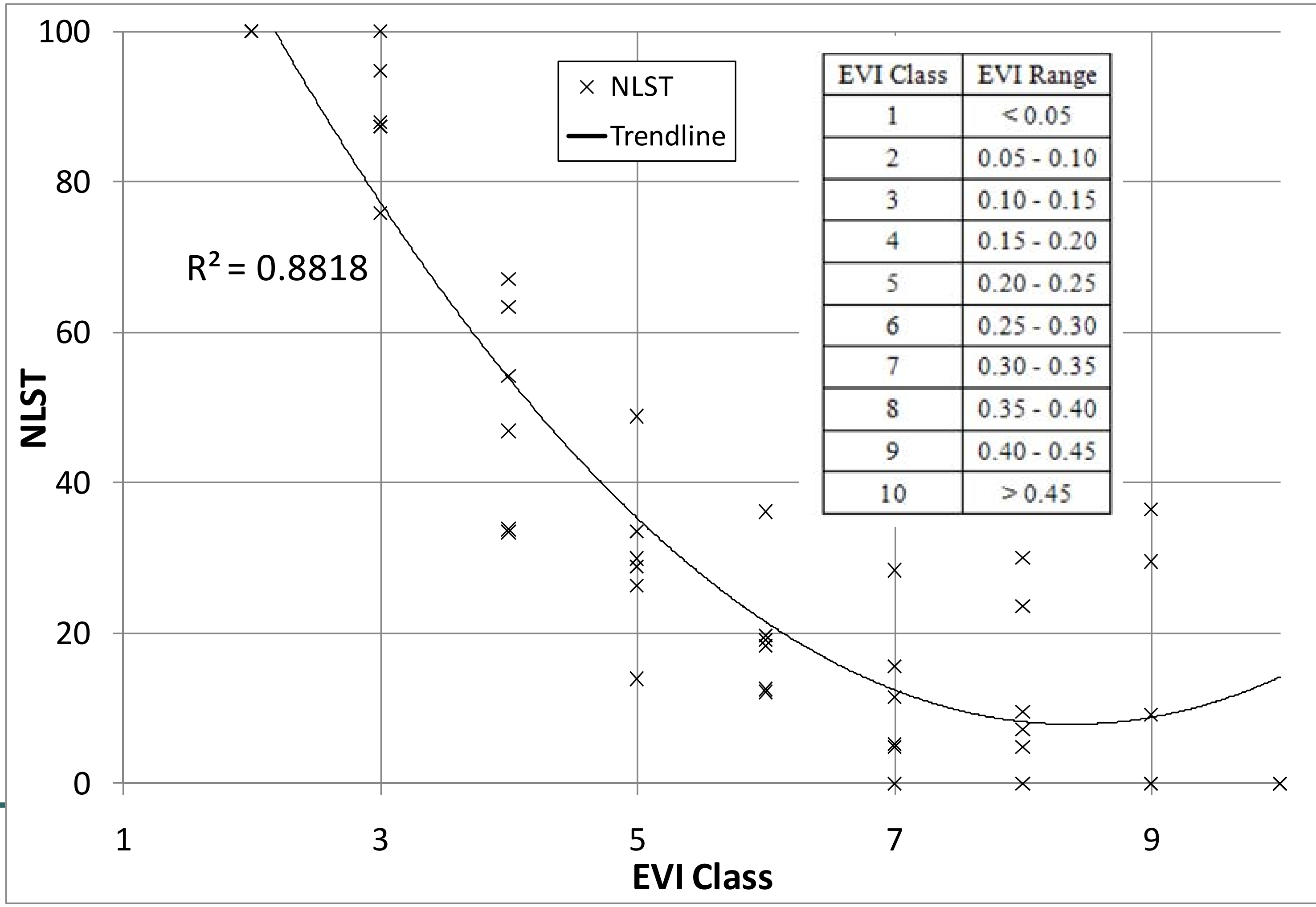
Recent Study: Urban Heat Island of Jaipur City

STUDY AREA

MODIS LST Image

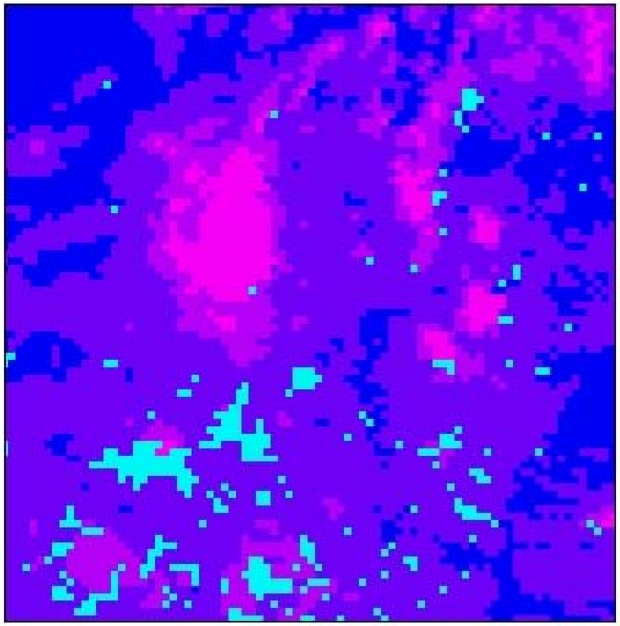


Relationship for Monsoon Season

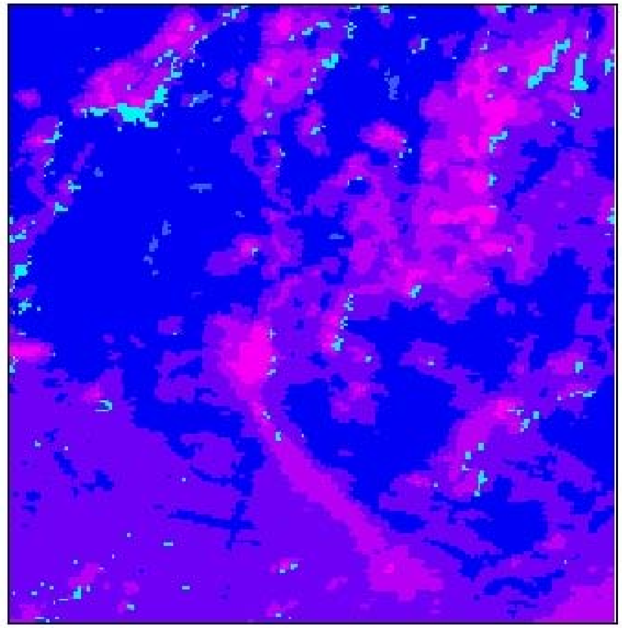


EVI Class	EVI Range
1	< 0.05
2	0.05 - 0.10
3	0.10 - 0.15
4	0.15 - 0.20
5	0.20 - 0.25
6	0.25 - 0.30
7	0.30 - 0.35
8	0.35 - 0.40
9	0.40 - 0.45
10	> 0.45

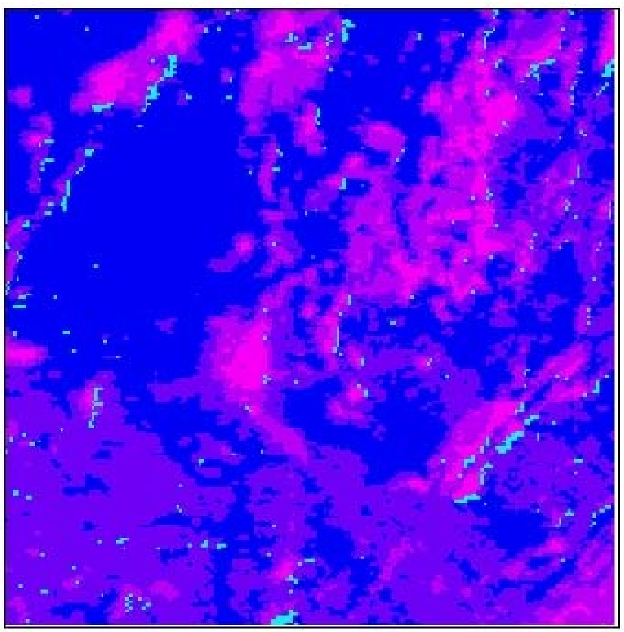
26 Oct 2009

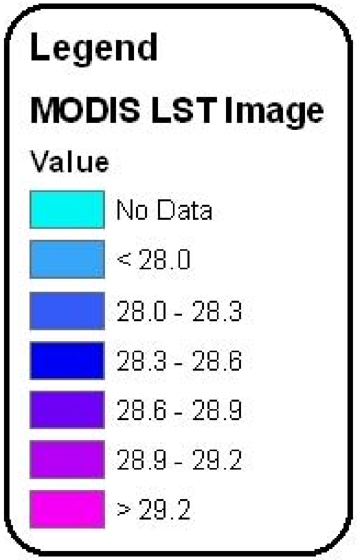


29 Oct 2009



30 Oct 2009



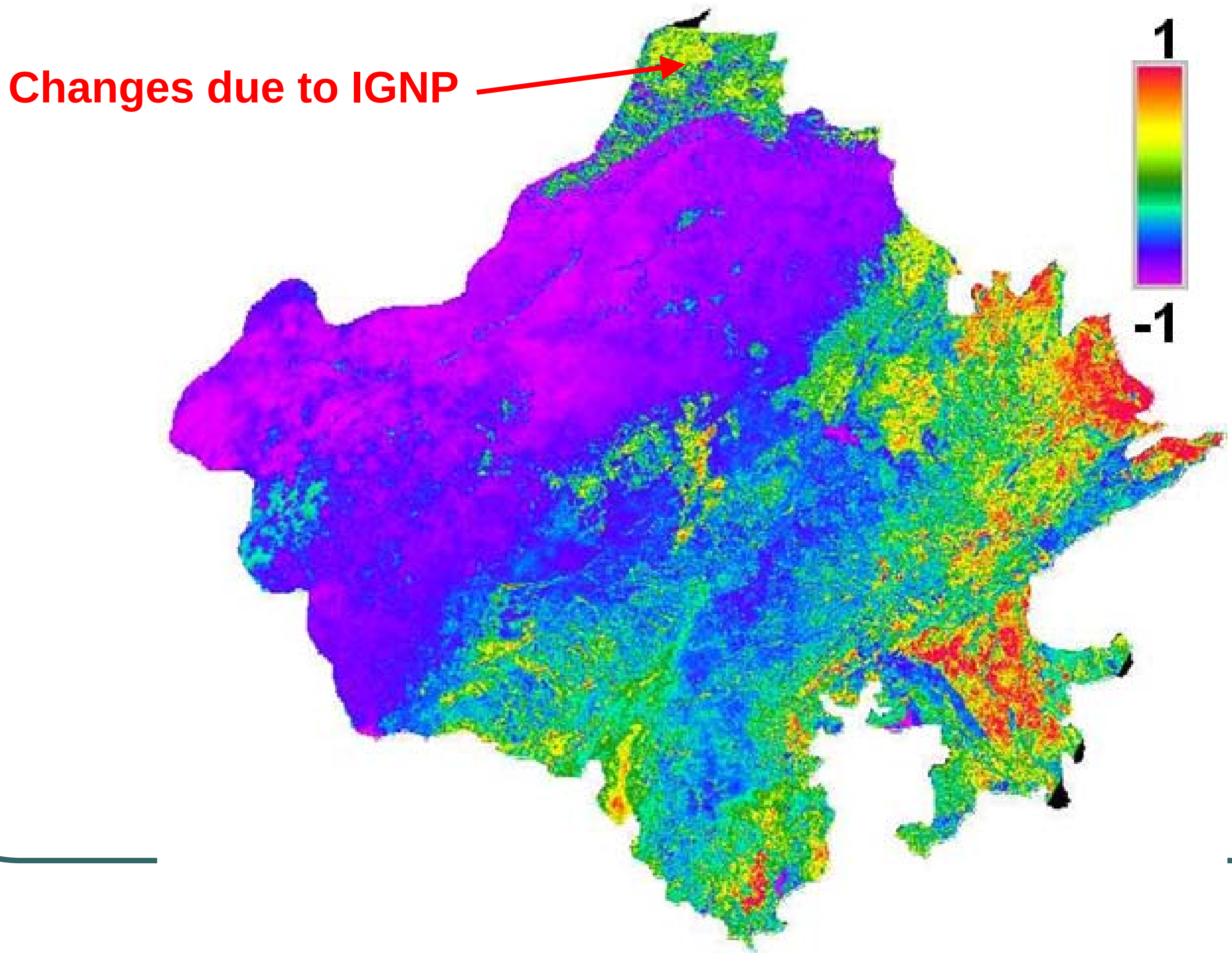


Recent IOC Depot Fire, Showing increase in LST affecting large area & importance of direction

NDVI

- Scientists have extracted and modeled various vegetation biophysical variables using remotely sensed data.
- Normalized Difference Vegetation Index (NDVI), which has been widely adopted to map changes in amount of green biomass and chlorophyll content.
- NDVI values typically range from -0.5 to +0.8.
  - Positive values indicate higher vegetation area.
  - 0 and Negative values typically indicate water/desert area.

NDVI Map of Rajasthan State using MODIS Data



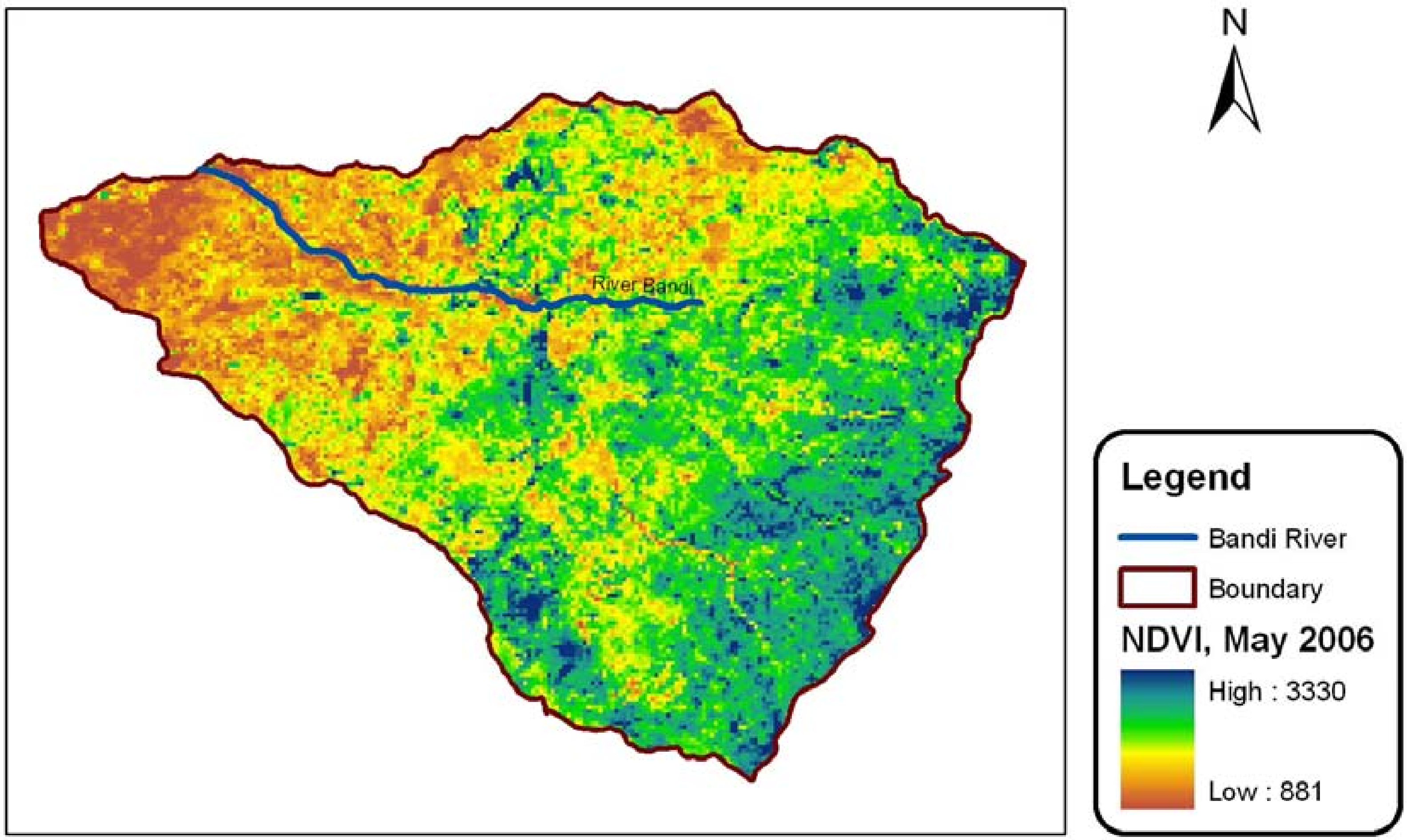
Study of Pali Area

- A Study has been conducted of Pali Area to found out relationship between water level recharge with various parameters such as Elevation, Vegetation level, Landuse-Landcover, Soil Type, Rainfall etc.
- Data of Years 2003 to 2006 has been used

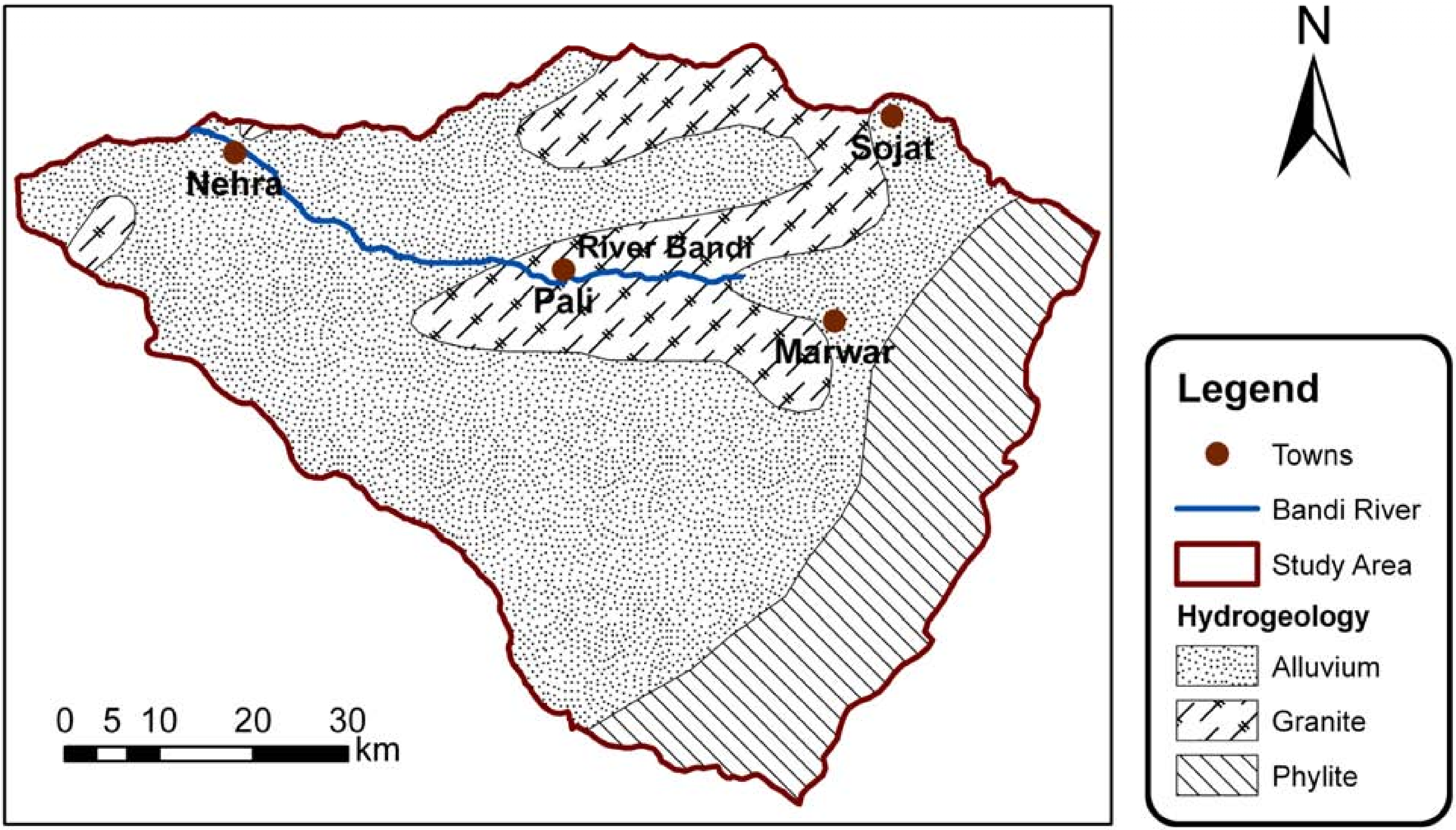
Following Data was used

- Rainfall of 2003 to 2006
- Ground Water Level, 2003 to 2006
- Vegetation Level by Remote Sensing (NDVI and EVI, for May, Oct. and Dec. 2003 to 2006)
- Hydrogeological Map to find out Specific Yield
- Soil Map, Elevation, Slope, Landuse-Landcover etc.

NDVI Image of Pali Study Area of May 2006



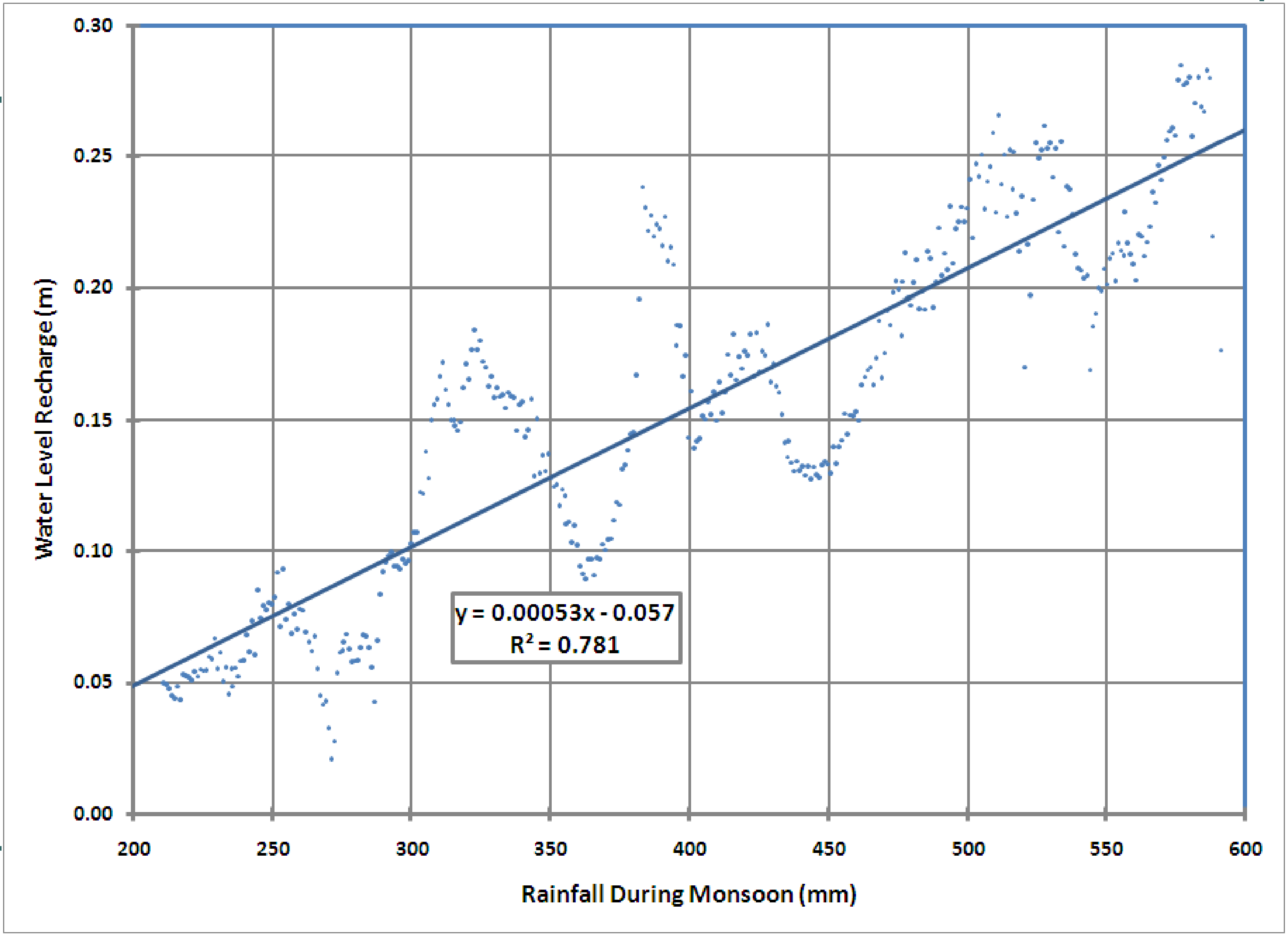
Hydrogeological Map of Pali Study Area



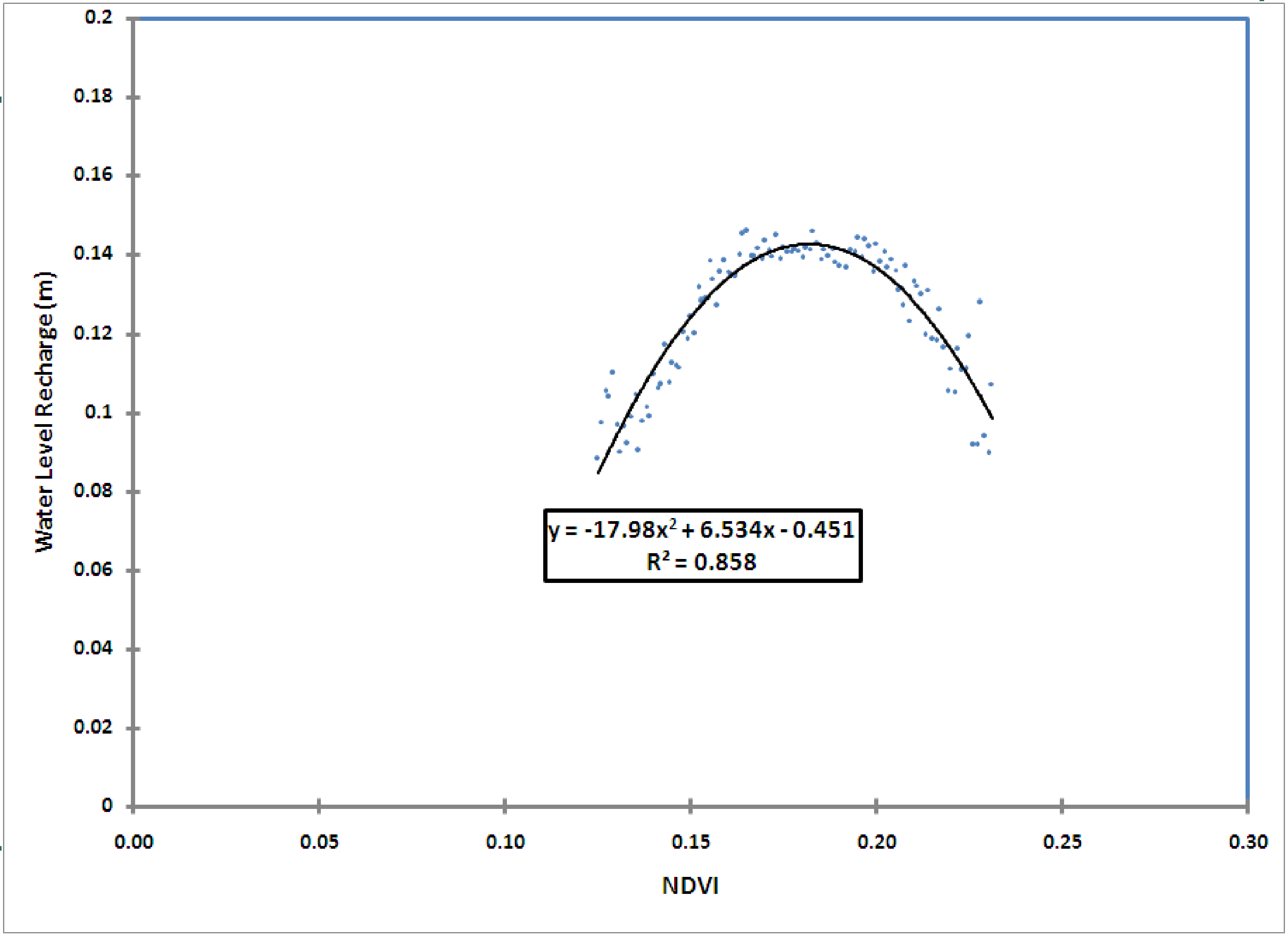
Methodology

- Area was Divided into small cells of size approximately 450 m x 450 m (Because Vegetation Index was available only at this spatial resolution)
- Values of parameters was found for each cell
- In all data of more than 95000 cells was used (combined for 4 years).
- In preparing charts only data points where average of minimum 100 cells were available were used and only good quality data was used for VI

Relationship Between Water Level Recharge & Rainfall



Relationship Between Water Level Recharge and NDVI (Level of Vegetation)



GIS

- Like Remote Sensing, GIS is nowadays being applied in remarkable ways.
- From Agriculture, Defense and Intelligence, Ecology and Conservation, Public utilities like electricity, gas, water to emergency services, government revenue records, forestry, mining and telecommunication, GIS has applications in diverse fields

Could GIS help???

- Does it involves spatial Data??
  - Yes. Streams, recharge zones, storage, reservoirs soil map, land slope etc.
- Does it requires spatial computations???
  - Yes. Catchment area, identify optimum sizes etc.
- Data Presentation????
  - Yes. You need to prepare maps, charts, reports

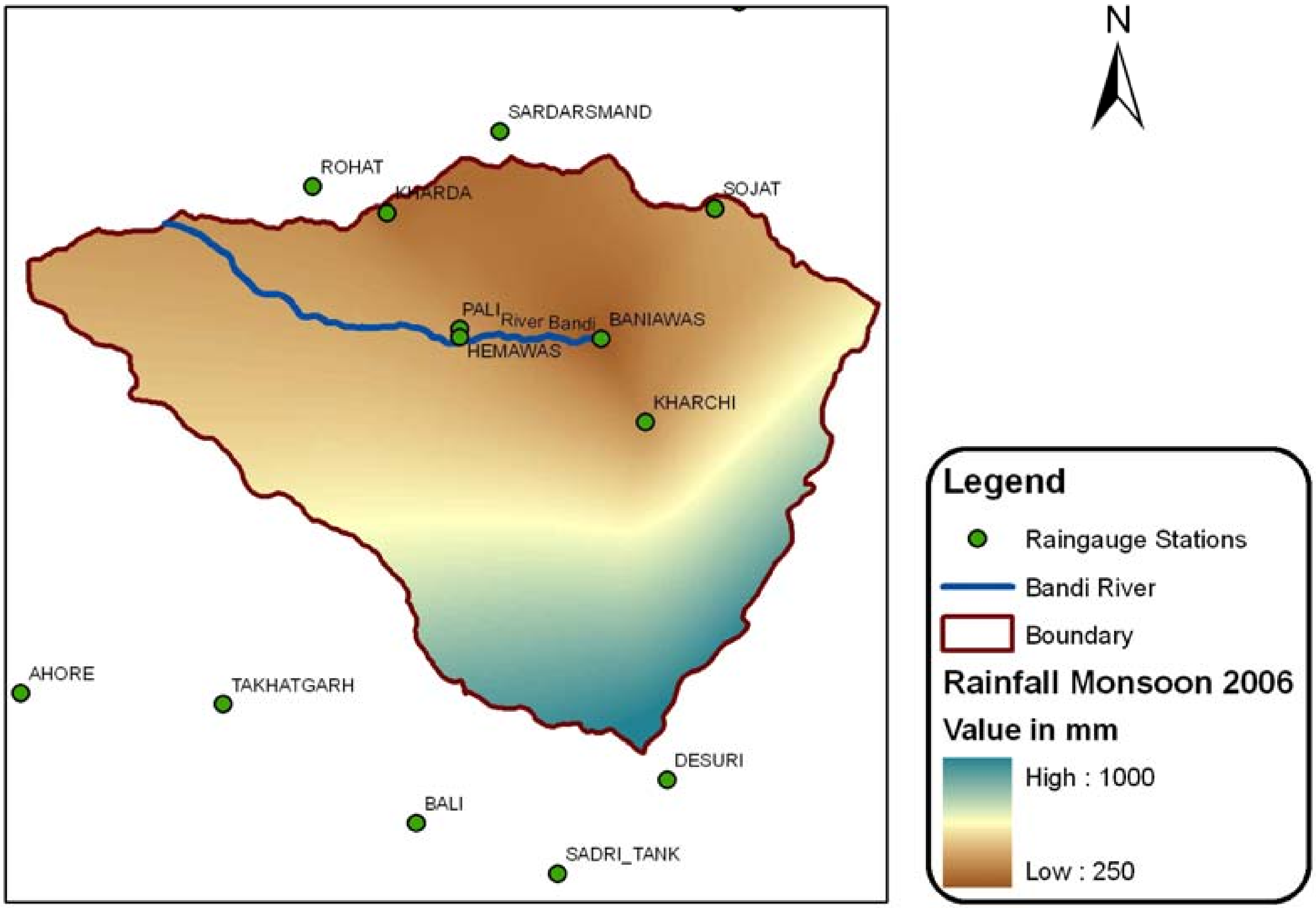
Exploring data using GIS turns data into information into knowledge

Database

ape	Area	State_name	State_fips	Sub_region	State_abbr	Pop1990	Pop1997	Pop90_sqmi	Households	Males
gon	67286.878	Washington	53	Pacific	WA	4866692	5604280	72	1872431	2413747
gon	147236.028	Montana	30	Mtn	MT	799065	888723	5	306163	395769
gon	32161.664	Maine	23	N Eng	ME	1227928	1244828	38	465312	597850
gon	70810.153	North Dakota	38	W N Cen	ND	638800	644782	9	240878	318201
gon	77193.624	South Dakota	46	W N Cen	SD	696004	736549	9	259034	342498
gon	97799.492	Wyoming	56	Mtn	WY	453588	484529	5	168839	227007
gon	56088.066	Wisconsin	55	E N Cen	WI	4891769	5169399	87	1822118	2392935
gon	83340.595	Idaho	16	Mtn	ID	1006749	1210819	12	360723	500956
gon	9603.218	Vermont	50	N Eng	VT	562758	591659	59	210650	275492
gon	84517.465	Minnesota	27	W N Cen	MN	4375099	4690847	52	1647853	2145183
gon	97070.748	Oregon	41	Pacific	OR	2842321	3245429	29	1103313	1397073
gon	9259.514	New Hampshire	33	N Eng	NH	1109252	1171443	120	411186	543544
gon	56257.220	Iowa	19	W N Cen	IA	2776755	2869063	49	1064325	1344802
gon	8172.482	Massachusetts	25	N Eng	MA	6016425	6106984	736	2247110	2888745
gon	77328.337	Nebraska	31	W N Cen	NE	1578385	1660613	20	602363	769439
gon	48560.579	New York	36	Mid Atl	NY	17990455	18177296	370	6639322	8625673
gon	45359.239	Pennsylvania	42	Mid Atl	PA	11881643	12061902	262	4495966	5694265
gon	4976.434	Connecticut	09	N Eng	CT	3287116	3277113	661	1230479	1592873
gon	1044.890	Rhode Island	44	N Eng	RI	1003464	988370	960	377977	481496
gon	7507.302	New Jersey	34	Mid Atl	NJ	7730188	8018326	1030	2794711	3735685
gon	36399.515	Indiana	18	E N Cen	IN	5544159	5874844	152	2065355	2688281
gon	110667.293	Nevada	32	Mtn	NV	1201833	1652983	11	466297	611880
gon	84870.185	Utah	49	Mtn	UT	1722850	2034167	20	537273	855759
gon	157774.187	California	06	Pacific	CA	29760021	32197302	189	10381206	14897627
gon	41192.862	Ohio	39	E N Cen	OH	10847115	11202691	263	4087546	5226340
gon	56297.954	Illinois	17	E N Cen	IL	11430602	11890819	203	4202240	5552233
gon	66.063	District of Columbia	11	S Atl	DC	606900	535027	9187	249634	282970
gon	2054.506	Delaware	10	S Atl	DE	666168	731218	324	247497	322968
gon	24228.213	West Virginia	54	S Atl	WV	1793477	1828832	74	688557	861536
gon	9739.753	Maryland	24	S Atl	MD	4781468	5100839	491	1748991	2318671
gon	104099.103	Colorado	08	Mtn	CO	3294394	3885615	32	1282489	1631295
gon	40318.777	Kentucky	21	E S Cen	KY	3685296	3906565	91	1379782	1785235
gon	82195.436	Kansas	20	W N Cen	KS	2477574	2582933	30	944726	1214645
gon	39819.194	Virginia	51	S Atl	VA	6187358	6728895	155	2291830	3033974
gon	69831.624	Missouri	29	W N Cen	MO	5117073	5387753	73	1961206	2464315
gon	113711.522	Arizona	04	Mtn	AZ	3665228	4528866	32	1368843	1810691
gon	70002.392	Oklahoma	40	W S Cen	OK	3145585	3318622	45	1206135	1530819
gon	49046.813	North Carolina	37	S Atl	NC	6628637	7411239	135	2517026	3214290

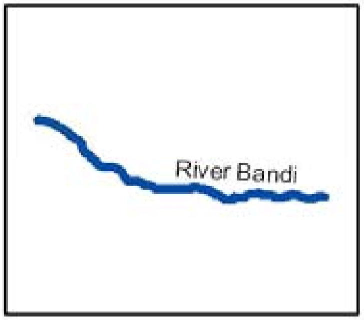
- Not easy to interpret
- Difficult to find how close one object is to other
- Difficult to find spatial pattern
  - Similar level of a parameter are from same nearby locations

Visualization
"Worth a Thousand Words"

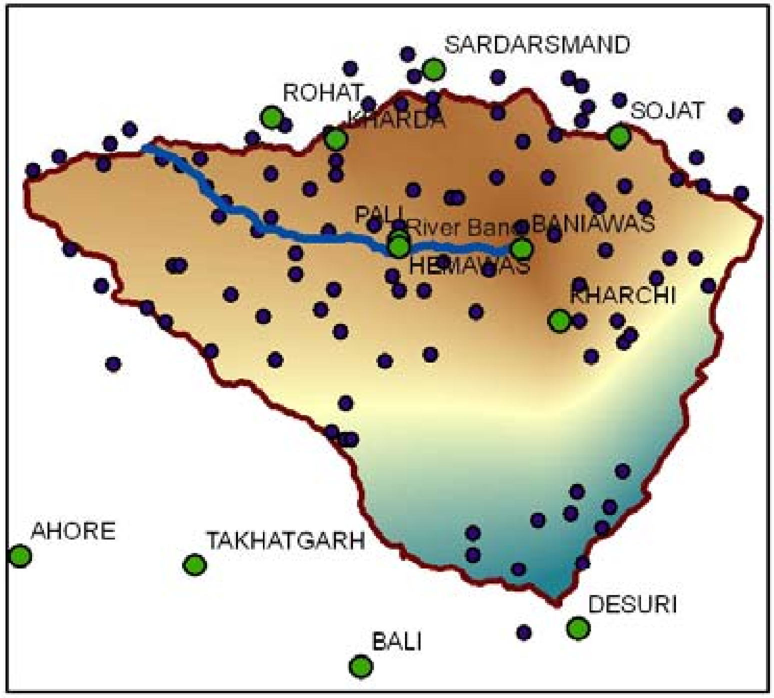


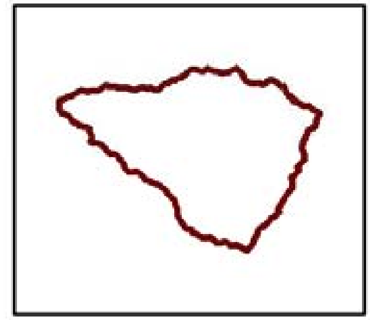
Distribution of Rainfall during Monsson 2006 in Study Area, Pali

Five Data Layers
“Alike” Features

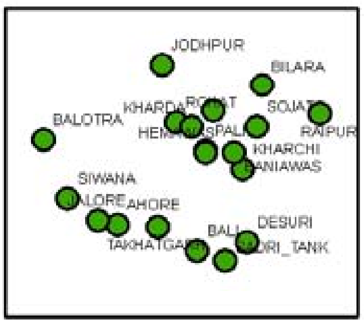


Bandi River

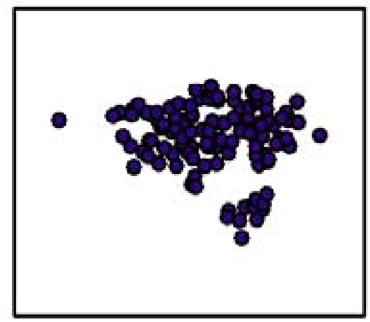




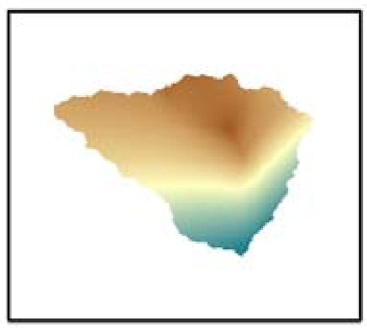
Boundary



Raingauge Stations



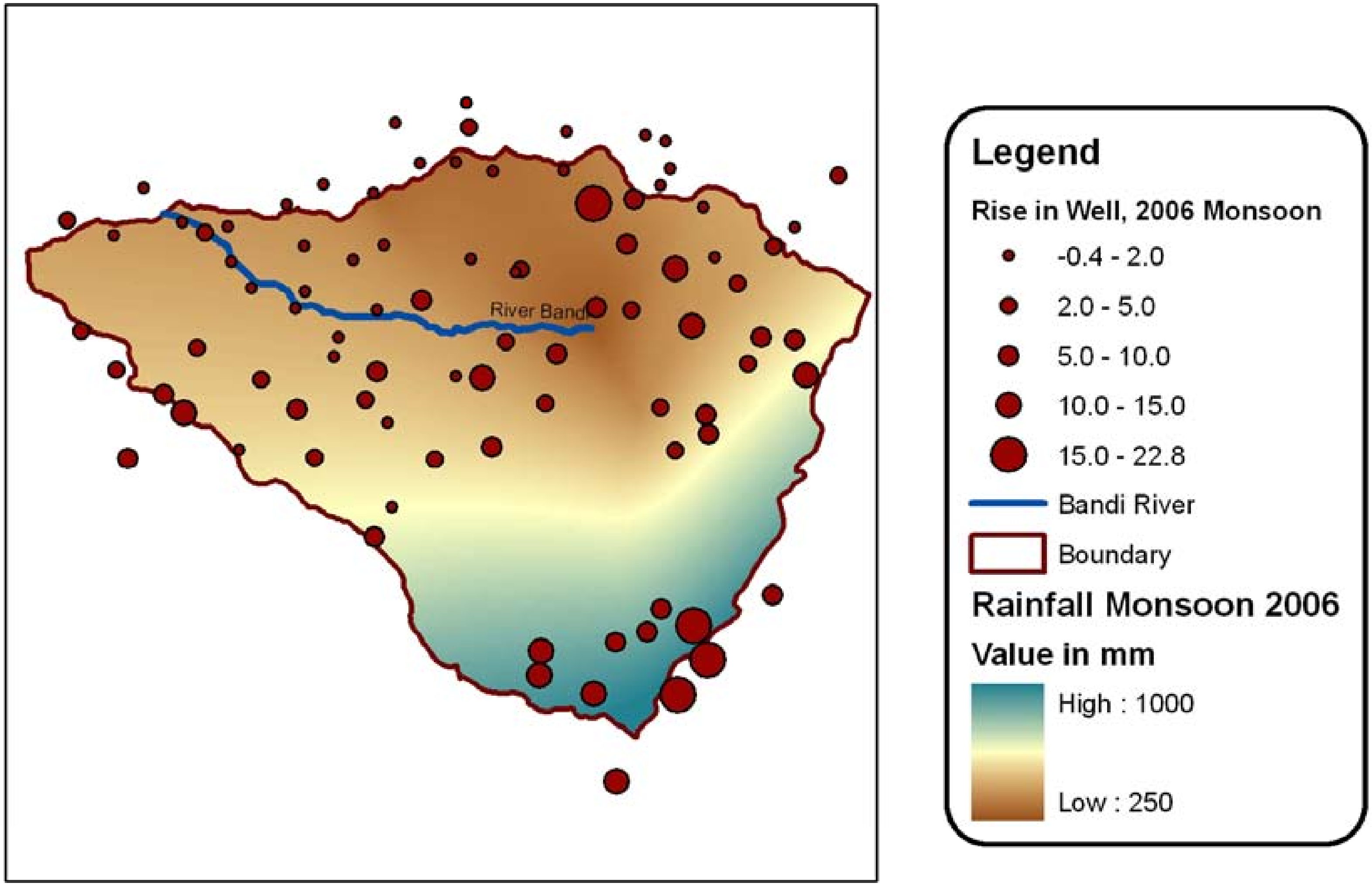
Wells



Rainfall Distribution

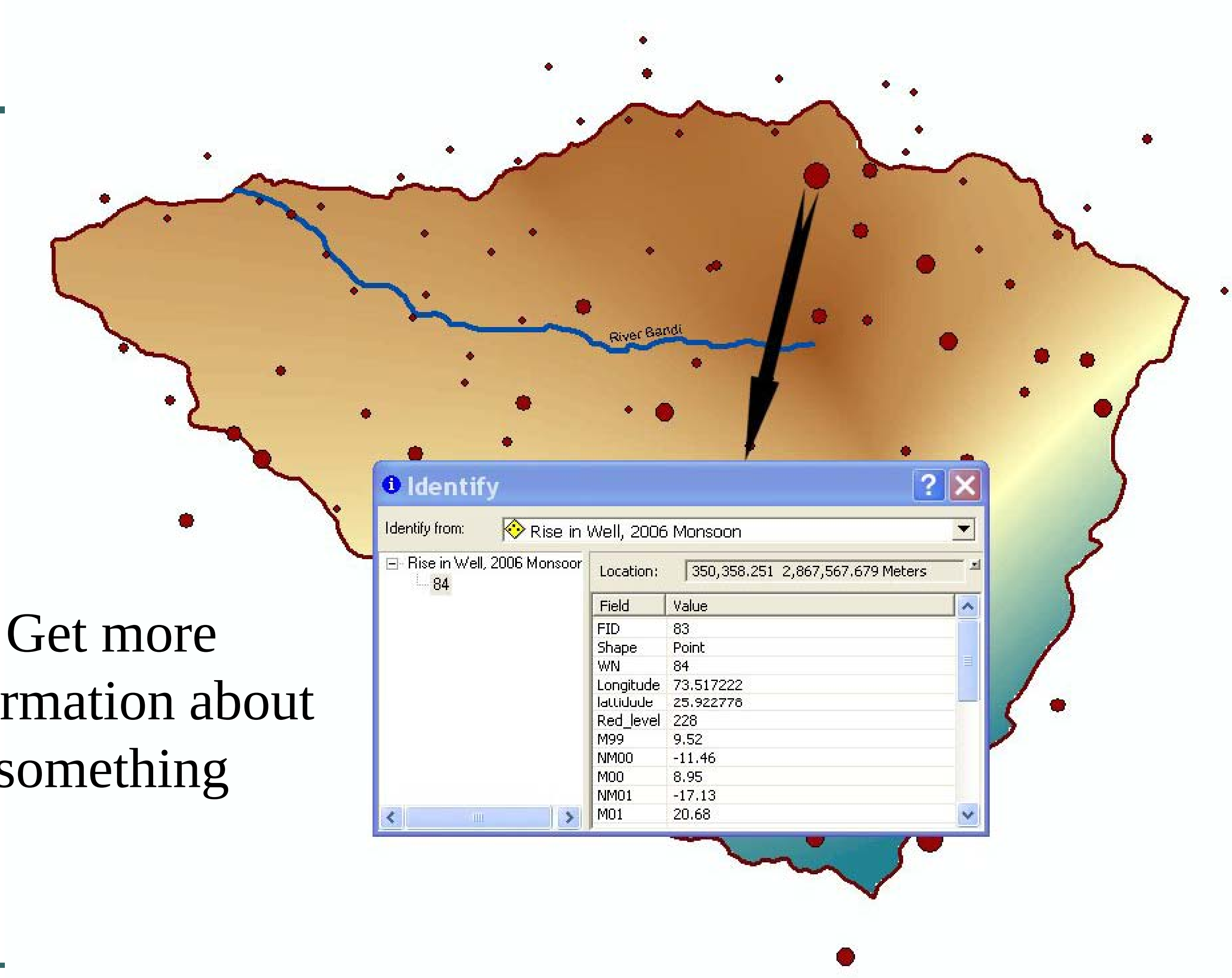
Turning Data into Information,

Shows Relationship Between Rainfall and Rise in WL



"Spatial Analysis" – not just a map

Asking A Question –Interaction



Get more information about something

Digital Terrain Model

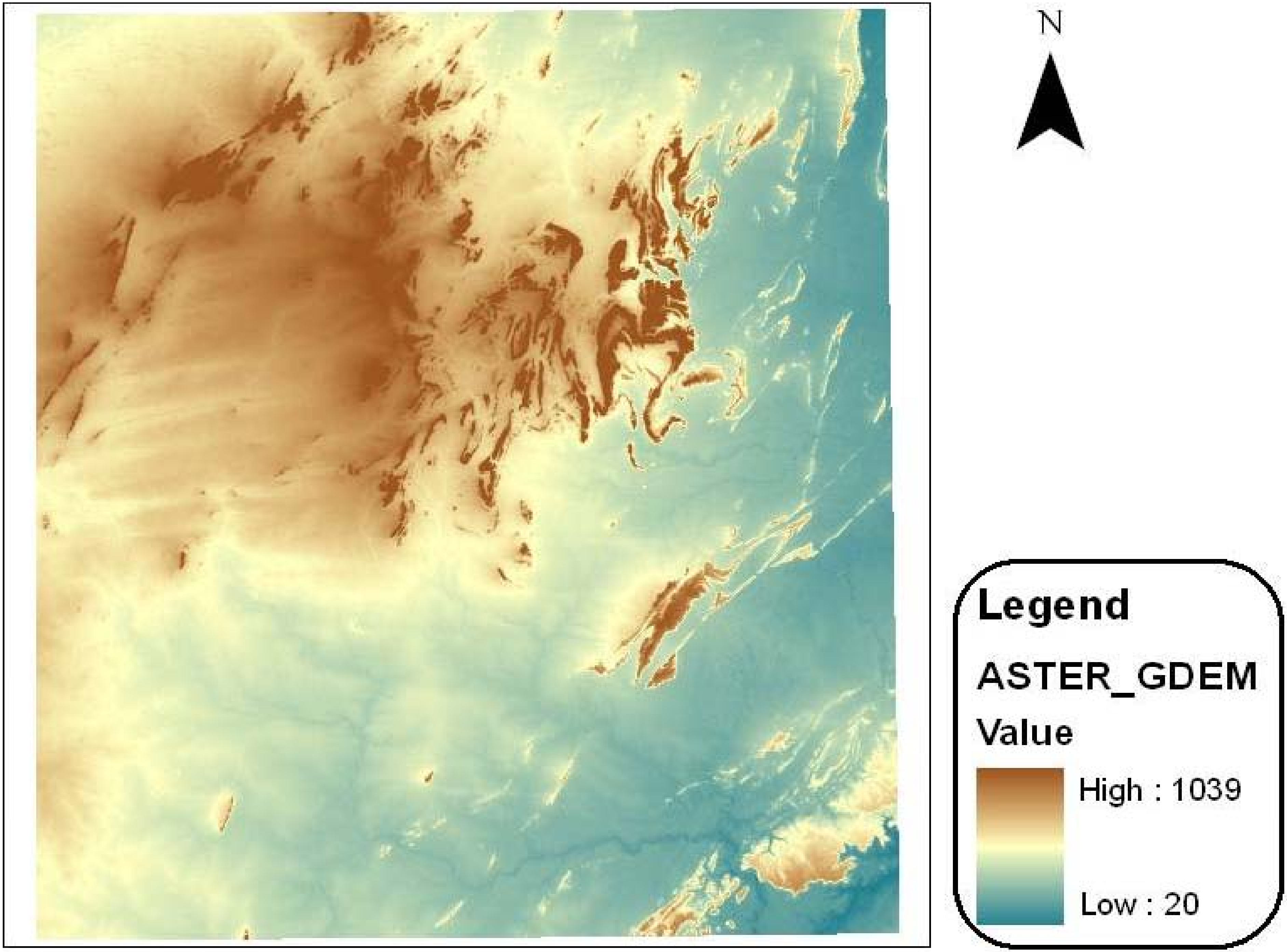
- In Most of the water related studies, digital terrain model is required in order to find out the direction of movement of water (By gravity)
- DTM or DEM (Digital Terrain/Elevation Model) is defined as the representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum, usually mean sea level.

Easily Possible

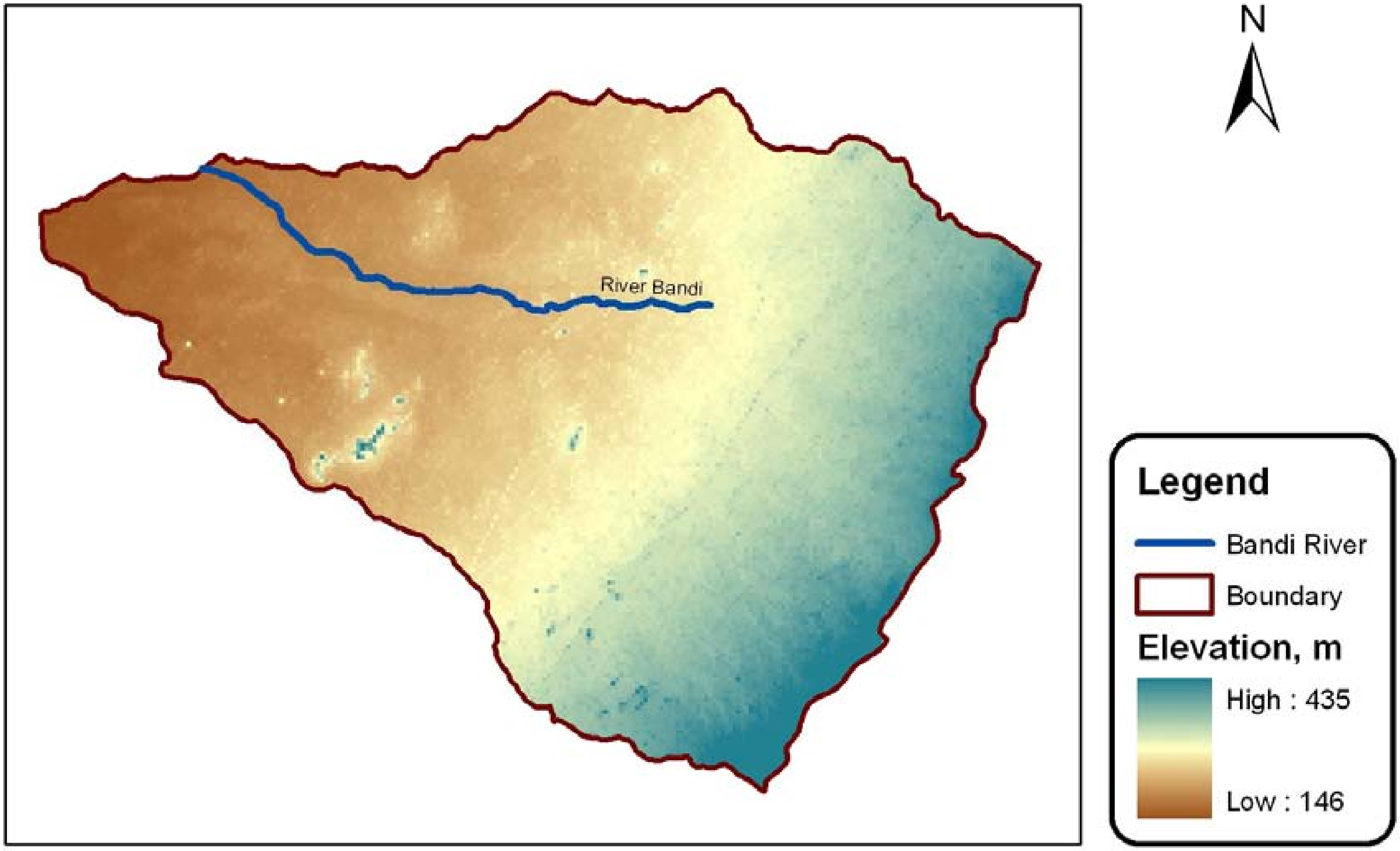
- It is absolutely easy to get DTM of any area in the world.
- Two different source of elevation data are available free of cost on Internet
  - Aster GDEM at a resolution of 30 m
  - Shuttle Radar Topography Mission (SRTM) at a resolution of 90 m
- Both are very much usable in many cases. May require improvement in some cases.

Elevation Data

- In February 2000, USA carried out Shuttle Radar Topography Mission (SRTM) to obtain elevation data on a near-global scale.
- The GLFC web site also provides SRTM data of World at two resolutions:
  - 3 arc-second/90-meter DEM of the world
  - 30 arc-second/1 km SRTM-GTOPO30 product corrected by GTOPO30 30 arc-second DEM
- SRTM data could be used for applications such as hydrological/civil engineering modeling, 3-D fly-throughs, viewshed analysis and generating slope and aspect layers etc.


N
Legend
ASTER_GDEM
Value
High : 1039
Low : 20

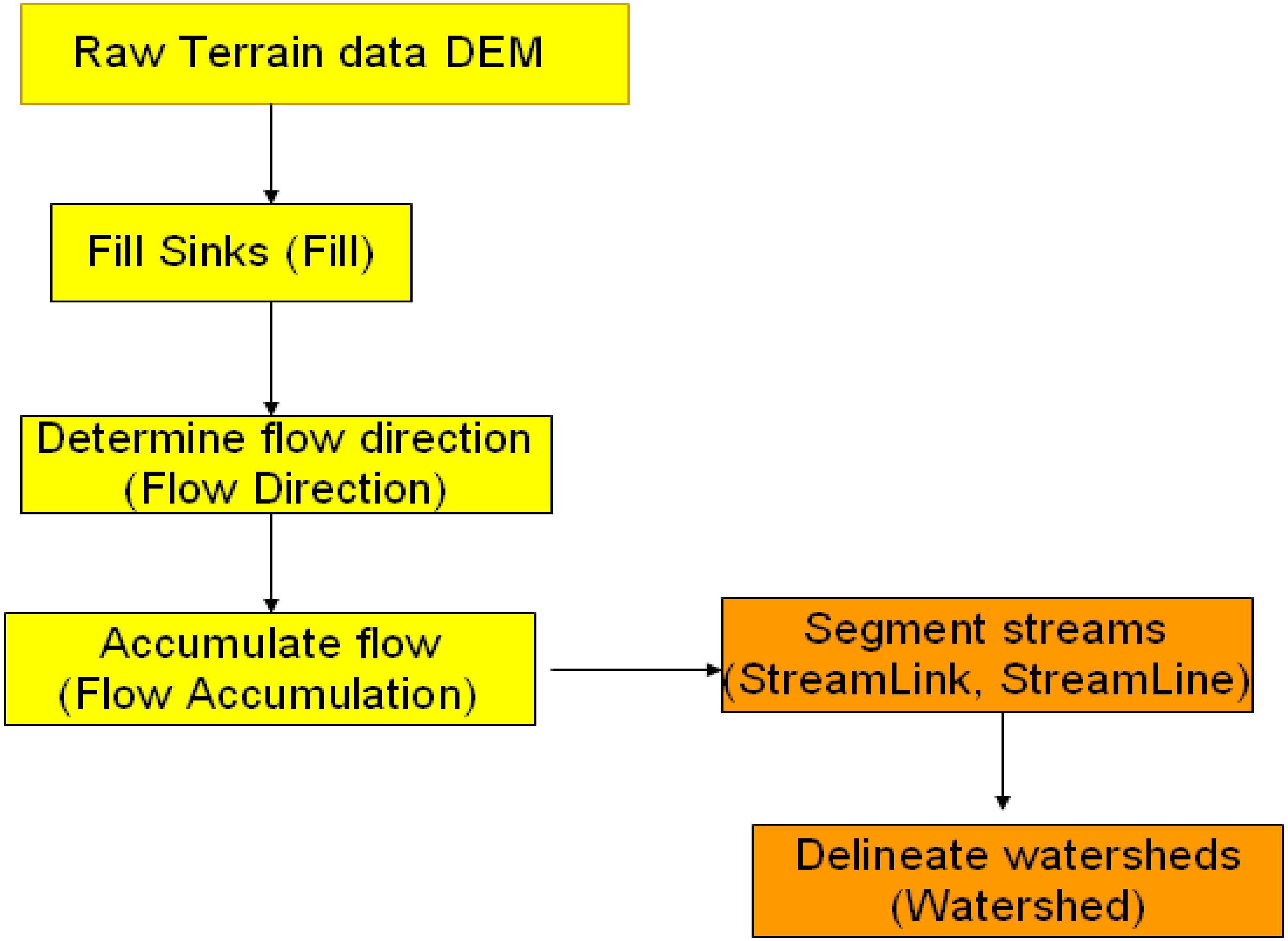
Elevation Map of Pali Study Area, Using Aster Data



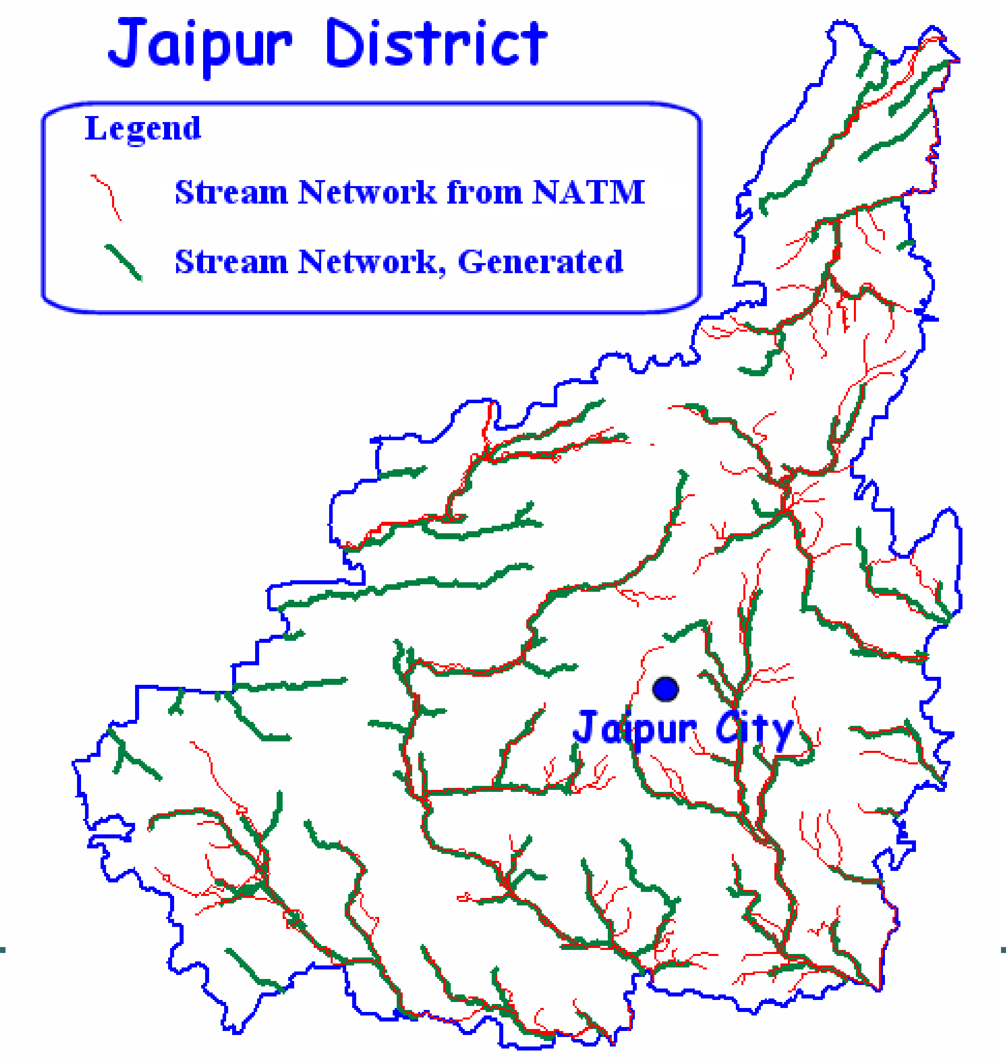
Hydrological Analysis using GIS

- Once DTM is available, it is possible to use several GIS tools to develop drainage map of that area and do some hydrological analysis.
- Once Drainage map is available, tools could be used to find catchment area at any point on drainage map.

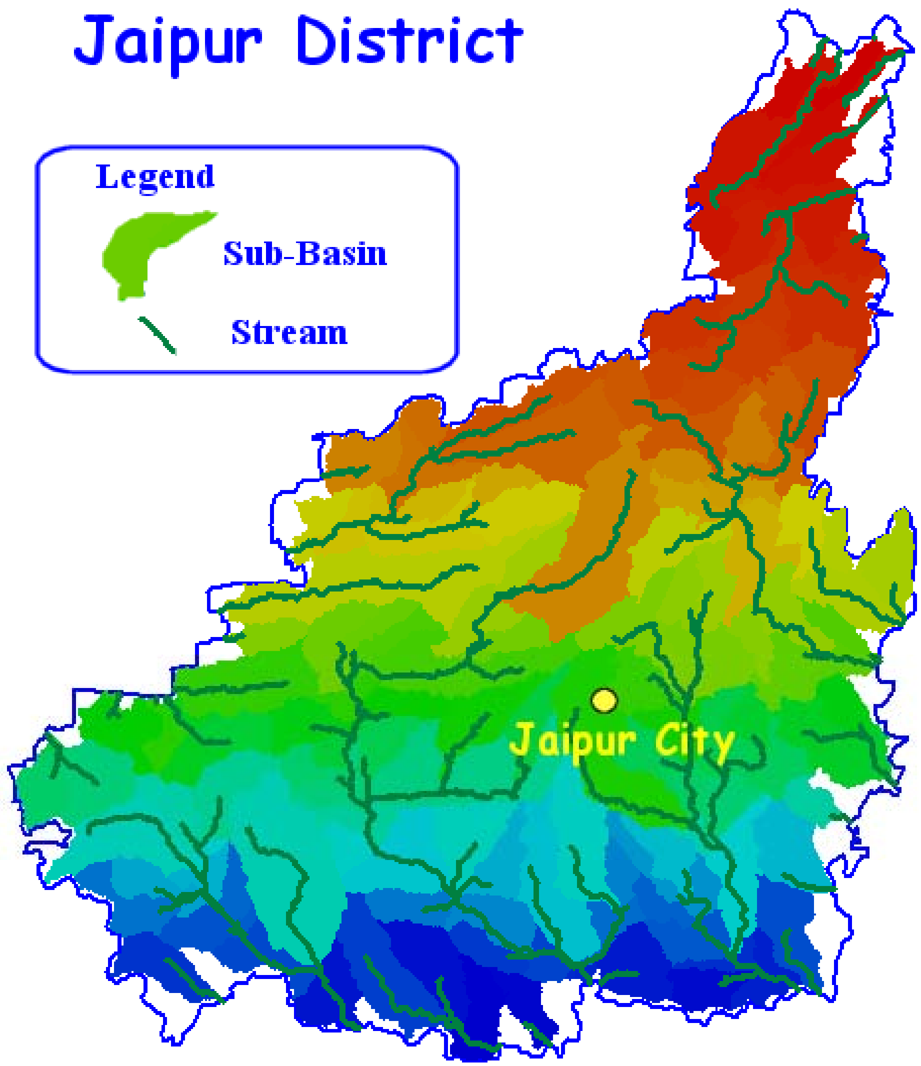
Flow diagram for sub-watershed delineation

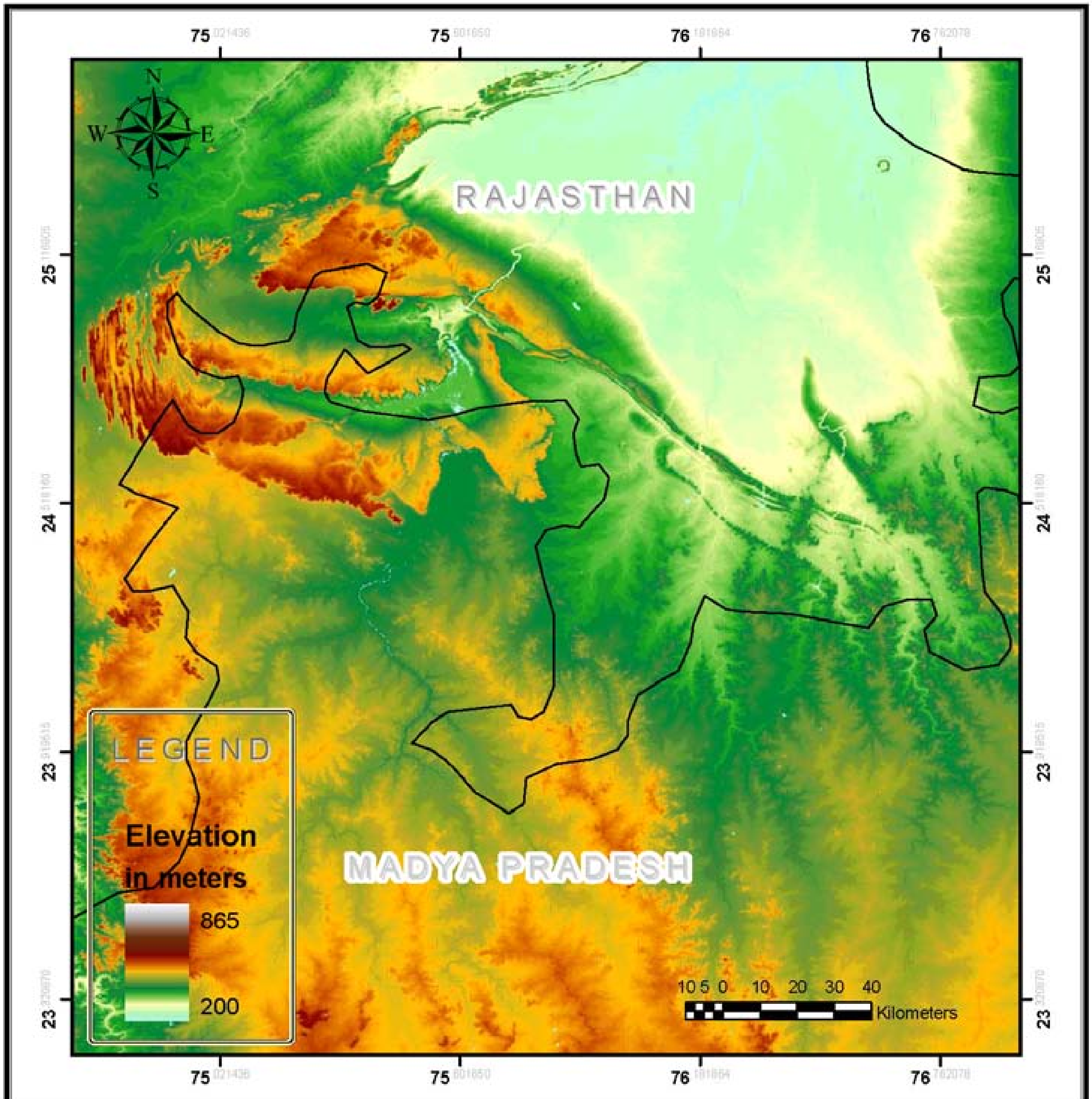


Comparison of Stream Network Derived from Different Sources

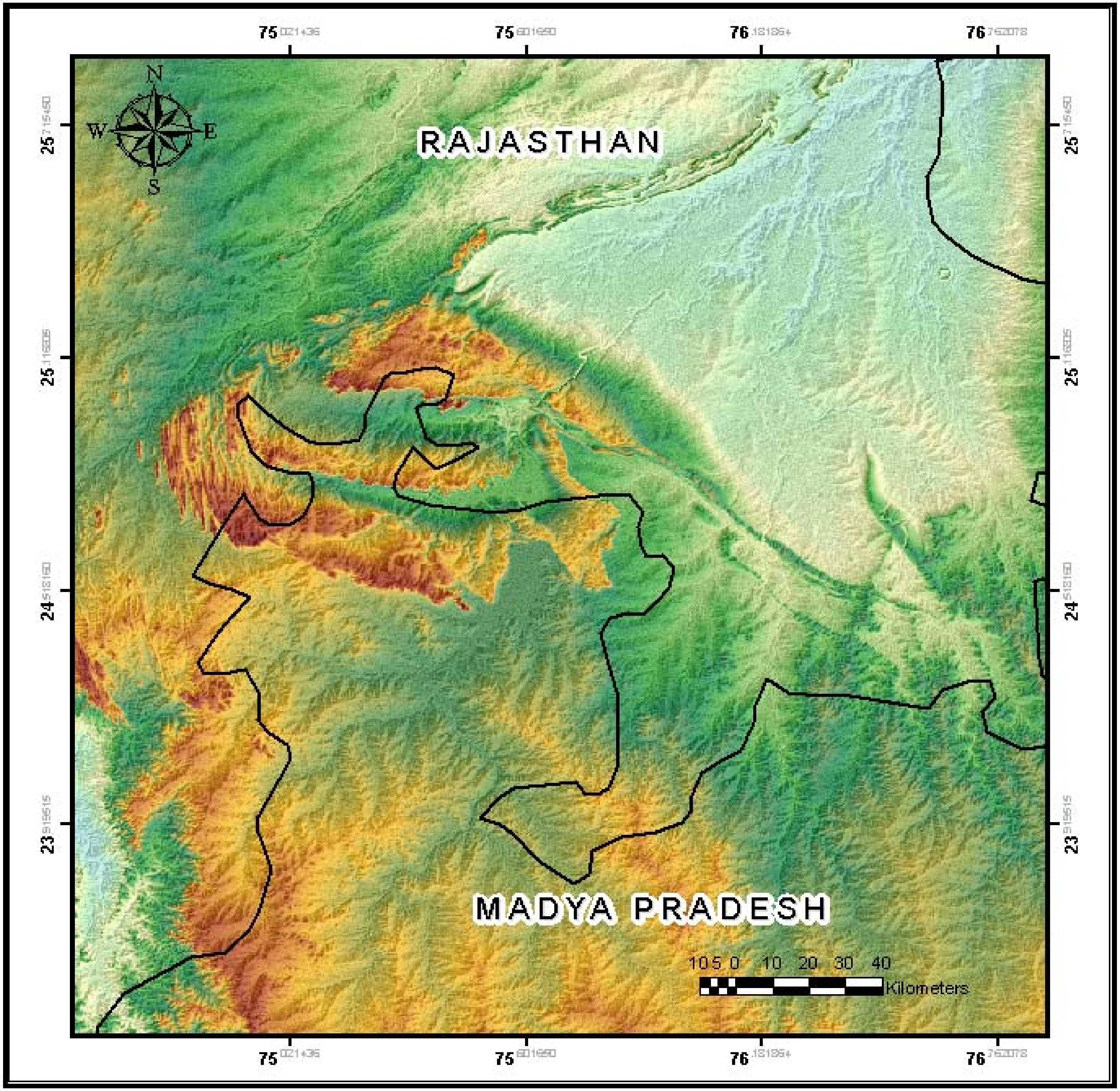


Sub-Basins of Segmented Streams

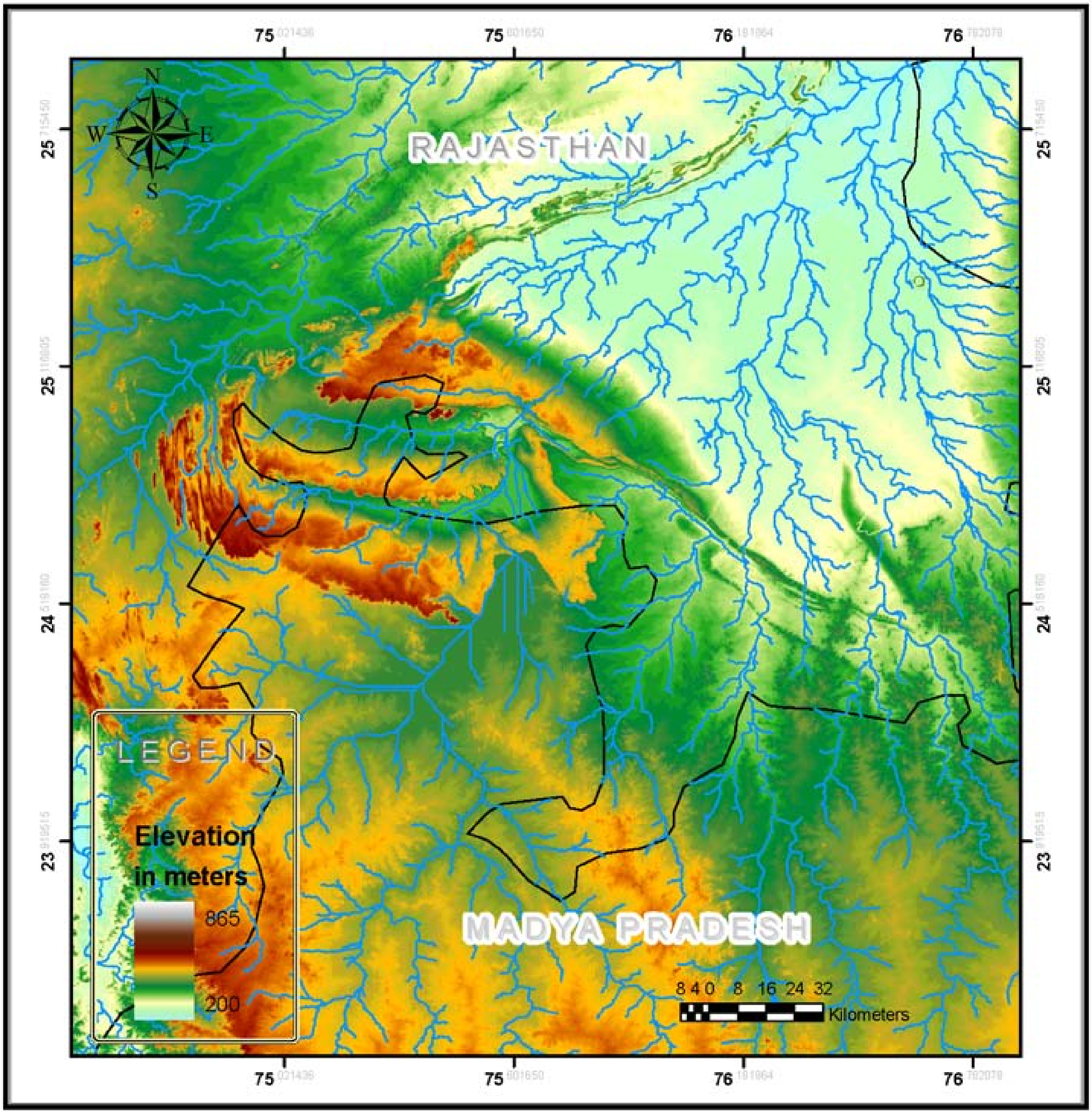




RAJASTHAN
MADYA PRADESH
N
S
E
W
LEGEND
Elevation in meters
865
200
10 5 0 10 20 30 40
Kilometers
75
76
25
24
23



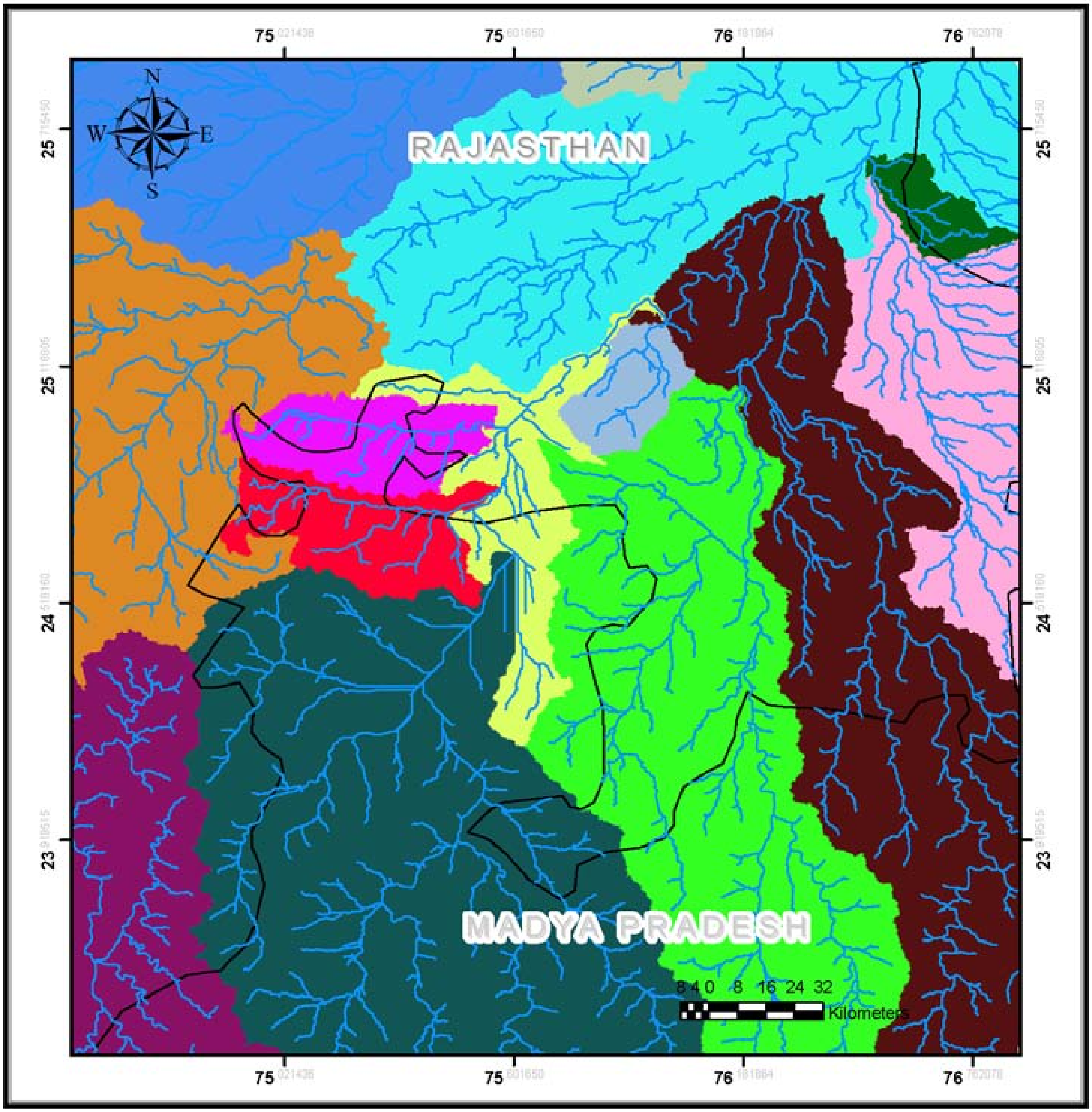
N
W
E
S
RAJASTHAN
MADYA PRADESH
10 5 0 10 20 30 40
Kilometers



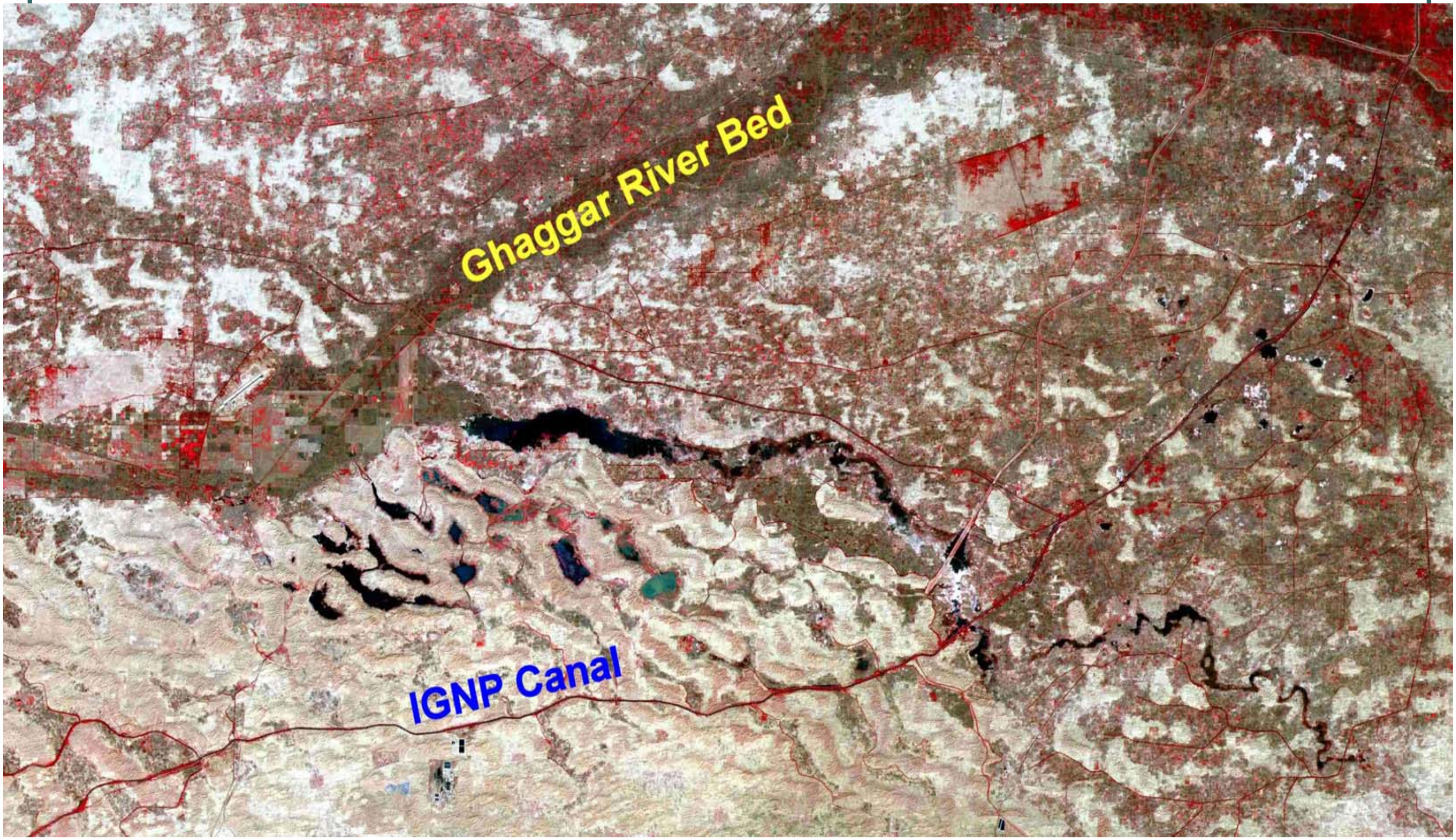
75
75
76
76
25
25
24
23
N
W
E
S
RAJASTHAN
MADYA PRADESH
LEGEND
Elevation
in meters
865
200
8 4 0 8 16 24 32
Kilometers

Watershed Delineation

- The stream network grid is converted into stream segments, where each head segment and segment between the junctions has a unique identifier.
- Then, each stream link is delineating the sub-watersheds in the stream network grid.


RAJASTHAN
MADYA PRADESH
N
S
E
W
8 4 0 8 16 24 32
Kilometers
75
76
25
24
23

IGNP Command Area, IRS data, LISS III



Ground Water Modeling

- MNIT, recently concluded a MHRD sponsored ground water modeling project for part of IGNP command area
- This area is facing sever problem of waterlogging and soil salinity
- Watertable started rising @ 1m/year after 1980.
- Waterlogged area (watertable up to 1 m bgl) reached from 8600 ha in 1991 to 22008 ha in 1997-98.

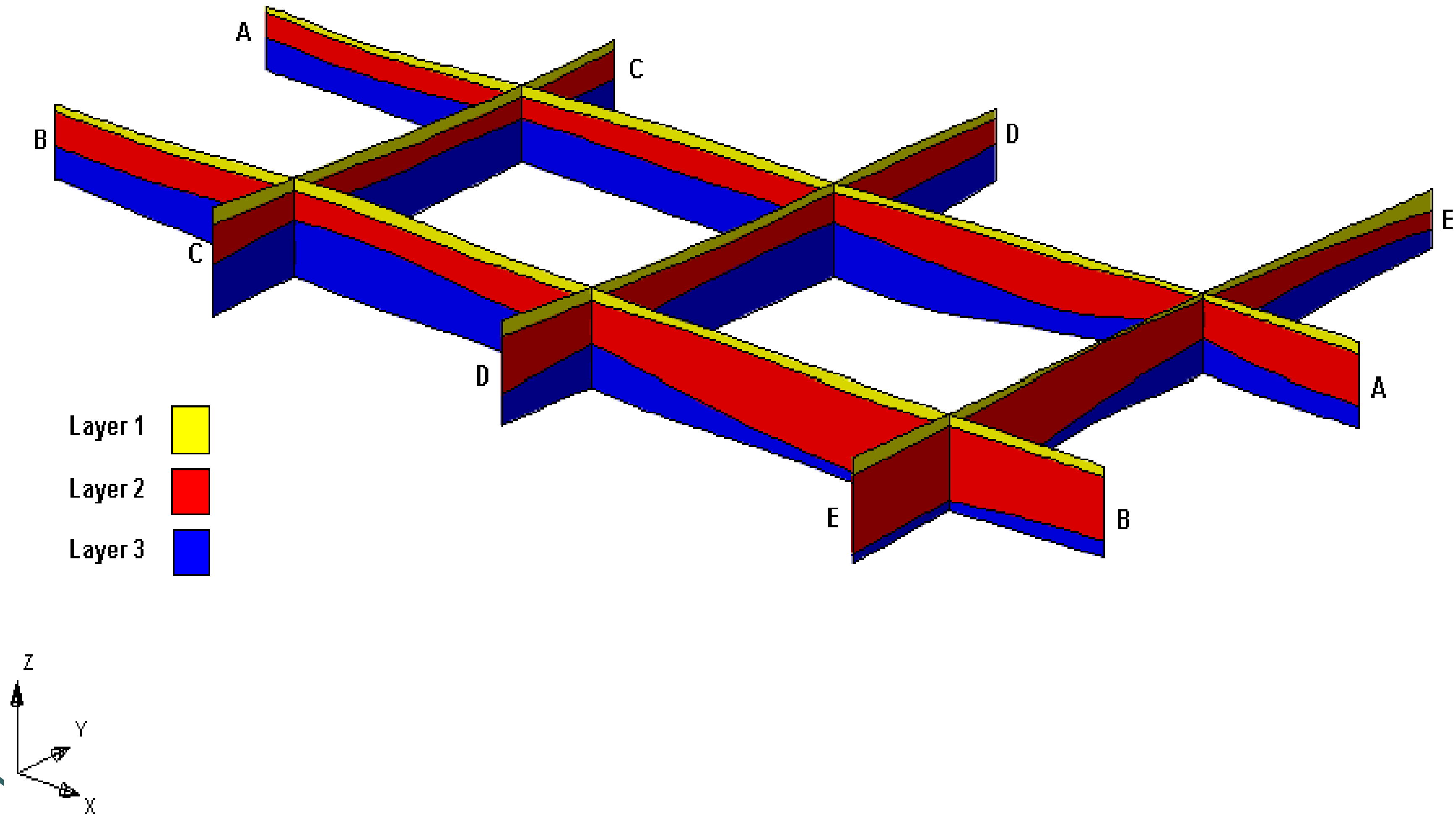
Effect of Waterlogging & Soil Salinity
Normal Cropped Area

Crop in Partially Waterlogged & Saline Adjacent Area

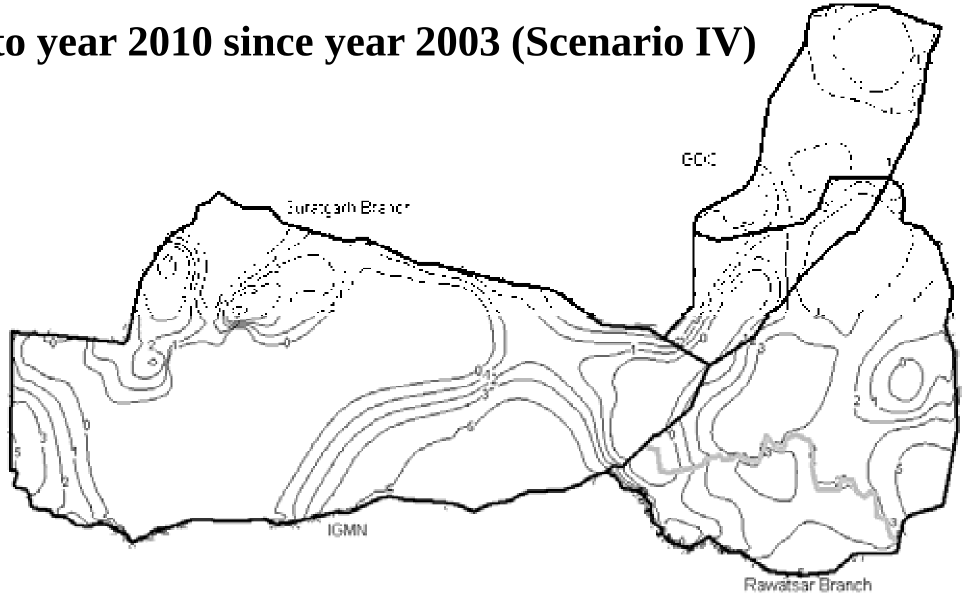
Ground Water Modeling

- To study different scenarios, ground water computer based model was developed
- Historical data of piezometers (100), sub surface geology, hydraulic properties of aquifer were used.
- GMS with MODFLOW as underlying groundwater flow modeling code was used to generate conceptual model and then convert it to finite difference ground water model.
- Six coverage's were developed: boundary, source/ sinks, recharge, Evapo-transpiration & for different layers.

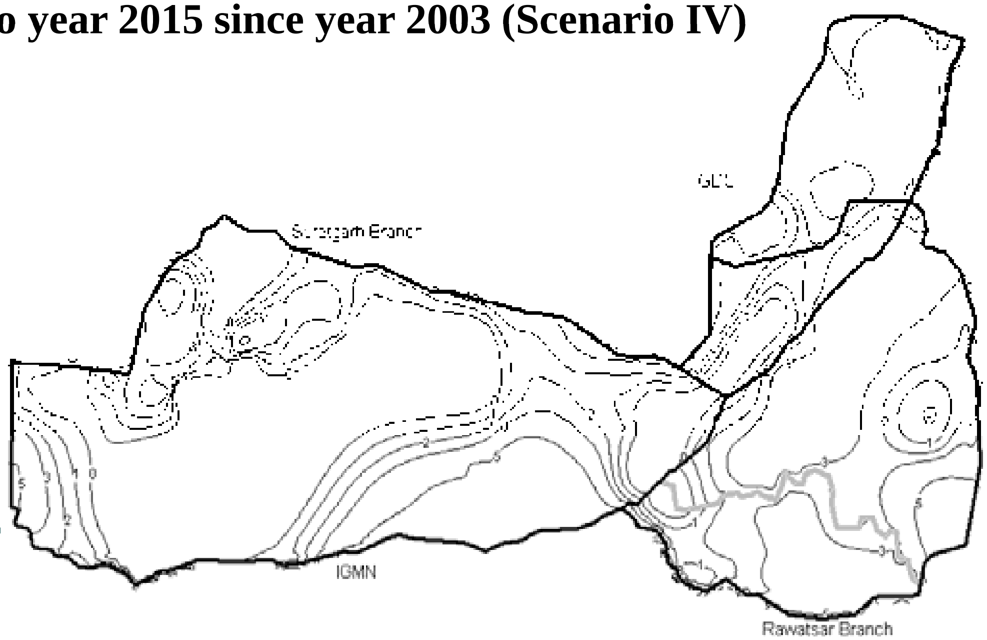
Vertical Soil Profiles



Rise in Watertable up to year 2010 since year 2003 (Scenario IV)



Rise in Watertable up to year 2015 since year 2003 (Scenario IV)



Conclusions

- Remote sensing data serves a variety of applications.
- Digital Terrain Model (DTM) of Jaipur District was developed using freely available remote sensing data on Internet.
- Using DTM, Stream network was derived and sub-watershed were delineated.
- It was found that the stream network derived from SRTM compared very well with National Atlas and Thematic Mapping (NATM) Maps.
- Groundwater Modeling of IGNP command was carried out using RS & GIS tools.

Reference

- Arun, P.S., Jana, R. and Nathawat, M.S. (2005). "A Rulebase Physiographic Characterization of a Drought Prone Watershed Applying Remote Sensing and GIS." J. of Ind. Soc. of Remote Sensing. 33(2).
- Bastiaanssen, W.G.M., Noordman, E.J.M., Pelgrum, H., Davids, G., Thoreson, B.P. and Allen, R.G. (2005). "SEBAL Model with Remotely Sensed Data to Improve Water-Resources Management under Actual Field Conditions." J. Irrigation and Drainage Engineering, ASCE. 131(1), February. 85-93.
- Biswas, S., Sudhakar, S. and Desai, V.R. (2002). "Remote Sensing and Geographic Information System Based Approach for Watershed Conservation." J. Surveying Engineering, ASCE. 128(3), August. 108-124.
- Colaizzi, P.D., Barnes, E.M., Clarke, T.R., Choi, C.Y., Waller, P.M., Haberland, J. and Kostrzewski, M. (2003). "Water Stress Detection Under High Frequency Sprinkler Irrigation with Water Deficit Index." J. Irrigation and Drainage Engineering, ASCE. 129(1), February. 36-43.

References, Contdâ€¦

- Droogers, P. and Bastiaanssen, W. (2002). â€śIrrigation Performance using Hydrological and Remote Sensing Modeling.â€ť J. Irrigation and Drainage Engineering, ASCE, 128(1), February. 11-18.
- Dymond, R.L., Regmi, B., Lohani, V.K. and Dietz, R. (2004). â€śInterdisciplinary Web-Enabled Spatial Decision Support System for Watershed Management.â€ť J. Water Resources Planning and Management, ASCE. 130(4), July. 290-300.
- Ikweiri, F.S. and Jin, Yee-C. (2004). â€śApplication of Remote Sensing and GIS to Model Mountainous Rivers.â€ť J. Hydrologic Engineering, ASCE. 9(3). May. 208-218.
- Lillesand, T.M. and Kiefer, R.W. (2002). â€śRemote Sensing and Image Interpretationâ€ť, 4th Edition.John Wiley & Sons.
- Jain, M.K., Kothyari, U.C. and Ranga Raju, K.G. (2005). â€śGIS Based Distributed Model for Soil Erosion and Rate of Sediment Outflow from Catchments.â€ť J. Hydraulic Engineering, ASCE. 131(9). Sept. 755-769.
- Jensen, J.R. (2003). â€śRemote Sensing of the Environment: An Earth Resource Perspective.â€ť Pearson Education, Inc. 361-365.

References, Contd...

- Ray, S.S., Sood, A., Das, G., Panigrahy, S., Sharma, P.K. and Parihar, J.S. (2005). “Use of GIS and Remote Sensing for Crop Diversification-A Case Study for Punjab State.” J. of Ind. Soc. of Remote Sensing. 33(2).
- Scott, C.A., Bastiaanssen, W.G.M. and Ahmad, M. (2003). “Mapping Root Zone Soil Moisture Using Remotely Sensed Optical Imagery.” J. Irrigation and Drainage Engineering, ASCE. 129(5), October. 326-335.
- Shih, S.F. and Jordan, J.D. (1993). “Use of Landsat Thermal-IR Data and GIS in Soil Moisture Assessment.” J. Irrigation and Drainage Engineering, ASCE. 119(5), September/October. 868-879.
- Singh, V.P. and Woolhiser, D.A. (2002). “Mathematical Modeling of Watershed Hydrology.” J. Hydrologic Engineering, ASCE. 7(4). July. 270-292.