Assessment of water quality using remote sensing for aquatic resource management

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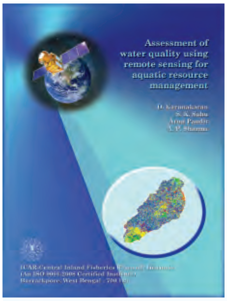

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FOREWORD

With the development of modern satellite systems and improvements in image transmission and ground receiving station technologies, remote sensing imageries can now be obtained rapidly and repeatedly over large areas. Satellite remote sensing can serve as a fast and relatively cost-effective tool for early and expeditious assessment of the spatial and temporal variability of large area of the earth's features. Remote sensing is used in diversified fields including land survey, agricultural planning and management, soil resources database, forest inventory, assessing climate change impact, water resources management, watershed analysis, management and development planning in coastal zone resources, monitoring and recording of weather data, disaster management.

India has vast area under the reservoirs with huge untapped production potential for fisheries. Optimum technological interventions are of prime importance to achieve their fish production potential. Assessment of water quality is pre-requisite to any scientific intervention for fisheries development as they are of prime importance in fisheries perspective. With the availability of remote Sensing imageries, assessment of water quality parameters is possible within a short period of time. The present work describes the methodologies and case studies for assessing water quality parameters including chlorophyll pigment concentration using remote sensing techniques. The bulletin also includes the basic principles of remotes sensing its uses and a brief account of Indian reservoirs. I believe that the bulletin will be useful to a wide spectrum of users including the fishery managers, entrepreneurs, students and Government departments

August, 2015

A. P. Sharma
Director,
CIFRI

CONTENTS

ACRONYMS

F.A.O	-	Food and Agriculture Organization
DO	-	Dissolved Oxygen
BOD	-	Biological Oxygen Demand
TDS	-	Total Dissolved Solid
Total N	-	Total Nitrogen
NO_3	-	Nitric Oxide
Mg	-	Magnesium
temp	-	Temperature
sp. cond.	-	Specific Conductivity
free co_2	-	Free Carbon Dioxide
TA	-	Total Alkalinity
Ca	-	Calcium
Resp.	-	Respiration
GIS	-	Geographical Information System
RS	-	Remote Sensing
IRS	-	Indian Remote Sensing
NRSC	-	National Remote Sensing Centre
SST	-	Sea Surface Temperature
NRSC	-	National Remote Sensing Centre
DoS	-	Department of Space
FASAL	-	Forecasting Agricultural output using Space, Agro-Meteorology and Land based observations
PFZ	-	Potential Fishery Zone
NASA	-	National Aeronautics and Space administration
SRTM	-	Shuttle Radar Topographic Mission (SRTM)
LISS-III	-	Linear Imaging Self Scanning - III
NIR	-	Near Infra Red
SWIR	-	Short-wave Infra Red
DN value	-	Digital Number value

Introduction

India is endowed with vast resources of inland open waters in the form of rivers, estuaries, reservoirs, wetland etc. Among them, river and canals cover 1.91 lakh km, reservoirs, 31.5 lakh ha, ponds and tanks 23.81 lakh ha and beels, oxbow lakes & derelict water bodies 7.98 lakh ha. These vast water bodies provide water for various uses such as drinking, industry, irrigation, power generation, fisheries, etc. These waters play an important role in socio-economic development of the country by way of its contribution to national income, livelihood, nutritional security and employment generation. Besides, they provide numerous invaluable ecological services.

Inland open water ecosystems are also repositories of valuable fish diversity. Especially the reservoirs and wetlands provide vast potential for fish production enhancement to meet nutritional requirement when fish production from marine sector is stagnating and freshwater aquaculture is becoming less remunerative. The fish yields from reservoirs though improved through development of enhancement technologies including culture based fisheries developed by ICAR-CIFRI from 30 kg/ha/year in the 1990s to 110 kg/ha/year by 2010 however, they are still far below than their potential of 500, 250 and 100 kg/ha/yr, for small, medium and large reservoirs. The potential production could be harnessed through ecosystem based approach of fisheries management (Vision 2050, CIFRI). Right management, scaling up and refinement of existing enclosure culture technologies, sufficient availability of right candidate fish species for specific water bodies or different agro-climatic zones, funding support, value addition and market chain development could help in bridging the gap. A smart management system with built in Remote Sensing (RS) and GIS, would be helpful in efficient management of these resources with enabling governance mechanisms.

Reservoir fisheries resources

A reservoir is an impoundment obstructing the surface flow of a river, stream or any water course (Sugunan, 1997). The Indian reservoirs are distributed from Himalayas to Southern peninsula, from Manipur to Gujarat. Reservoirs 'the man-made lakes' are constructed with the aim of generation of electricity and water storage for purpose of irrigation (Sarkar *et al.*, 2015). Along with that these water bodies have tremendous potential for fisheries that in turn has several economic and social advantages. But so far reservoirs in India are concerned they are not contributing to that extent towards fisheries.

Reservoirs are classified as small (<1,000 ha), medium (1,000 to 5,000 ha) and large (>5,000 ha) categories based on their hectrage by National Consultation held in 1997 at Central Inland Fisheries Research Institute (CIFRI, 1997), Barrackpore. The cumulative area of reservoirs in India are estimated to be 14.86 lakh ha, 5.07 lakh ha and 11.61 lakh ha under small, medium and large reservoir categories, respectively (Vass and Sugunan, 2009).

Table 1: State-wise area of small, medium and large reservoirs (ha) in India

State	Small	Medium	Large	Total
Tamil Nadu	315,941	19,577	23,222	358,740
Karnataka	228,657	29,078	179,556	437,291
Madhya Pradesh	172,575	149,259	138,550	460,384
Andhra Pradesh	201,927	66,429	190,151	458,507
Maharashtra	119,515	39,161	115,054	273,750
Gujarat	84,124	57,748	144,358	286,230
Bihar	12,461	12,523	71,711	96,695
Odisha	66,047	12,748	119,403	198,198
Kerala	7,975	15,500	6,160	29,635
Uttar Pradesh	218,651	44,993	71,196	334,840
Rajasthan	54,231	49,827	49,386	153,444
West Bengal	732	4,600	10,400	15,732
North eastern states	2,239	5,835	-	8,074
Himachal Pradesh	200	-	41,364	41,564
Haryana	282	-	-	282
Total	**1,485,557**	**507,298**	**1,160,511**	**3,153,366**

Source: Vass and Sugunan (2009)

The size-wise distribution of reservoirs in India is presented in table 1. Out of the total area under reservoirs, 36.8% are under large (above

5,000 ha), 16.09% under medium (1,000 – 5,000 ha) and the rest 47.11% are under small (<1,000 ha) category. Indira Sagar (91348 ha) constructed across river Narmada is the largest reservoir in India followed by Hirakud (74,592 ha), constructed across river Mahanadi in Odisha, Gandhi Sagar (64,750 ha) across river Chambal in Madhya Pradesh and Govind Ballabh Pant Sagar (46,539 ha) across Rend, a tributary of river Sone in Uttar Pradesh. The reservoirs are predominantly located in the peninsular States, *viz*., Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Odisha, and Maharashtra. These six States account for more than 56 percent of the total reservoir area in the country. Of the 19,134 small reservoirs, 17,989 (94%) are located in southern India. Similarly, 34 per cent of the medium reservoirs are also distributed in these States.

The reservoirs form a large resource size carrying a huge untapped production potential for fisheries owing to this they are called the sleeping giants of the Indian fisheries. Reservoirs are the major inland fishery resource amenable to fisheries development to meet growing fish demand in the country. However their scattered distribution, diverse management regime, lack of application of scientific knowledge, weak governance and policy support are creating hindrances in realizing their fish production potential. Optimum technological interventions are prime importance to achieve their fish production potential. Although, proper institutional arrangements, conducive socio-economic environment, better harvesting schedules and appropriate conservation measures are also essential for sustainable utilisation of these inland fisheries resources. Thus, a holistic and concerted approach combining both ecological principles and stakeholder participation need to be followed while formulating management norms for augmenting fisheries in them for maintaining their ecological integrity.

Analysis of water quality of reservoir

The demand for fish to cater to nutritional and livelihood security to millions of countrymen including resource-poor fishers has been on the rise. The estimated demand for fish by 2020 in the Indian domestic market would be around 13.3 million tonnes (Awasthy et al. 2011) against the present production of 9.58 m t (2013-14), nearly two-third (61%) of which comes from the inland sector. The target fixed for the XII Five Year Plan period is to increase the inland fish production from 5.383 million metric tons to 7.910 million metric tons (+ 2.527mmt). The reservoir can contribute a large share of this targeted production if proper scientific management protocols are followed.

Water quality is a general descriptor of water properties in terms of physical, chemical, thermal, and/or biological characteristics. Assessment of water quality parameters *viz*. pH, alkalinity dissolved oxygen, nitrate, phosphate, chloride and biochemical oxygen demand (BOD) physical parameters such as temperature, salinity, pH, temperature, turbidity, depth and biological parameter like chlorophyll concentration is pre-requisite to any scientific intervention for fisheries development as they are of prime importance in fisheries perspective. However, monitoring water quality parameters of such vast area like reservoir is not an easy task with the conventional tools and methods. In situ techniques for measuring water quality variables are time-consuming and it requires excessive traveling, sampling, and expensive laboratory analysis and it is very difficult to report and predict the water quality situation in a real time basis. However, with the advent of Geographical Information System technique and Remote Sensing imageries, assessment of water quality parameters is possible within a short period of time. The present study is an effort to this direction where water quality parameters and chlorophyll pigment concentration were assessed using remote sensing and GIS Techniques.

Advantage of remote sensing

Remote sensing technique offers a number of important advantages over the subjective view of the human. It provides a synoptic view of the earth's features. With the development of modern satellite systems and improvements in image transmission and ground receiving station technology, remote sensing imagery can now be obtained rapidly and repeatedly over large areas. Satellite remote sensing can serve as a fast and relatively cost-effective tool for early and expeditious assessment of the spatial and temporal variability of lake water quality conditions (Zilioli and Brivio, 1997). It is also a very cost effective tool for rapid and effective assessment of large area of the earth's features. Imageries are not very expensive and in some cases they are even freely available. These imageries are helpful to monitor fisheries habitats, rivers, reservoirs and wetlands. Many researchers assessed water quality parameters using the optical remote sensing since 1970s. Ritchie *et al.* (1974) developed an early empirical approach to estimate the suspended sediments. Various workers reported that remote sensing is a powerful tool which could be applied to regional water quality monitoring and assessment (Ritchie and Charles, 1988; Schalles *et al.*, 1998; Chopra *et al.* 2001; Dekker *et al.*, 2002; Gupta*et al.* 2003).

Studies have demonstrated stable/significant reliable relationships between water quality parameters, such as total phosphorus, total nitrogen, dissolved oxygen, pH, salinity, secchi depth, sodium, potassium, and radiance data from the satellites (Dewidar and Khedr 2001; Alparslan *et al.* 2007). The econometric tool of regression technique has strong potential for the application of Remote Sensing (RS) data in monitoring water quality of inland waters in estuaries (Choubey, 1997). Several authors found correlations between remotely sensed data and turbidity, although they are unique for a specific water body (Fraser, 1998). In one study Gupta *et al.*, 2003 found primary production and remote sensing data have good corelation. This advantage has been widely exploited to monitor and map shallow coastal waters also (Bierwirth *et al.*, 1993).

Uses of remote sensing and GIS

GIS and RS technologies are applied for a wide range of fields including the followings.

- Land Resources : Land use planning, land survey, land use and land cover mapping

- Agricultural Resources : Agricultural planning and management, soil resources database, soil survey, soil erosion assessment and prediction, climate change impact on agriculture

- Forest Resources : Forest inventory, climate change impact on forests

- Water Resources : Water resources management, watershed analysis, fisheries resources development planning, river bank erosion and accretion, monitoring morphological changes and hydrology of rivers, navigation and dredging, construction and maintenance of embankments, flood forecasting and management, water pollution

- Coastal zone resources: Management and development planning, land erosion, construction and maintenance of embankments, salinity, water logging, shrimp culture, marine fisheries, mangrove forest, sea level rise.

- Protection and conservation: Habitat and ecosystem, wetlands, wildlife, protected areas, ecotourism development

- Weather: Monitoring and recording of weather data - rainfall, temperature, humidity, *etc.*; weather forecasting and warning

- Environment: Monitoring, modeling and management of land degradation; weather and climate modeling, prediction and forecasting; river and coastal erosion modeling; flood management

- Climate change : Climate change impact assessment, vulnerability assessment, adaptation to climate change

- Disasters: Disaster management, disaster forecasting, disaster risk management, cyclone recovery and restoration, assessment and monitoring of damage, flood risk and vulnerability assessment

- Socio-demographic studies: Demographic studies and development analysis, population census

In India RS & GIS has been applied / is being applied in a wide range of areas including application by Central and State Govt. agencies. Some of them are as follows:

- Land use/ land cover/wetlands mapping on l:250,000 scale have been prepared for the whole country using IRS-1 multi data to help in the preparation of operational plans for 15 agroclimatic zones of India.

- Reservoirs, flood plans, ponds, tanks maps on scale of 1:50,000 have been prepared for selected states using LISS-III multispectral data to help in preparation of fisheries development plan (Sahu*et al.*, 2007)

- High resolution satellite data is providing advance information at tehsil /district level, on the extent and severity of agricultural drought conditions and fortnightly drought assessment.

- Identification of crops, acreage estimation and forecasting their yield have been operationalized for major crops such as wheat, rice, sorghum, cotton, groundnut, tobacco, tea *etc*.

- Wasteland maps including the information on type and extent of village level are being used in conjunction with geographical information system to generate comprehensive plans for reclamation of wastelands.

- Remote Sensing has been very effectively used in India for identifying prospective ground water potential zones for suitable exploitation with reduced time and efforts.

- Satellite data are contributing significantly for the forest management through biennial forest cover mapping and use of these maps for maintaining of ecological balance in critical areas.

- In the area of water resource management, remote sensing data are being used for prioritization of watersheds, surface water monitoring, rainfall runoff studies, snowmelt runoff forecasting and irrigation scheduling.

- Digital analysis of multi-date data has been used to prepare urban sprawl maps of major cities in the country with over 1 million population, as a baseline information for perspective planning of their growth. Geographical information system is being utilized for analyzing the multi-parameter data for providing guidelines to city planners to solve urban related problems.

- Study of the entire coastal line of the country for tidal wetlands, coastal landforms, potential aquacultures sites, mangroves, estuarine dynamics/shoreline changes, and off-shore aspects like suspended sediment dynamics and coastal currents, near shore bathymetry, internal waves have been made.

- A preliminary map on coral reefs has been completed giving details of coral reef extent and related environmental aspects.

- A national programme on ocean remote sensing programme on (i) Sea Surface Temperature (SST) retrieval and applications (ii)

Microwave applications (iii) setting up of a national ocean information system and iv) ocean modeling.

National Remote Sensing Centre (NRSC), an autonomous organization under the Department of Space (DoS), is responsible for acquisition, processing, supply of aerial and satellite remote sensing data and continuously exploring the practical uses of remote sensing technology for multilevel applications. Some of the important projects carried out in the country include groundwater prospects mapping under drinking water mission, forecasting agricultural output using space, agro-meteorology and land based observations (FASAL), forest cover/type mapping, grassland mapping, biodiversity characterization, snow & glacier studies, land use/cover mapping, coastal studies, coral and mangroves studies, wasteland mapping. Potential Fishery Zone (PFZ), flood mapping and monitoring, national wastelands monitoring, watershed monitoring and development, etc. The information generated by large number of projects has been used by various departments, industries and others for different purposes like development planning, monitoring, conservation etc

ICAR-CIFRI study

ICAR-CIFRI has assessed water quality parameters and chlorophyll concentration in the water bodies of Purulia and Bankura districts of West Bengal, Jhansi district of Utter Pradesh, Mandya and Hassan districts of Cauvery basin in Karnataka both during pre-monsoon and post-monsoon period. Water quality parameters assessed in this study were temperature, transparency, dissolved oxygen (DO), sp. conductivity, pH, total dissolved solid (TDS), total alkalinity, free CO_2, chlorinity, salinity, NO_3, total nitrogen, PO_4, sulphate, silicate, hardness, Ca, Mg, and chlorophyll.

Study area

Twenty two samples of water and soil were collected from the fourteen

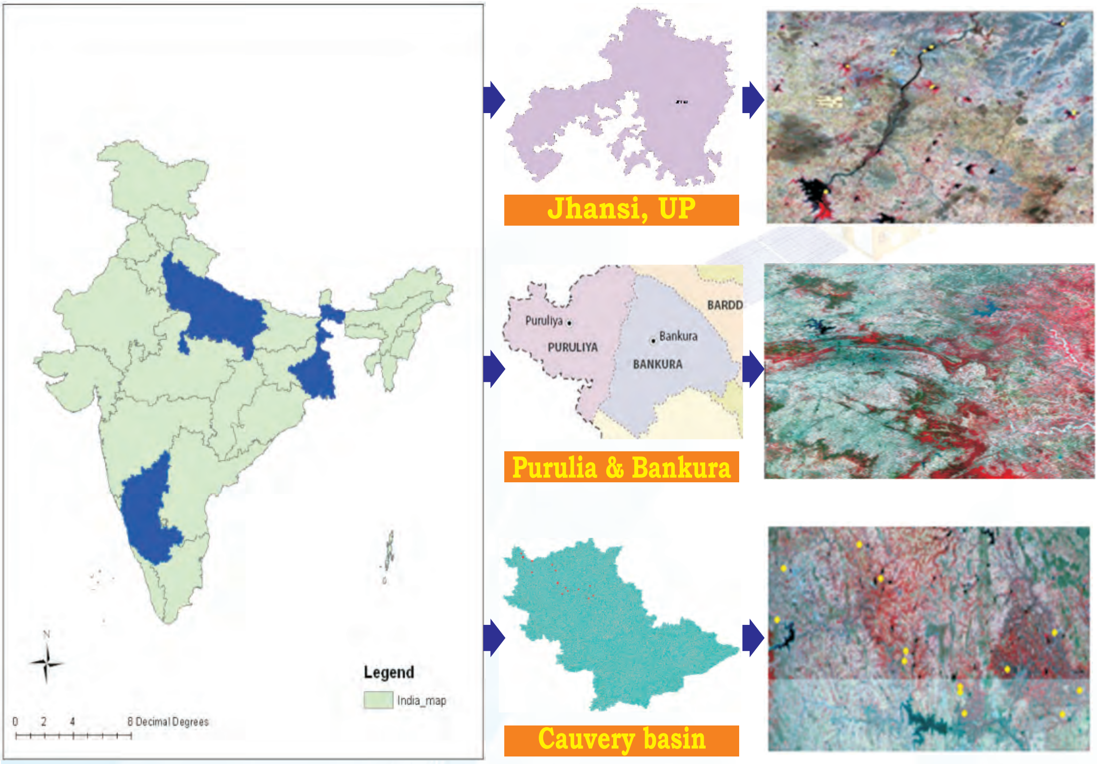

Fig. 1. Location of Study area

water bodies during post monsoon (13^{th} November 2007 to 23^{rd} November 2007) period and fourteen samples during pre-monsoon (22^{nd} May 2008 to 30^{th} May 2008) period from Purulia and Bankura districts of West Bengal. The same study was conducted in Jhansi district of UP. Remote sensing data of IRS P6 LISS-3 images for pre-monsoon (2^{nd} June 2009) and post-monsoon (10th August 2009) were procured for Jhansi district and water and soil samples were collected exactly during the same period. Thirty three samples were collected from 8 water bodies across the district.

Similarly thirty one water samples were collected from 19 water bodies across the Mandya and Hassan districts of Karnataka in Cauvery river basin during post-monsoon period. The ground truth data were collected exactly during the period of IRS-P6 overpass. Based on NASA Shuttle Radar Topographic Mission (SRTM) 90 m digital elevation data, flow paths and watersheds were delineated using TNT MicroImage software.

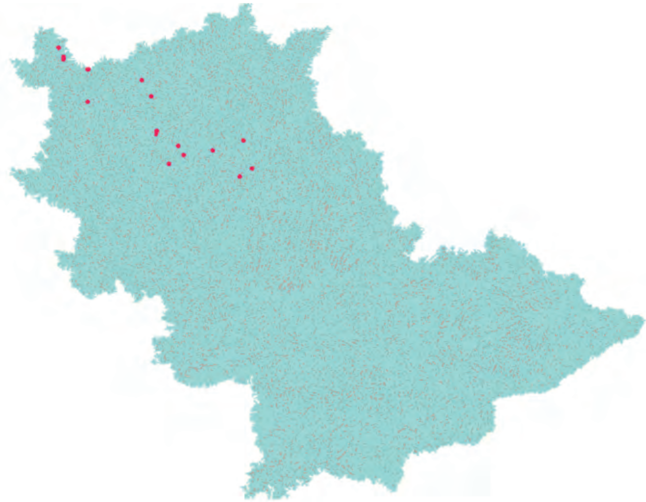

Fig. 2. Cauvery basin delineated based on SRTM DEM data

It is computed that Cauvery basin is of 85349.52 km^2 area, which is nearly 2.5% of the total geographical area of the country. The catchment of the river basin lies in the states of Karnataka, Tamil Nadu, Kerala and Union Territory of Puducherry. Indian Remote Sensing Satellite, IRS P6 LISS-III multi-spectral data (Fig. 1.) dated 20th February 2012 for post monsoon period were procured from National remote sensing center, Hyderabad for this study. LISS III sensor has four multispectral bands based on wavelengths: Green (0.52-0.59 μm), Red (0.62-0.68 μm), Near Infrared (0.77-0.86 μm), Short wave infrared (1.55-1.70 μm). It has a spatial resolution of 24 m, temporal resolution of 24 days, radiometric resolution of 7 bit and the swath of 141 km which is useful for this study.

The sample collection and analysis were carried out in the laboratory using standard methodologies.

Procurement of satellite data

Indian Remote Sensing Satellite's (IRS) Linear Imaging and Self Scanning Sensor (LISS-III) images at 23.5m spatial resolution have been used for this study. LISS-III is a multispectral sensor operating in four spectral bands, three in the visible and near-infrared (VNIR) bands and one in the short-wavelength infrared (SWIR) region, with 23.5-m spatial resolution and covers a swath of 141 Km in all the 4 bands (Table 2). Cloud cover is most limiting factor in scene selection. Good quality cloud free IRS P6 LISS III data were procured from National Remote Sensing Centre (NRSC), Hyderabad for the study area (Table 3).

Table 2. Description LISS-III image

Sensor	Resolution					Swath (km)
	Spectral		Spatial (m)	Temporal (days)	Radiometric	
	Bands	Wavelength (μm)				
LISS –III	Band 2(green) Band 3(red) Band 4(NIR) Band 5(SWIR)	520-590 620-680 770-860 1550-1700	23.5	24	7 bit	141

Table 3. IRS P6 LISS-III data used for the study

Sl. No	Area of study	Path-Row	Date
1.	Purulia	106/55	10 May 08 and 29 Nov 07
		106/56	10 May 08 and 24 Nov 07
2	Bankura	107/55	15 May 08 and 29 Nov 07
		107/56	15 May 08 and 29 Nov 07
3.	Jhansi	108/55 & 108/56	2 June 2009 and 10 August 09
4.	Mandya and Hassan	98/64	20th February 2012
		99/64	20th February 2012
		99/65	20th February 2012

Methodology

The flow chart of getting the corrected DN value has been presented in Fig. 3. Initially the water sampling and chlorophyll measurements were conducted concurrent with the Indian Remote-Sensing Satellite (IRS-P6) overpass. Following this IRS-P6 Liss-III imagery was normalized by removing atmospheric effects and noise using TNTmips image processing software. Lastly correlation study was done with rectified satellite reflectance values against in-situ water quality parameters and chlorophyll data. Imagery collected by the satellites are generally affected by the disturbance of atmospheric particles through absorption and

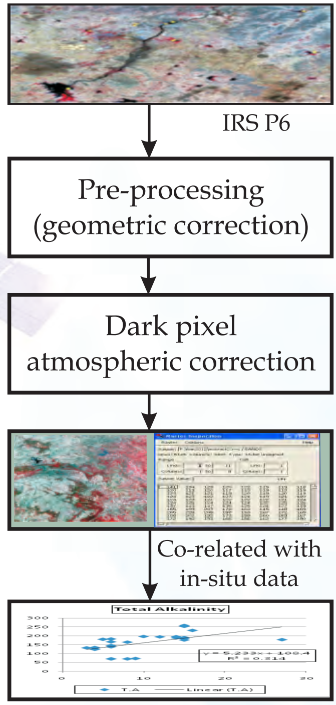

Fig. 3. Methodology for assessing water quality

scattering. This problem is more acute in assessing water quality and chlorophyll in inland waters. These effects can be removed using suitable atmospheric corrections and bi-directional reflectance models (Hadjimitsis and Clayton 2008). IRS P-6 imagery procured for assessing water quality and chlorophyll pigment concentration were subjected to an atmospheric correction using Dark Pixel subtraction method (Karunakaran *et al.*, 2013).

Results and discussion

Correlation with water quality parameters

Purulia (Post Monsoon)

The atmospherically corrected spectral reflectance values from all the bands were correlated with in-situ water quality parameters. It is found that there were very significant correlations between spectral reflectance

(Infra Red band) and Air temperature (R^2 = 0.5653, p < 0.01, n=55), Water temperature (R^2 = 0.6147, p < 0.01, n=15) chloronity (R^2 = 0.5775, p < 0.01, n=15), and salinity (R^2 = 0.5781, p < 0.01, n=15). Chlorinity, salinity are significant in 0.01 level in IR, red and green band, association is high in red band (R^2 = 0.81). NO_3 is significant in 0.05 level in IR band. Total – N significant in red and green in 0.05 level. Sulphate is significant in red and NIR band in 0.01 level and 0.05 level in green band. Correlation coefficients for different physio-chemical parameters with various bands are presented in Table 4.

Table 4. Correlation coefficients for different physio-chemical parameters of water with various bands in the water bodies of Purulia during post monsoon

Water quality Parameter	IR	Red	Green	NIR
Air temp	-0.7518**	-0.5260*	-0.2697	-0.38233
water temp	-0.7840**	-0.4857	-0.2670	-0.34667
Chlorinity	-0.7599**	-0.8047**	-0.6054*	-0.87792**
Salinity	-0.7603**	-0.8049**	-0.6053*	-0.87796**
No_3	0.5195*	0.4116	0.2238	0.374231
Total N	-0.3388	-0.5380*	-0.5811*	-0.40998
Sulphate	-0.5025	-0.6443**	-0.5915*	-0.64581**
Hardness	-0.3919	-0.5322*	-0.3793	-0.41434
Mg	-0.1200	-0.2723	-0.1908	-0.56245*

** p<0.01 * p<0.05

Scatter diagrams were plotted to visually assess the relationship between significantly correlated water quality parameters and spectral signature (Fig. 4). The trend line was drawn and linear regression equation was developed by best-fit procedures to predict water quality parameters and chlorophyll.

The linear regression models so developed for predicting water quality parameters were as follows: Air temp: y = -0.0377x + 21.827, R^2 = 0.5653, p < 0.01, n=15; water temp: y = -0.0386x + 20.772, R^2 = 0.6147 p < 0.01, n=15; Salinity: y = -7E-05x + 0.0433, R^2 = 0.5781, p < 0.01, n=25; Chlorinity: y = -4E-05x + 0.0074, R^2 = 0.5775, p < 0.01, n=15.

Purulia (Pre Monsoon)

The parameters, sp. conductivity and TDS are correlated with all four

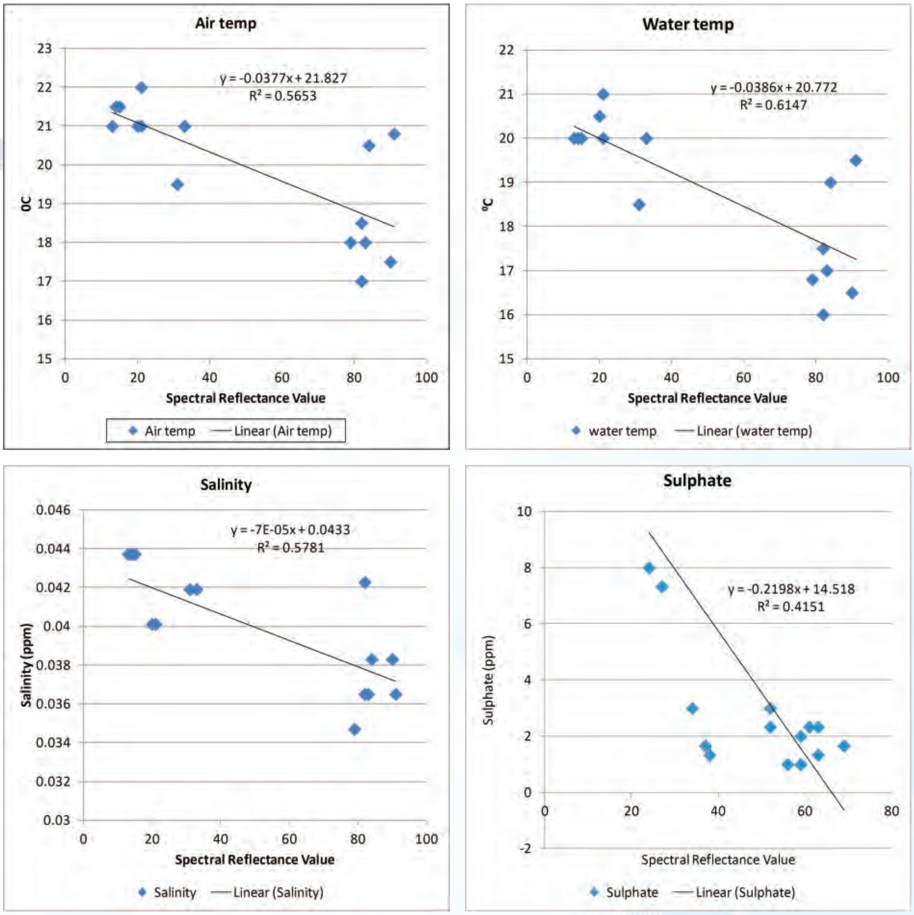

Fig. 4. Scatter diagrams with linear regression equations

bands and Gross production is correlated with Infra Red and Near Infra Red band. The details are presented in the Table 5.

Table 5. Correlation coefficients for different physio-chemical parameters with various bands in Purulia water bodies during pre-monsoon.

Water quality Parameter	IR	Red	Green	NIR
Sp .cond	-0.788931315*	-0.83128*	-0.80493*	-0.78651*
TDS	-0.788835922*	-0.83123*	-0.8049013*	-0.78641*
Gross	0.853831255*	0.717767	0.61193743	0.849516*

* $p<0.05$

Bankura (Post Monsoon)

In Bankura it was found that depth is correlated (significant in 0.01) level with IR band and Transparency, No_3 and respiration are correlated significantly (p<0.05) with NIR band.

Table 6. Correlation coefficients for different physio-chemical parameters with various bands in water bodies of Bankura during post monsoon

DN value	IR	Red	Green	NIR
Depth	-0.980161627**	-0.872483263*	-0.86689*	-0.5633942
Trans	-0.719492097	-0.67588515	-0.7022	-0.7739157*
NO_3	-0.389655324	0.295509501	-0.32179	-0.7674075*
Respiration	0.439686279	0.355567559	0.374017	0.80199436*

** p< 0.01* p<0.05

Bankura (Pre Monsoon)

In pre-monsoon as water spread area were less, the nitrate and silicate is highly significantly correlated. The correlation coefficients are mentioned in Table 7.

Table 7. Correlation coefficients for different physio-chemical parameters with various bands in the water body of Bankura during Post monsoon

DN value	IR	Red	Green	NIR
No3	0.599406	0.643023	0.62329468	0.947521*
Silicate	-0.754859709	-0.84485*	-0.737272	-0.18129

* p<0.05

Jhansi, UP

The same methodology was applied in Jhansi district of Uttar Pradesh. Remote sensing data of IRS P6 LISS-3 images for pre-monsoon (2nd June 2009) and post-monsoon (10th August 2009) were procured and water and soil samples were collected exactly during the same period. Thirty three samples were collected from 8 water bodies across the district. All the bands of IRS P6 imagery were tested to find out degree of relationship with ground trouthing water quality, soil parameters and chlorophyll.

It is observed that free CO_2 is significantly correlated with ($p < 0.01$) IR, red and green bands, NO_3 ($p < 0.05$) with IR and NIR bands and DO and pH has significant correlation ($p < 0.05$) with Red band during pre-monsoon (Table 8). In the post monsoon period DO was correlated with IR band, Ca in red band and sp. conductivity, TDS, TA, hardness and Ca with significantly correlated with green band (Table 9).

Table 8. Correlation coefficients for different Physio-chemical parameters with various bands of Jhansi during Pre-monsoon

DN value	IR	Red	Green	NIR
Depth	-396*	-0.213	-0.196	-0.214
water temp	-0.253	-0.376	-0.447 *	-0.109
D.O	-0.232	-0.400 *	-0.397	-0.183
pH	0.182	0.390*	0.347	-0.183
Free Co_2	0.576**	0.567**	0.560**	0.381
No3	0.393 *	0.291	0.326	0.472*
Silicate	-0.207	-0.299	-0.221	-0.360

** p< 0.01* p<0.05

Table 9. Correlation coefficients of different physio-chemical parameters with various bands in the water bodies of Jhansi during post-monsoon period

DN value	IR	Red	Green	NIR
D.O	0.521**	0.051	0.266	0.138
pH	-0.343	-0.324	-0.69	-0.386*
Sp.cond	0.215	0.334	0.515**	0.016
TDS	0.215	0.334	0.515**	0.016
TA	0.284	0.457*	0.620**	0.042
Silicate	0.295	0.354	0.374*	0.284
Hardness	0.222	0.381*	0.519**	0.081
Ca	0.251	0.513**	0.563**	0.078
Respiration	-0.34	0.00	-0.008	-0.519**

** p< 0.01* p<0.05

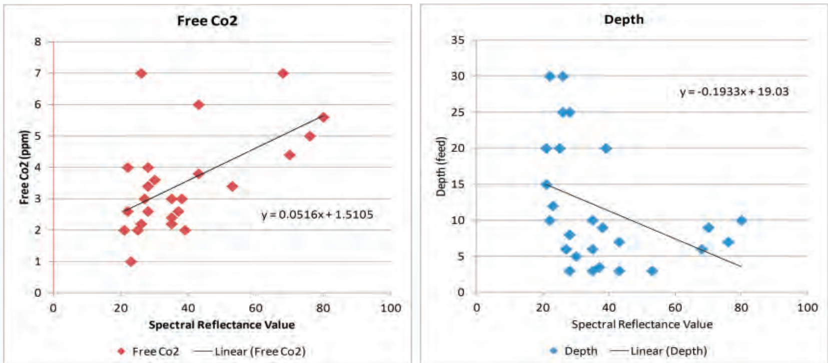

Fig. 5. Scatter diagram with linear regression equations for Free Co_2 and Depth

Chlorophyll pigment concentration

Post monsoon imageries of water bodies of Jhansi district were analyzed to predict the chlorophyll pigment concentration from the spectral reflectance signature of all the four bands. It was observed that in the Infra red band, chlorophyll a, chlorophyll b and chlorophyll c were significantly correlated (R^2=0.526 R^2=0.589, R^2=0.611 and R^2= 0.615) respectively and capable of predicting Chlorophyll pigment concentration from this bands (Fig.6).

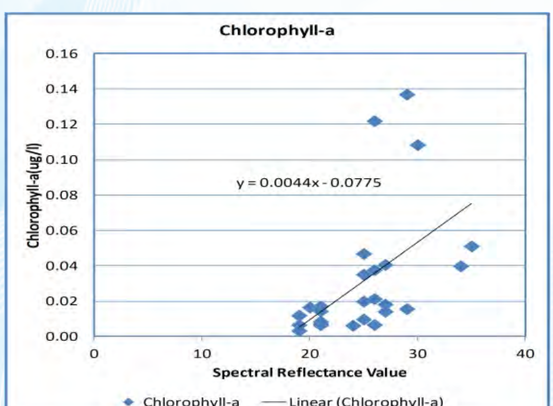

Fig. 6. Scatter diagrams with linear regression equations

Similar studies were conducted in Mandya and Hassan districts of Cauvery watershed during post-monsoon period. Thirty one water samples were collected from 19 water bodies having more than 50 ha area across the two districts. Atmospheric effects were corrected prior to

Table 10. Reflectance values of Cauvery reservoirs before and after atmospheric correction (AC) in IRS P6 imagery

	IRS P6 NIR Band		IRS P6 Red Band		IRS P6 Green band		IRS P6 SWIR Band	
Water bodies	Before AC	After AC	Before AC	After AC	Before AC	After AC	Before AC	After AC
Thailuru Kere	42	27	41	14	71	13	20	5
KRS Dam location 1	18	4	29	12	63	19	18	7
KRS Dam location 2	18	4	29	12	62	18	17	6
Marehalli Kere location 1	29	15	32	15	61	17	20	9
Marehalli Kere location 1	29	15	32	15	64	20	19	8
Hadly Kere	30	16	35	18	67	23	24	13
Deviramani location 1	21	6	34	7	65	7	22	7
Deviramani location 1	23	8	34	7	68	10	21	6
Hosaholalu location 1	21	6	31	4	69	11	22	7
Hosaholalu location 2	21	6	31	4	69	11	21	6
Tonnuru Kere location 1	18	3	28	1	59	1	19	4
Tonnuru Kere location 2	19	4	29	2	60	2	19	4
Kunthi Kere location 1	20	5	32	5	62	4	20	5
Kunthi Kere location 2	21	6	30	3	64	6	20	5
Bedigantha location 1	24	9	34	7	68	10	22	7
Bedigantha location 2	23	8	33	6	68	10	23	8
Bagur location 1	30	15	37	10	77	19	26	11
Bagur location 2	29	14	36	9	72	14	24	9
Kalkere	25	10	40	13	80	22	29	14
Hunasina Kere location 1	30	15	35	8	77	19	26	11
Hunasina Kere location 2	30	15	36	9	74	16	25	10
Hemavathi location 1	21	6	35	8	73	15	26	11
Hemavathi location 1	21	6	35	8	76	18	26	11
Konanahalli Kere location 1	27	12	34	7	65	7	22	7
Konanahalli Kere location 2	29	14	32	5	66	8	20	5

Correlation with water quality parameters

extract useful information from the imageries following the method already discussed. Table 10 shows the results of impact of rectification.

The atmospherically corrected spectral reflectance values from all the bands were correlated with in-situ water quality and chlorophyll parameters. It is found that there were very significant correlations between spectral reflectance (Near Infra Red band) and depth (R^2=0.3384, p < 0.001, n=25), specific conductivity (R^2=0.4177, $p < 0.001$, n=25), total alkalinity (R^2=0.3145, $p < 0.001$, n=25), chlorinity (R^2=0.3364, $p < 0.001$, n=25), salinity (R^2=0.3369, $p < 0.001$, n=25) and turbidity (R^2=0.3932, $p < 0.001$, n=25). Reflectance values from the green (0.52-0.59 μm) and red (0.62-0.68 μm), bands did not show correlation with any of the water quality parameters. Highly significant correlation was also found between Short wave infrared(SWIR) (1.55-1.70 μm) band and chlorophyll - a (R^2=0.3722, $p < 0.001$, 25). Correlation coefficients for different Physio-chemical parameters and chlorophyll with various bands are presented in (Table 11 and Table 12) respectively.

Table 11. Pearson correlation coefficients for different physio-chemical parameters with various bands in water bodies of Cauvery watershed during post-monsoon period

	NIR	RED	GREEN	SWIR
Depth	-0.582**	-0.509	-0.510	-0.345
Specific conductivity	0.646**	0.528	0.412	0.311
Total Alkalinity	0.561**	0.464	0.243	0.135
Chlorinity	0.580**	0.326	0.482	0.546
Salinity	0.580**	0.326	0.483	0.546
Turbidity	0.208	0.057	0.327	0.627**

** p< 0.01

Table 12. Correlation between various bands and chlorophyll of water bodies of Cauvery watershed during Post-monsoon

Particulars	Pearson Correlation Coefficients, N = 25 Prob > |r| under H0: Rho=0				
	Reflectance value (SWIR)	chlo_a	chlo_b	chlo_c	total_chlo
Reflectance value(SWIR) Reflectance value	1.00000	0.61006 0.0012	0.54525 0.0048	0.31967 0.1193	0.65689 0.0004
chlorophyll a (chlo a)	0.61006* 0.0012	1.00000	0.93410 <.0001	0.32711 0.1105	0.88766 <.0001
chlorophyll _b (chlo b)	0.54525 0.0048	0.93410 <.0001	1.00000	0.40434 0.0450	0.96428 <.0001
chlorophyll _c (chlo c)	0.31967 0.1193	0.32711 0.1105	0.40434 0.0450	1.00000	0.44134 0.0272
total_ chlorophyll (total chlo)	0.65689* 0.0004	0.88766 <.0001	0.96428 <.0001	0.44134 0.0272	1.00000

*p< 0.01

Scatter diagrams were plotted to visually identify relationship between significantly correlated water quality parameters and spectral signature. The trend line was drawn and linear regression equation was developed by best-fit procedures to predict water quality and chlorophyll parameters. The linear regression models so developed for predicting water quality parameters were as follows: depth: $y = -2.0233x + 45.192$, $R^2 = 0.3384$, specific conductivity: $y = 0.0169x + 0.2498$, $R^2 = 0.4177$, $p < 0.001$, $n=25$, total alkalinity: $y = 5.2339x + 108.43$, $R^2=0.3145$, $p < 0.001$, $n=25$) Chlorinity: $y = 0.0018x + 0.0095$, $R^2=0.3364$, $p < 0.001$, $n=25$, Salinity: $y = 0.0032x+0.0471$ $R^2=0.3369$, $p < 0.001$, $n=25$ and turbidity: $R^2=0.3932$, $p < 0.001$, $n=25$. The diagrams so developed were presented in Fig. 7.

Modeling land use patterns and water quality

Modeling the effects of land use and land cover changes on water quality is important for watershed managers to understand how anthropogenic modifications to land surfaces may alter water quality of the ecosystem. Models of land-use and land-cover changes are powerful tools that can be used to understand and analyze the important linkage between socio-economic processes associated with land development, agricultural activities, and natural resource management strategies and the ways that these changes affect the structure and function of ecosystems (Turner and Meyer, 1991). Furthermore, land use modifications may degrade water quality. By testing the physical and chemical characteristics of water, researchers may examine the relationship between land use changes and water quality and determine which water bodies are failing to meet water quality standards.

Catchment area of 8 water bodies from Jhansi and Purulia districts were delineated Using toposheet. Streams were digitized and classified and grouped into first, second and third order water bodies based on its stream orders. The catchment area of water bodies were classified using pre-monsoon imagery by supervised image processing methods (Fig. 8) and landscape matrix was prepared like percentage of forest, settlement,

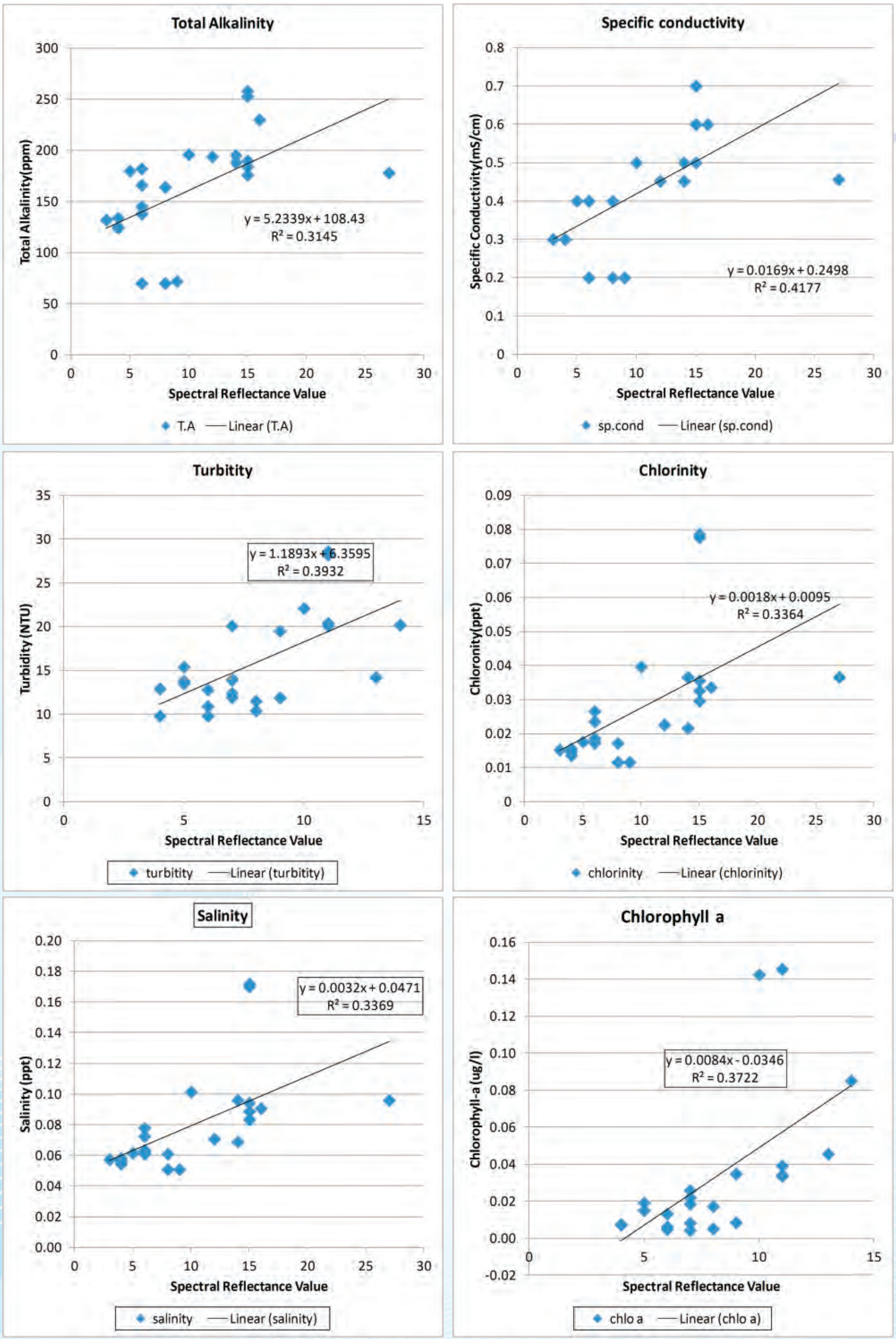

Fig. 7. Scatter diagrams with linear regression equations

agricultural land, water body and grass land in the catchment area (Table 13). Regression model was developed to using landscape matrix with water quality parameters.

Table13. Percentage of cluster counts in the catchment area on 10th August 2009

Landscape Matrix (%)					
	Forest	Settlement	Agr. land	Water Body	Grass Land
Baruasagar	23.34	28.79	35.18	03.00	09.69
Kamalasagar	18.97	04.93	38.63	10.00	27.47
Pahuj	13.14	06.25	27.71	08.10	44.80
Barwar	34.46	01.86	25.32	13.40	24.96
Garmu	17.33	10.62	22.92	25.06	24.07
Matatila	12.10	0.96	13.68	24.83	48.43
Murugama	20.50	0.20	17.96	14.00	47.34
Padaurma	9.06	3.03	24.43	7.38	56.10

Based on land matrix multiple linear regression model for Sp. conductivity was developed. Specific Conductivity model (R^2=0.9, $P < 0.01$), The compositional attribute (%) Grass land and settlement could be considered as the first and second important explanatory variables.

Sp.cond = -204.24 + 13.70G + 13.32S, Where; G = grass land (%) in the watershed; S =settlement (%) in the watershed

This model will be useful for predicting specific conductivity, which can estimate the salinity of the water.

Conclusion

The above discussion leads us to conclude that IRS P6 LISS III band Near Infrared (0.77-0.86 μm) is useful to assess the water quality parameters like depth, specific conductivity and turbidity. Similarly, short wave infrared band (1.55-1.70 μm) is useful for assessing chlorophyll-a after the images are atmospherically corrected. The models are region specific and they have the potential for monitoring water qualities of large water bodies in regular interval by use of Liss-III images. Using the landscape matrices, water quality parameters like specific conductivity and salinity can also be assessed.

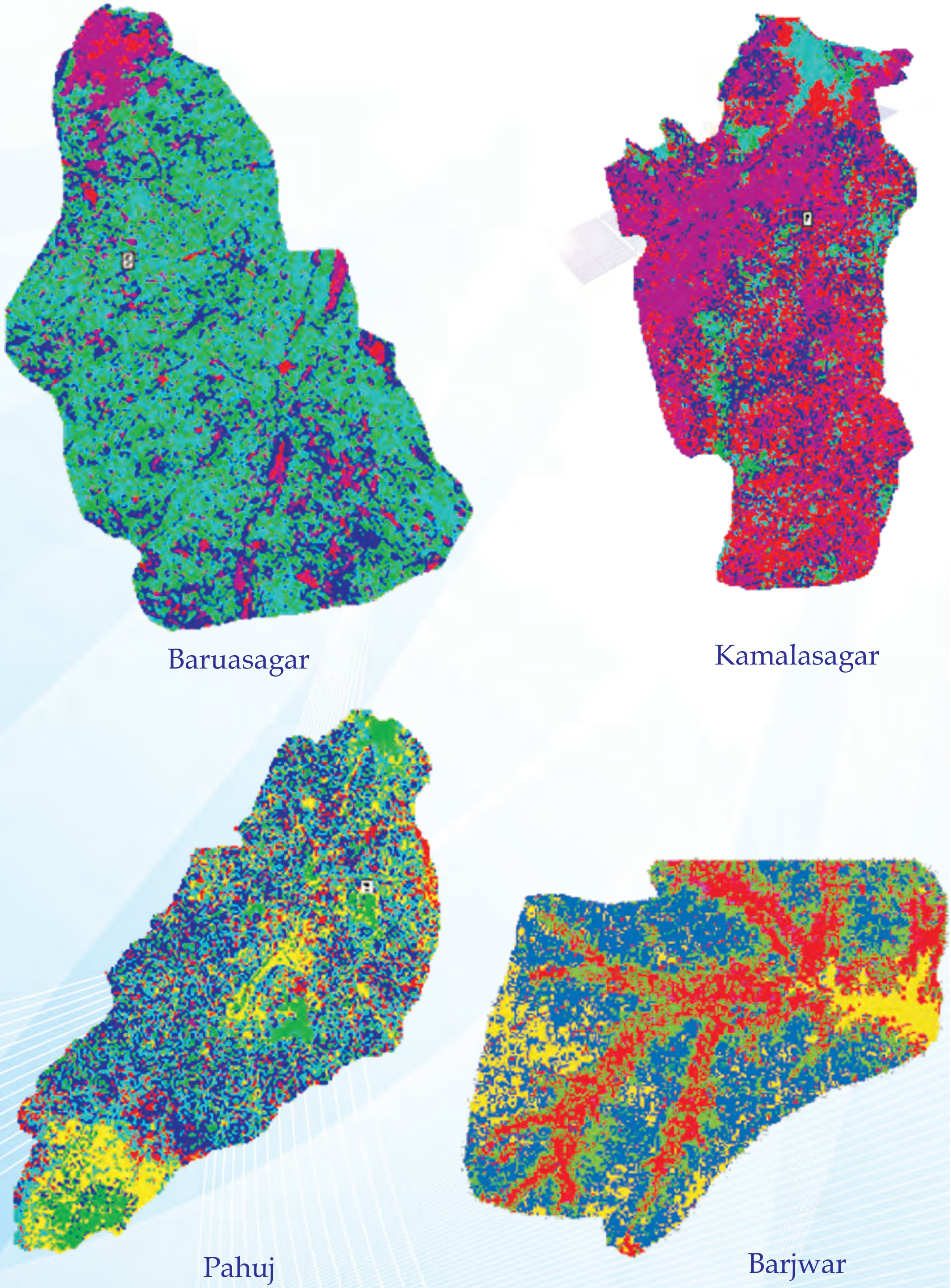

Fig. 8.

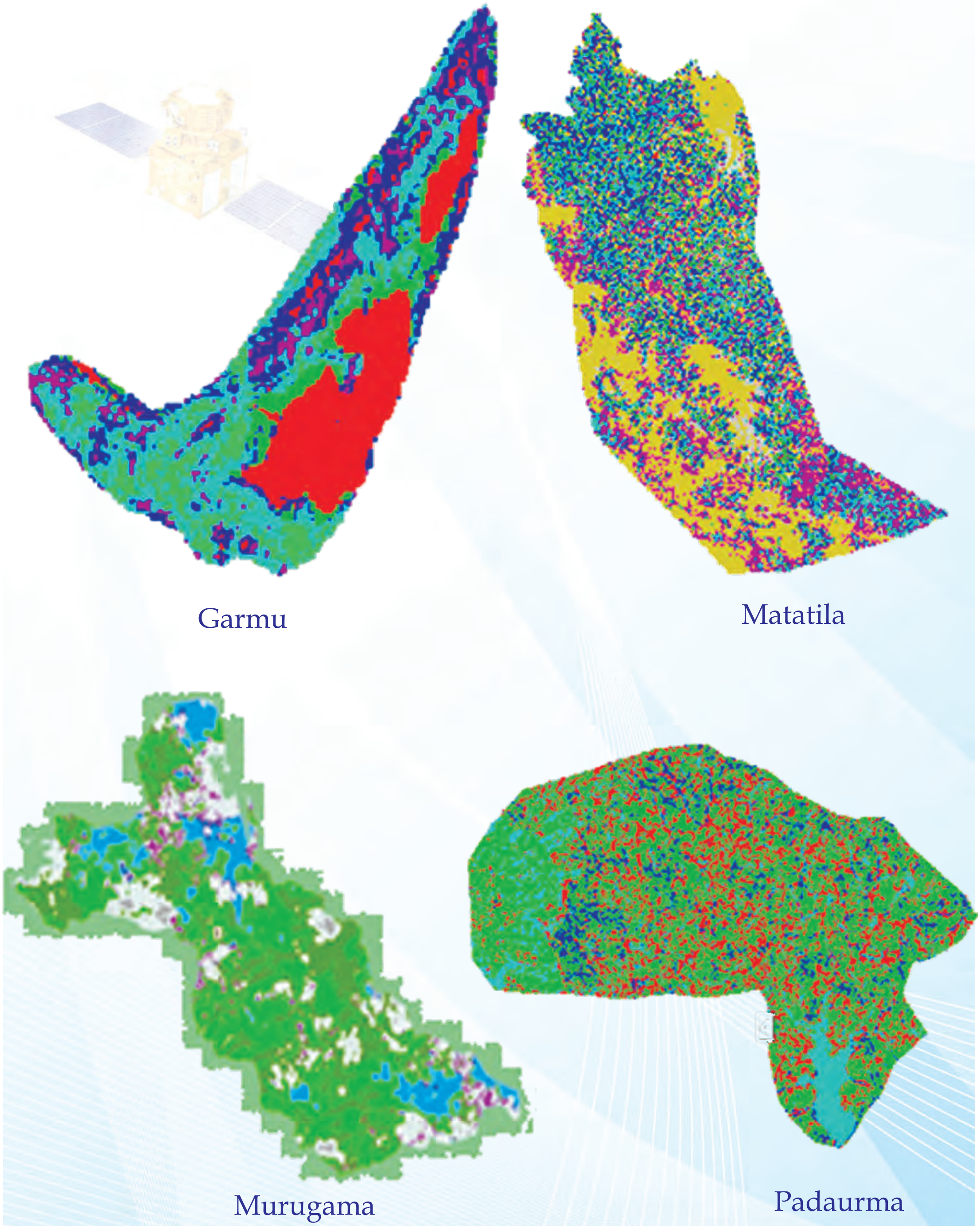

Fig. 8. Group of water bodies having 2^{nd} order streams in their catchment area

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