Review Article

Technologies for enhancing water productivity through remote sensing and GIS

ABSTRACT

Water is the essential component of the agricultural system as well as another biota so that precisely management needs to save it for the future generation. So many types of water problems are there on the earth to affect the ecosystem whereas some dangerous problems are created by the uneven management of water such as flood, drought, metallic contamination, water pollution, wastage of water, and drainage, etc. Remote sensing and GIS technology are important and useful tools for the sustainable agricultural management system. The integrated use of remote sensing and GIS technology in several areas for the sustainable agricultural management system in India. Even with their importance, data required monitoring the productivity of land and water resources over the vast areas are usually not available or accessible. Satellite measurements from the National Oceanic and Atmospheric Administration (NOAA) weather satellite are combined in this study with the ancillary *in situ* data into a Geographic Information System (GIS). Remote sensing measurements are converted to crop yield, to actual evapotranspiration and indirectly to the net groundwater use. The GIS data consist of canal-water deliveries and rainfall records. For each of the canal commands, the productivity of water is calculated. Maximum variability in the data is found from different canals commands area in the Indus basin. It has resulted that water productivity is being controlled by the crop yields than by water input. Remote sensing and GIS technology are being effectively utilized in India in several areas for sustainable agricultural development and management. The areas of sustainable agricultural development include cropping system analysis, agro-ecological zonation, quantitative assessment of soil carbon dynamics and soil productivity, soil erosion inventory, integrated agricultural drought assessment and management and Integrated Mission for Sustainable Development (IMSD). Remote Sensing and GIS

technology demonstrated to be an effective tool for suggesting action plans or management strategies for agricultural sustainability of any region.

Key Words: IMSD, Integration, NOAA, Sustainable agriculture, Rainfall

Introduction

The demand for water has increased greatly, while the available amount of water is limited worldwide. There is an ever-increasing competition for water among agriculture, industry and domestic use. It is estimated that domestic and industrial water use~~s~~ will increase by 15% of the available water resources in 2025 against the present use of 3%. Managing water resources is a major challenge for the country. Water resources development calls for addressing the key issues of storage, conversation and subsequently utilization. Most major irrigation projects worldwide employ extensive open channel conveyance systems to distribute available water supply to farmers. The conveyance systems, associated irrigation systems and the engineering work are used to redirect water resources to be used for irrigation constituting the system infrastructure.

The sustainability of irrigation projects of this type depends to a great extent on the ability of ~~the~~ conveyance system to economically satisfy farm water needs and to ensure maximum utilization of water commanded for irrigation purposes. Space technology plays a crucial role in managing country's available water resources for evolving a comprehensive management plan in suitable conservation and utilization of water resources. Systematic approaches involving judicious combination of conventional ground measurements and remote sensing techniques pave way for achieving optimum planning and operational of water resources projects. The synoptic and repetitive coverage provided by the satellites can effectively complement the conventional data to monitor the progress and impact of the above projects.

Thus, remote sensing imagery from the polar orbiting satellites is a potential tool for mapping and monitoring of many water resources management projects. The principal crops include wheat, maize, rice, cotton, sugarcane, oilseeds, fruits, vegetables and pulses. There have been noteworthy improvements in productivity of some commodities like wheat, cotton and sugarcane during the last three decades. Water is allocated to canals and watercourses in fixed proportion on the basis of cultivable commanded area. Within a watercourse command, it is distributed amongst the farmers on a fixed turn system. The World Bank estimates that presently 80 countries of the world have been facing water shortage that poses threat to health and economy since 1990. The human use of freshwater has increased from 500 km^3 per year to around 2500 km^3 per year at present. Consequently, at this rate, the usage will doubled in the next 20 years. However, the supplies cannot cope with such a rising demand and the increasing scarcities are inevitable, regardless of whether change might change the rainfall patterns. Within the agricultural sector, the contribution from crop production is about 52%, while livestock contributes almost 44%. Water is considered to be a limiting factor for crop production in the country. Moreover, field application efficiency prevailing in the conventional flood irrigation method is very low because the fields are not properly levelled and their size is not in related to the with stream size. The new technologies like GIS dotted other countries to raise their agriculture production. GIS is a computer software with many existing applications in various domains including agriculture is as one of them. Using field data and images processed by GIS it can assist in management of environmental problems.

Water Resources

Remote sensing in combination with the Global positioning system (GPS) and Geographical Information System (GIS) produces terrain maps at the given accuracy and contains detailed information on variables in the study area. In India, satellite remote sensing technology is being used effectively in a variety of areas including irrigation performance evaluation, snowmelt-runoff forecasts, reservoir sedimentation, watershed treatment, drought monitoring, flood mapping and management, to mention a few.

The continuous increase in data volume available from the Indian Remote Sensing Satellites – IRS-1A, 1B, P2, 1C, P3, 1D and P4 (Oceansat) have facilitated operationalizing of many application areas under the aegis of the National Natural Resources Management System (NNRMS). Space technology applications capabilities are being further enhanced by the series of new satellites with increasing spatial, spectral and temporal resolution. The more recent IRS satellites – the RESOURCESAT (IRSP6) offers multispectral data at a resolution of better than 6 m from LISS-IV and large area coverage with high repeatability from the AWiFS payloads and the CARTOSAT-1 has a PAN camera of 2.5 –m resolution with a stereo view. Thus, the IRS constellation has become one of the most versatile remote sensing satellite series, offering a wide range of data and services to meet the variety of applications. Thus multiple satellites concurrently in operation and steerable sensor systems enable dynamic coverage of specific areas. In complement to these developments in ~~the~~ space segment, we are witnessing a dramatic improvement in the ground segment, paying the way for planning, execution and monitoring of water resources projects of different magnitudes.

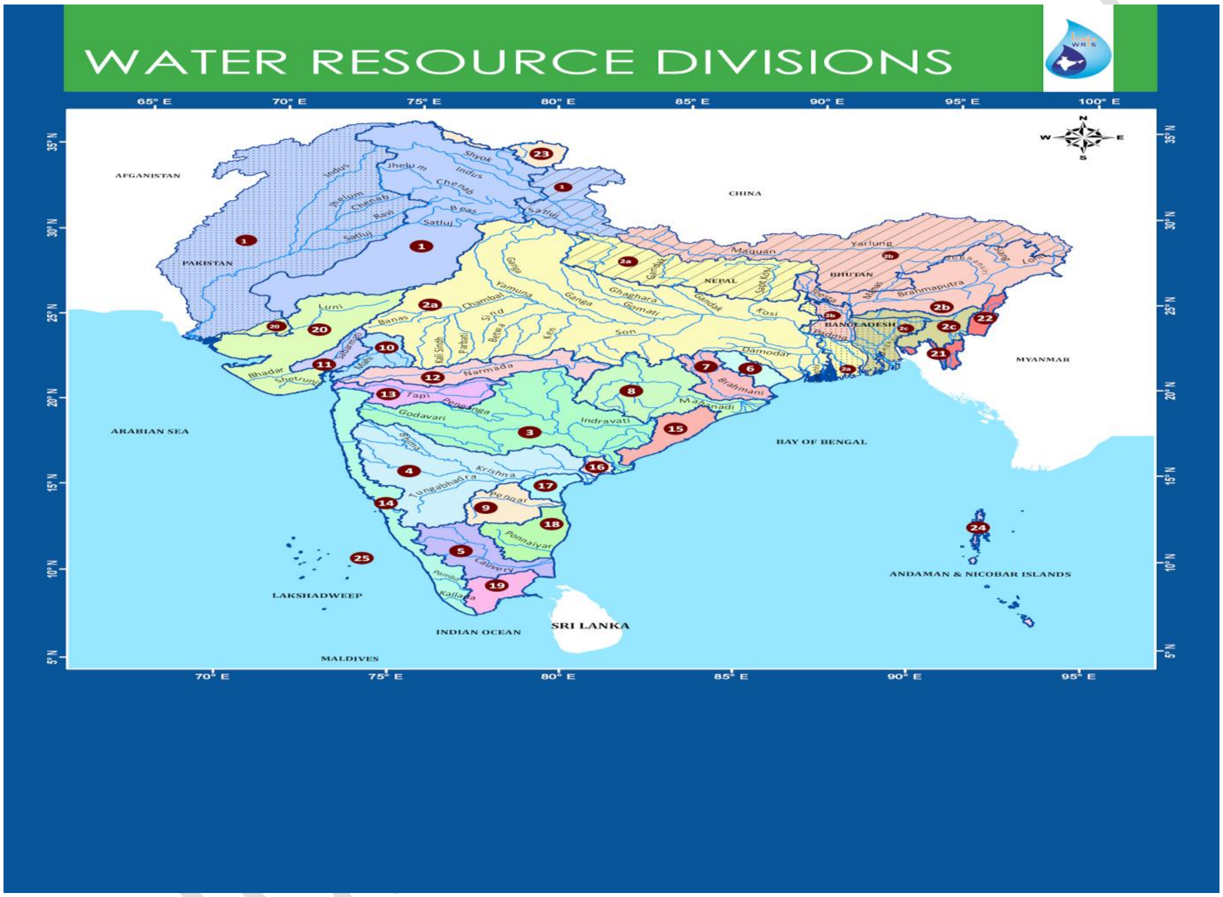


Fig 1. Water Resource Division

Trans-boundary Basins of India

Basin Name	Trans-boundary Basins		
	India	Drainage coming from other countries	Drainage flowing to other countries
Ganga			
Indus			
Brahmaputra			
Barak and others Basin			
WFR of Kutch and Saurashtra including Luni			

Fig 2: Trans-boundary basins of India

Concept of watershed~~:-~~ Watersheds play a critical role in ~~the~~ natural functioning of the Earth. Thus, it is considered as one of the primary planning units in the field of natural resource management. Watershed approach is more rational because land and water resources have optimum interaction and synergetic effect when developed on the watershed basis. The hydrologic unit boundary is important for determining what areas are involved in contributing runoff, sediment, and pollutants. The watershed or hydrological unit is considered as a scientific and appropriate base for necessary surveys and investigations for assessment of natural resources and subsequent planning and implementation of various development approaches. Drainage basin or hydrologic-unit maps are necessary tools for many water resource studies, such as flood assessments, water quality sampling, water use reporting, watershed protection, conservation planning, and resource management.

Watershed boundaries define the aerial extent of land surface from which the runoff flows to a defined drain, channel, stream or river at any particular point. It is a general phenomenon governed by the topography of the terrain. The boundary between the two adjacent watersheds is called drainage divide line. Pour point is the point at which water flows out of the area. This is the lowest point in elevation along the boundary or drainage lines. Depending on the size and topography, watersheds can contain numerous tributaries, such as streams and ditches, and ponding areas, such as detention structures, natural ponds and wetlands. Boundary of any watershed plays an important role because hydrologic processes can be described, and to some degree controlled or managed within a watershed. As watershed boundaries are scalable, ~~in that~~ one can define a watershed size to be large enough to exhibit or accommodate the ecological processes of interest. Multiple sizes of watersheds can be delineated, and they can be nested for hierarchical analysis. Each sub-basin has been divided into a number of watersheds, which are the small-sized hydrologic units in the lower level category based on the pour points. The topography and hydrological features as well as area criteria have been considered for placing appropriate pour points. Watersheds are delineated from upstream to downstream. In total 4566 watersheds have been delineated from the above sub-basins.

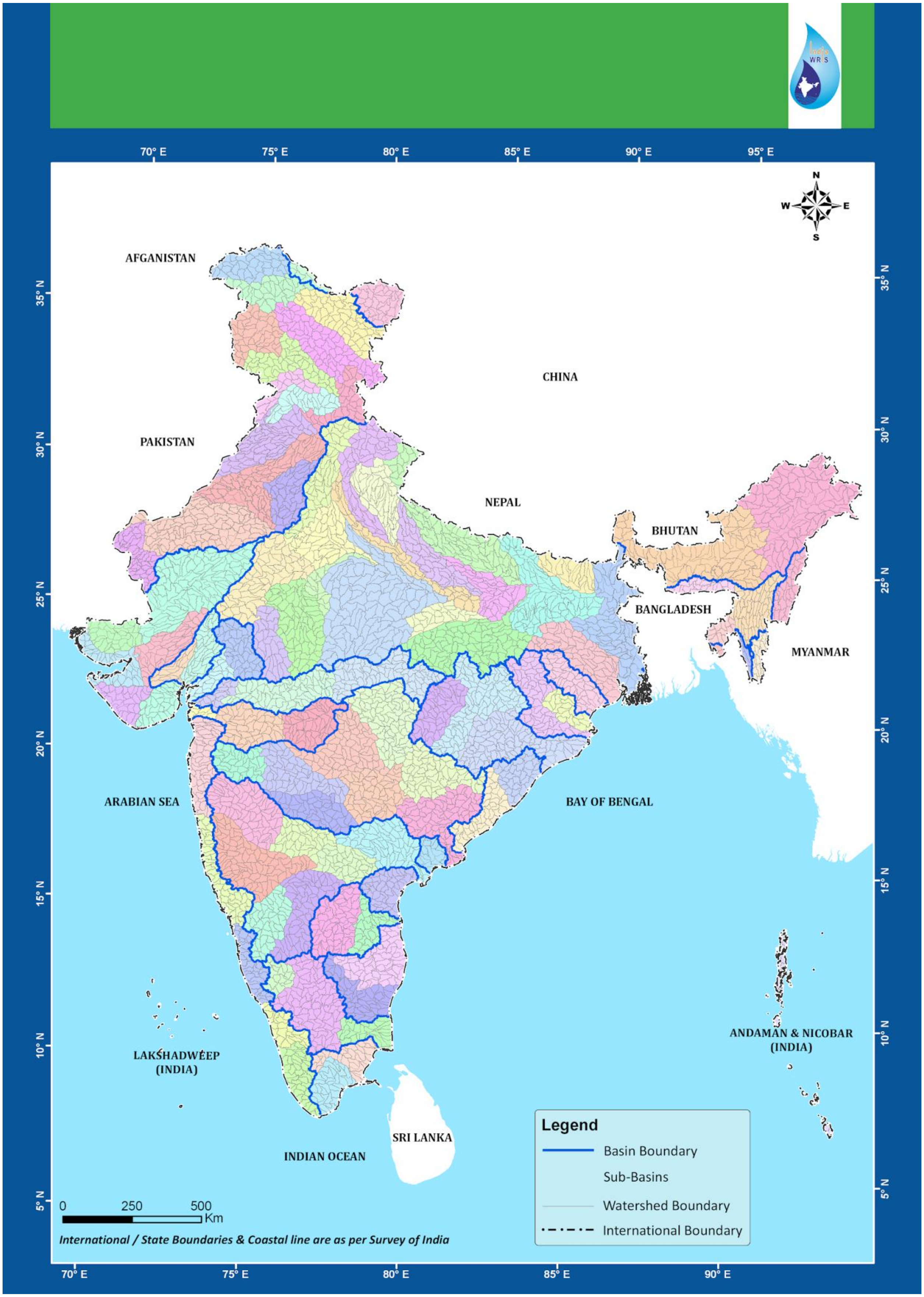
Table 1: Basin wise watershed of India

Name of Basin	
1.	Indus
2.	Ganga
3.	Brahmaputra
4.	Barak
5.	Godavari
6.	Krishna
7.	Canvery
8.	Subermarekha

9.	Brahmani & Baitarni
10.	Mahanadi
11.	Pennar
12.	Mahi
13.	Sabarmati
14.	Narmada
15.	Tapi
16.	West flowing rivers south of tapi
17.	East flowing rivers between Mahanadi & Godavari
18.	East flowing rivers between Godavari & Krishna
19.	East flowing rivers between Krishna & Pennar
20.	East flowing rivers between Pennar & Canvery
21.	East flowing rivers south of Canvery

22.	West flowing rivers of kutch & South Saurastra including luni
23.	Minor rivers draining into Bangaladesh
24.	Minor rivers draining into Myanmar
25.	Area of north ladakh not draining into Indus
26.	Drainage area of Andman & Nicobar Islands
27.	Drainage area of Lakshadeep islands

Fig 3: Watershed of India



70° E
75° E
80° E
85° E
90° E
95° E
35° N
30° N
25° N
20° N
15° N
10° N
5° N
N
W
E
S
AFGANISTAN
CHINA
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
MYANMAR
ARABIAN SEA
BAY OF BENGAL
LAKSHADWEEP (INDIA)
ANDAMAN & NICOBAR (INDIA)
SRI LANKA
INDIAN OCEAN
Legend
Basin Boundary
Sub-Basins
Watershed Boundary
International Boundary
0 250 500 Km
International / State Boundaries & Coastal line are as per Survey of India

Ganga Basin- The Ganga basin spreads in India, Tibet (China), Nepal and Bangladesh over an area of 10,86,000 km^2. In India, it covers states of Uttar Pradesh, Madhya Pradesh, Rajasthan, Bihar, WestBengal, Uttarakhand, Jharkhand, Haryana, Chhattisgarh, Himachal Pradesh and Union Territory of Delhi draining an area of 8,61,452 km^2, which is nearly 26% of the total geographical area of the country. The basin lies between the 73°2' to 89°5' E and 21°6' to 31°21' N having a maximum length and width of approximately 1,543 km and 1024 km. The basin is bounded by the Himalayas on the north, by the Aravalli on the west, Vindhyas and Chota Nagpur plateau on the south and Brahmaputra Ridge on the east. The Ganga rises in the Gangotri glacier in the Himalayas at an elevation of about 7,010 m in the Uttarkashi district of Uttarakhand. At its source, the river is called the Bhagirathi. It descends down the valley up to Devprayag where after joining another hill stream Alaknanda, it is called Ganga. The total length of river Ganga (measured along the Bhagirathi and the Hooghly) up to its outfall into the Bay of Bengal is 2,525 km. The principal tributaries joining the river from the right are the Yamuna and the Son. The Ramganga, the Ghaghra, the Gandak, the Kosi and the Mahananda join the river from the left. The Chambal and the Betwa are the two other important sub-tributaries. The major part of the basin in Indian territory is covered by agricultural land accounting to 65.57% of the total area and 3.47% of the basin is covered by water bodies.

Salient Features of Ganga Basin

Basin Extent

- Longitude- 73° 2' to 89° 5' E
- Latitude - 21° 6' to 31° 21' N
- Length of Ganga River (Km)- 2525
- Catchment Area (~~Sq.~~km^2)- 861452
- Average Water Resource Potential (Million m^3)- 525020
- Utilizable Surface Water Resource (Million m^3)- 250000
- Live Storage Capacity of Completed Projects (Million m^3)- 42060.2
- Live Storage Capacity of Projects Under Construction (Million m^3)- 18600.18
- Total Live Storage Capacity of Projects (Million m^3)- 60660.38
- No. of Hydrological Observation Stations- 318
- No. of Flood Forecasting Stations- 83

Table 2: Water Resource assets

S.No	Name of Sub-basin	Area (Km^2)	No. of Dam	No. of Reservoirs	No. of Surface water bodies
1.	Above Ramganga Confluence	39104.61	3	7	945
2.	Banas	51651.61	76	172	16624
3.	Bhagirathi & other (Ganga lower)	64038.97	12	12	77873
4.	Chambal lower	10941.26	3	10	1198
5.	Chambal upper	25546.57	31	31	4878
6.	Damodar	41965.49	39	29	51641
7.	Gandak & others	56260.43	30	21	24116
8.	Ghaghara	58634.18	11	15	5622
9.	Ghaghara confluence to Gomti confluence	26254.06	12	19	5903
10.	Gomti	29865.21	0	0	2006
11.	Kali Sindh & other upto confluence with parbati	48492.61	125	106	6468
12.	Kosi	18413.58	0	0	20696
13.	Ramganga	30839.69	11	12	1786
14.	Sone	65110.05	159	149	27469
15.	Tons	16905.74	32	29	5214
16.	Upstream of Gomti confluence to	29061.37	14	13	2057

	Muzaffarnagar				
17.	Yamuna lower	124867.19	201	199	16022
18.	Yamuna middle	34586.39	19	22	3576
19.	Yamuna upper	35798.19	6	14	2842

Source:- watershed atlas of India (2012)

Table 3: Watershed Statistics

S.No	Name of Sub-basin	No. of Watershed	Mini. size of Watershed (Km^2)	Maxi. size of Watershed (Km^2)	The average size of Watershed (Km^2)
1.	Above Ramganga Confluence	51	430.18	1301.20	766.76
2.	Banas	64	330.66	1432.97	807.05
3.	Bhagirathi & other (Ganga lower)	75	308.24	1754.95	853.85
4.	Chambal lower	14	405.59	1135.93	781.52
5.	Chambal upper	30	405.14	1403.97	851.55
6.	Damodar	60	326.14	1301.09	699.42
7.	Gandak & others	76	334.87	1308.88	740.27
8.	Ghaghara	76	374.93	1300.49	771.50
9.	Ghaghara confluence to Gomti confluence	36	372.40	1761.77	729.28
10.	Gomti	41	333.29	1333.50	728.42
11.	Kali Sindh & other upto confluence with parbati	64	429.86	1275.01	757.70
12.	Kosi	19	303.77	1694.96	969.14

13.	Ramganga	40	350.05	1442.76	770.99
14.	Sone	83	380.66	1389.01	784.46
15.	Tons	23	442.40	1173.36	735.03
16.	Upstream of gomti confluence to Muzaffarnagar	40	364.16	1281.12	726.53
17.	Yamuna lower	98	735.54	1781.43	1274.15
18.	Yamuna middle	43	410.43	1232.25	804.33
19.	Yamuna upper	47	321.77	1241.11	761.66

Source: Watershed Atlas of India (2012)

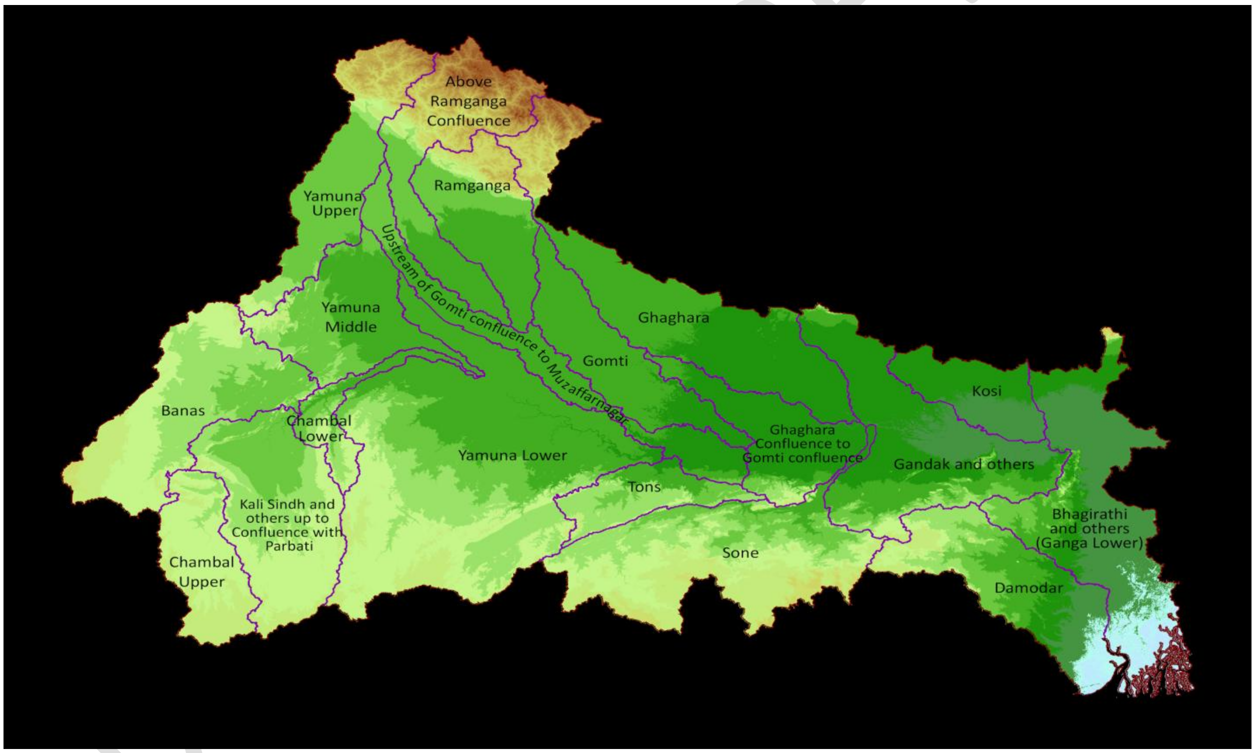
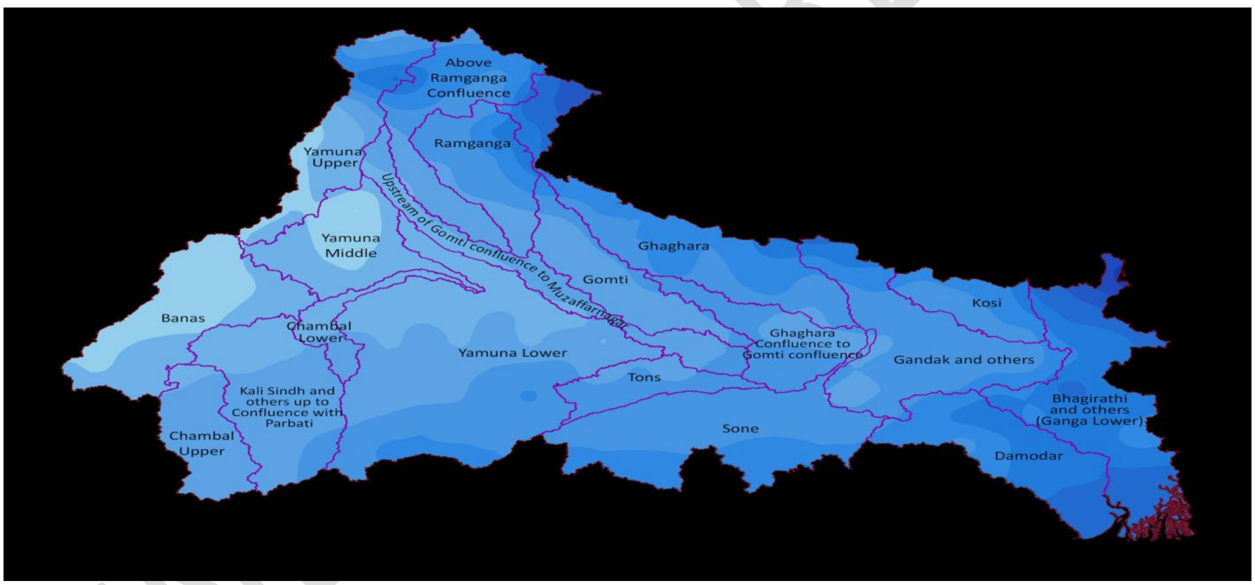


Fig 4. Elevation Zone

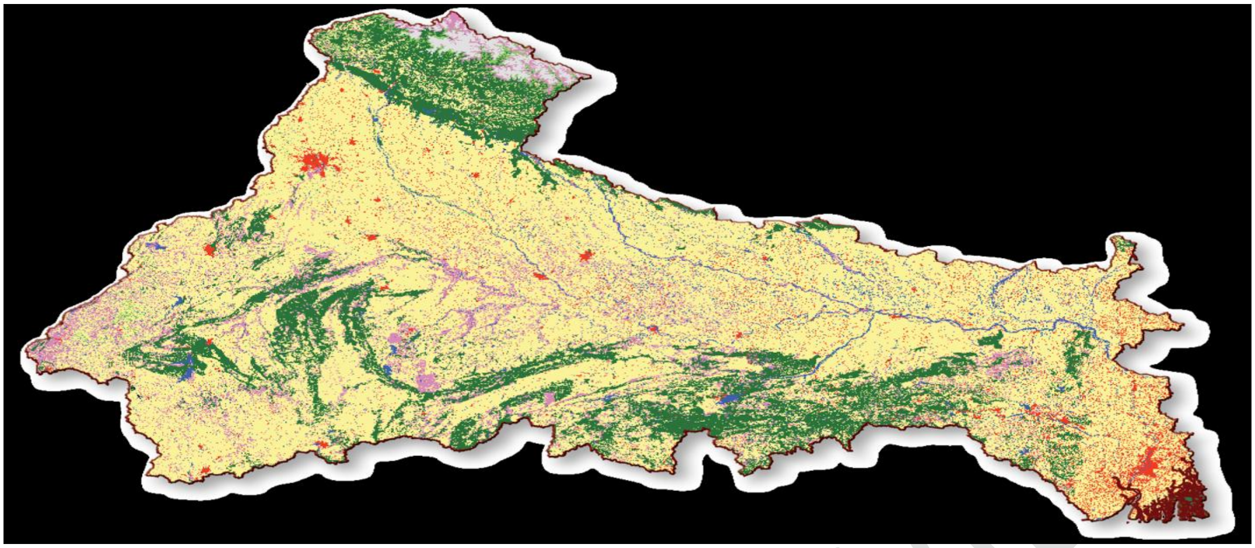
Symbol	Elevation (m)	Area (Sq. km)	% of Total Area
	< 5	10441.16	1.21
	5-10	8320.58	0.97
	10-50	58940.57	6.84
	50-100	122902.46	14.27
	100-200	200790.42	23.31
	200-300	123124.65	14.29
	300-400	105002.90	12.19
	400-500	114920.62	13.34
	500-750	59722.04	6.93
	750-1000	8741.36	1.01
	1000-1500	11636.73	1.35
	1500-2000	10699.95	1.24
	2000-3000	9540.63	1.11
	3000-4000	4886.73	0.57
	4000-5000	6320.05	0.73
	5000-6000	5096.32	0.59
	6000<	364.83	0.04

Fig 5. Average annual rainfall (1971-2005)



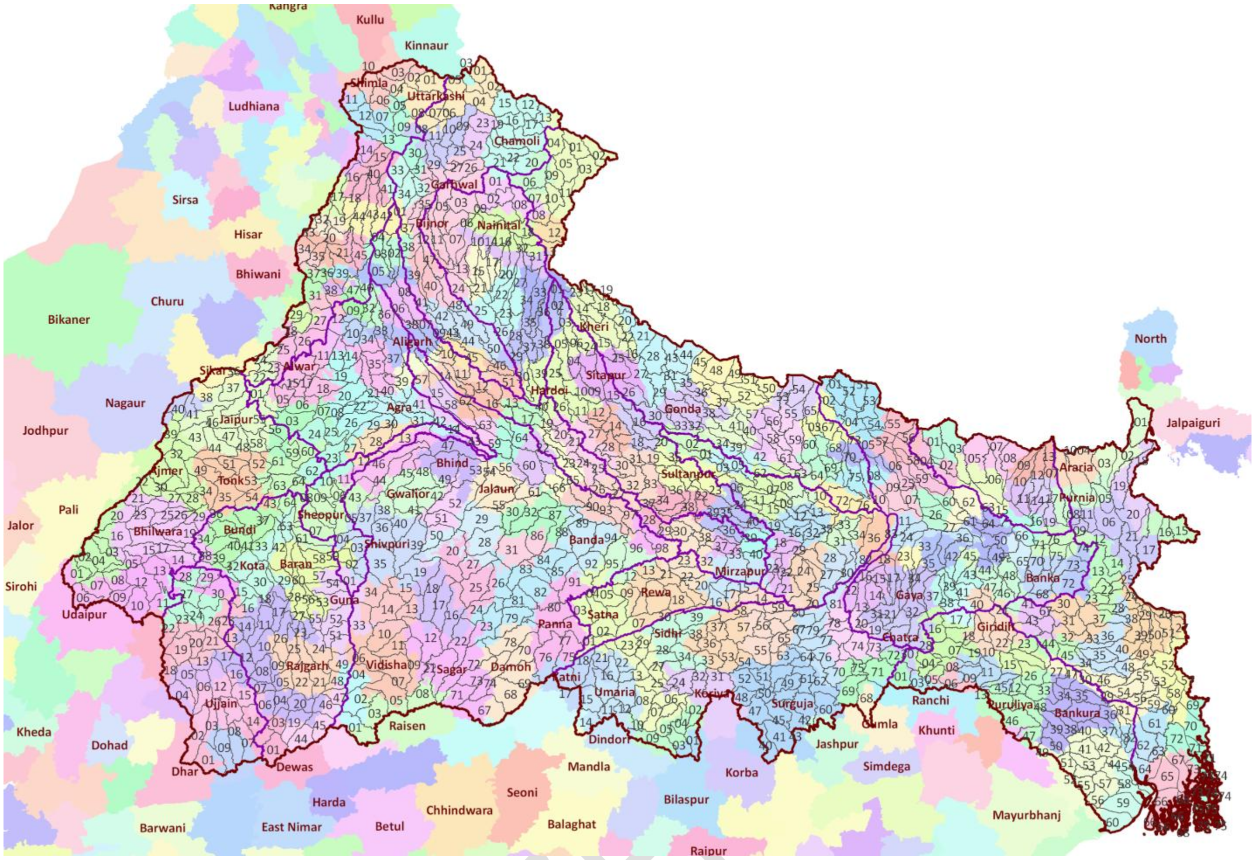
Symbol	Rainfall (mm)	Area (Sq. km)	% of Total Area
	400-600	51801.50	6.01
	600-800	133582.47	15.51
	800-1000	199380.12	23.14
	1000-1200	235227.30	27.31
	1200-1400	123142.02	14.29
	1400-1600	73770.83	8.56
	1600-2000	36637.34	4.25
	2000-2500	5390.68	0.63
	2500-3000	2016.69	0.23
	3000-4000	503.07	0.06

Fig 6. Land Use/ Land Cover (2005-2006)



Symbol	Category	Area (Sq. km)	% of Total Area
	Built Up Land	36908.24	4.28
	Agricultural	564866.02	65.57
	Forest	137816.45	16.00
	Grassland	7324.27	0.85
	Wasteland	76603.61	8.89
	Waterbodies	29876.51	3.47
	Snow/Glaciers	8056.90	0.94

Fig 7. Districts



Water Resources Management issues through Space Technology

Space-borne spectral measurements have been used for the following goals:

(i) rainfall estimation, (ii) snow and glacier studies leading to snowmelt runoff forecasting, (iii) irrigation water management and identification of potential irrigable lands, (iv) reservoir sedimentation, (v) watershed management, (vi) disaster management, (vii) water quality assessment, (viii) ground water assessment and prospecting, (ix) planning and implementation of developmental activities, (x) infrastructure development, (xi) disaster management and environmental monitoring.

Airborne laser based terrain mapping (ALTM), in conjunction with detailed mapping through the digital camera, and traditional photographic survey provide valuable information on terrain characteristics in terms of topography, association, detailed land use/cover, geological features, etc. for water resources infrastructure projects viz. Interlinking of Rivers Project (ILR).

A. Rainfall

Rainfall is one of the most important processes in the hydrological cycle. At the same time, it is also one of the most difficult phenomena to monitor. Since the late 1960s, many researchers have attempted to derive techniques for the estimation of rainfall from the visible and infrared imagery provided by meteorological satellites. Manual, interactive and automatic methods have been developed for the estimation of rainfall at a number of temporal and spatial scales, and these have been applied in many different areas and situations with varying degrees of success. More research is needed to determine the best method of incorporating typically sparse "point" ground station measurements into homogenous and extensive satellite estimate fields. Snow and glacier investigations and snow melt runoff forecasting are yet another area where satellite remote sensing imagery is providing information on retreading glaciers as well as possible potential snow melt run-off. Seasonal and short-term (weekly) forecasts of snowmelt runoff have been provided for Sutlej and Beas and Parabati basins in Western Himalayas by the National Remote Sensing Agency since the 1970s.

B. Irrigation management

India, the ultimate irrigation potential has been estimated at 140 Mha. The irrigation potential created up to 2004 is 98 Mha. While enormous irrigation potential has been created at a huge cost, the gap between the created potential and utilization is significantly large (around 9 Mha). Thus, along with the thrust towards the creation of higher irrigation potential, efforts are also needed to be directed to optimal utilization of the created potential.

C. Reservoir capacity monitoring.

A National action plan of sedimentation survey of 124 reservoirs using remote sensing technology has been taken up in India during the 10 five year plan. Inappropriate land use practices in the upstream catchment leads to accelerated soil erosion and consequent silting up of reservoirs. Watershed management is thus an integral part of any water resources project. Space borne multispectral data have been used to generate baseline information on various natural resources, namely soils, forest cover, surface water, ground water and land use/land cover and subsequent integration of such information with slope and socioeconomic data in a GIS to generate locale-specific prescription for sustainable development of land and water resources development on a watershed basis. The study covering around 84 M~~-~~ha and spread over 175 districts has been taken up by the Department of Space, Government of India under a national level project titled “Integrated Mission for Sustainable Development (IMSD)”. The implementation of the appropriate rain water harvesting structures in selected watersheds under this programme has demonstrated ~~the~~ significant benefits by way of the increased groundwater recharge and agricultural development of once barren areas. Multi-year satellite data is also used to monitor the impact of the implementation of watershed management programs.

D. Groundwater prospecting

During the past one-and-half decades, it has been demonstrated that satellite imagery is highly useful in mapping and targeting groundwater prospective zones. Under the National Drinking Water Technology Mission, the Department of Space with the active cooperation of various user departments has prepared district-wise hydro-geo-morphological maps on a 1:250,000 scale covering all 447 districts in the country using satellite imagery with limited field checks and available information. These maps have been found to be very useful in narrowing down ~~the~~ target zones and selection of sites for drilling besides their usefulness in regional / district level planning and identifying alternate sources of drinking water for many problem villages across the country. In order to provide safe drinking water to rural masses, the Department of Space has taken up a project titled "Rajiv Gandhi Drinking Water Mission". This project aims at generating groundwater prospects maps at a scale of 1:50,000 using the IRS-1C/1D LISS-III data for the entire country. Ten states, namely Rajasthan, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Karnataka, Jharkhand, Orissa, Gujrat, Himachal Pradesh and Kerala have been covered so far.

E. Natural calamities

In the event of natural calamities that adversely affect water security, like drought, flood and cyclones, space technology has made substantial contributions in different phases such as preparedness, prevention and relief. The Earth Observation satellites, which include both geostationary and polar orbiting satellites, provide comprehensive, synoptic and multi-temporal coverage of large areas in real time and at frequent intervals, thus, have become valuable tools for continuous monitoring of atmosphere as well as surface parameters related to droughts and floods.

Geo-stationary satellites provide continuous and synoptic observations over large areas of weather including cyclone tracking. Polar orbiting satellites have the advantage of providing much higher spatial resolution images that could be used for detailed monitoring, damage assessment and relief management. Satellite images have been found to be of immense help in providing early information and monitoring accidental water resources events. Though sitcom-based applications for the management of water resources in the country had a modest beginning with Central Water Commission (CWC) and Snow and Avalanche Study Establishment (SASE) have deployed INSAT- DRT based DCP services for real time hydro-meteorological data collection, they are expected to assume greater significance in the context of proposed interlinking of rivers Programme.

Future perspective

Since the modest beginning of surface water inventory, the remote sensing application scenario has witnessed a phase transition from resource mapping to decision-making. Remote sensing has thus become one of the most important tools for evaluation of the physical attributes of water and land resources in the country. A number of case studies on command area development, groundwater inventory, canal alignment, irrigation performance evaluation, etc., have proved beyond doubt that integration of remote sensing and conventional approach significantly decrease the cost and time involved as well as~~,~~ improve the steadfastness. Various issue related to the topographic~~al~~ surveys, water resource assessment, Information on Command area Expansion (command area surveys), Planning of New Storage Reservoirs, stabilizing existing enroute command areas, reservoir sedimentation, geological and geomorphological surveys, etc., can be suitably addressed through the satellite/aerial-derived data. Satellite remote sensing along with the appropriate collateral data enable the inventory of quantity, quality as well as values of the resources. The repetitive nature of the space-based Earth observation provides a unique opportunity to do accounting on a periodic basis.

Water is a major input in agriculture and its relative availability in different agro-climatic zones calls for efficient water resource development plans. There is a close relationship between water scarcity and reduced food productivity, mainly applicable to the rain-fed areas of the country. The water resource development on a watershed basis has shown encouraging results in mitigating the water need in water-stressed agriculture. Major institutional, policy and technological initiatives are therefore required to ensure the efficient, socially equitable and environmentally sustainable management of water resources towards achieving water security along with food security for the country.

For ensuring sustainable water security, water resource management in the country needs to be planned and implemented within the framework of integrated resource management, which requires consideration of a range of impacts, sometimes extending far beyond the immediate hydrological system, and over considerable time periods. Spaceborne multispectral measurements have in some cases replaced ground-based observations and in others complemented at varying levels. Improved spatial, spectral and temporal resolution data from present IRS satellites together with aerial remote sensing provides a unique opportunity towards comprehensive monitoring of water resources dynamics in the country.

(Ref: Indo-US Workshop on Innovative E-technologies for Distance Education and Extension/Outreach for Efficient Water Management, March 5-9, 2007, ICRISAT, Patancheru/Hyderabad, Andhra Pradesh, India Proceeding Paper - Remote Sensing and GIS - Water Management by P.S. Roy and V.V. Rao)

Application areas of Remote Sensing in Agriculture

The interpretation of remotely sensed images may provide valuable information to the Agricultural Engineer, some of which are discussed below for various fields of applications.

- Command area development & Irrigation Engineering. Crop areas, Crop yield, Crop growth condition, Crop areas that are water-stressed and are in need of water. Estimating the amount of irrigation water that is to be supplied to an irrigated area over different seasons. Location and alignment of field channels and structures.

- Hydrology & Watershed management. Different types of soils, rocks, forest and vegetation of a watershed, soil moisture. Estimating runoff from a watershed, where the land-cover type and soil moisture would decide the amount that would infiltrate. Estimating soil loss and capacity reduction of reservoirs. Identification of drought periods and planning mitigation measures.

- Reservoir sedimentation. Plan views of reservoir extent at different times of the year and over several years. Estimating the extent of sedimentation of a reservoir by comparing the extent of reservoir surface areas for different storage heights.

- Drainage of the flooded area, Flood inundated areas, Flood plain mapping and zoning for the design of drainage, Planning surface/ subsurface drainage.

Water Resources Project Planning in Remote Sensing and GIS in Water productivity

Identification of wasteland, mapping of infrastructure features like existing roads, embankments, canals, etc. apart from the plan view of a river. Recent information helpful in planning and designing a water resources project based on the present conditions of the project area.....

- Water availability and demand and Nations.
- Irrigation projects and schemes of India.
- Concepts and definitions.
- Command Area Development and Water Management.
- On-Farm-Development works.
- Water Productivity.

- Tank & Tube well irrigation.

Conclusions

At the tail end, the vegetation growth is less than that in the middle side of the canal embankment. After the lining of the canal more vegetation. More water and more healthy crops. The performance evaluation has shown the discrepancies and relative ranking of the distributaries vis-à-vis crop water requirements.

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