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Theme Paper ***Theme VIII***

Role of remote sensing and geographical information system (GIS) in water resources management

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Abstract
Since water is life and the crisis is about not having water but managing water badly. The management of water can be improved by using the space technology couple with geographic information system. In this review paper the advances in the space technology in the field of water resources are discussed in two parts as hydrologic elements such as precipitation, infiltration / soil moisture and evapotranspiration. In addition to this operational applications of remote sensing such as Runoff and Hydrological modelling, Flood Management, Watershed Management, Drought Monitoring, Reservoir Sedimentation, Irrigation water Management, Water Quality etc. are discussed. The trend of the technology is towards integrating the satellite derived input into a geographic information system and using it more spatially than conventional point data in hydrology. The future direction is that with the availability of high resolution satellite data more cartographic information is extracted and integrated with the satellite data for better planning and management of water resources.

INTRODUCTION

Water is life, in all forms and shapes. This basic yet profound truth eluded many of us in the second half of the 20 th century. Water professionals and scientists around the world were ringing the alarm bells of an impending water crisis. Yet attempts to address some of the issues or to offer partial solutions met with limited success. The ever-growing world population and the concomitant expansion of agriculture and industry have placed increasing demands on the limited water resources. (WRI, 1992).

"*There is a water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people—and the environment—suffer badly*". (World Water Council, 2000)

Global Scenario
Global population is expected to reach 8 billion by 2020, with most of the increase being in the developing countries. This will lead to a decline in per capita availability of arable land and clean water. About 12 % of the world's total land surface is employed presently

for cultivation of crop species. According to FAO, (FAO, 1990) an additional 2.0×10^{12} sq. m. of new crop land would be required over the next 30 years to feed the increasing population, given the available food production trends (Fig. 1). (Rao, 1999)

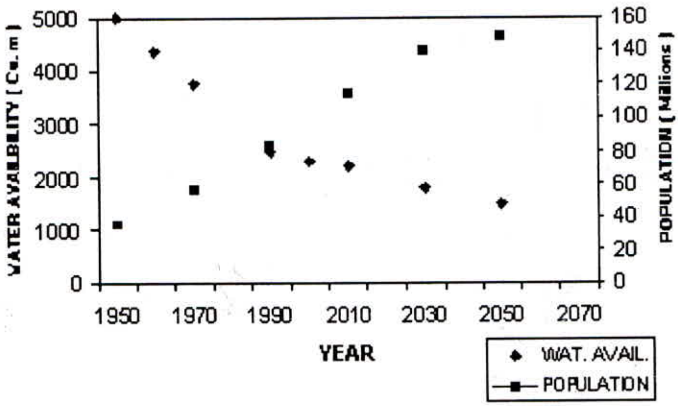

Figure 1. Population growth and water availability in India.

Indian Scenario

The water resources of India is given in Box 1.

Box 1. Water Resources of India – A Glance.

Total Rainfall	*- 4813 billion cu.m.*
Natural Runoff (Surface & Ground Water)	*- 1869 billion cu.m.*
Estimated Utilisable Surface Potential	*- 690 billion cu. m.*
Ground Water Resource	*- 432 billion cu. m.*
Available Groundwater Resource for Irrigation	*- 361 billion cu. m.*
Net Utilisable Ground Water Resources for Irrigation	*- 325 billion cu. m.*
Groundwater provision for Domestic, Industrial and Other (Source : ICID, March, 1998)	*- 71 billion cu. m.*

While the total availability of water presently shows a comforting picture, its spatial and temporal distribution, however, is incompatible with the consumption patterns. There is thus an urgent need for planning and operation of irrigation schemes, water supply to towns and industries, coping with natural disasters such as drought and flood, maintaining acceptable water quality for human and other uses, designing and operating conveyance system, etc. based on reliable and objective assessment of quantity and quality of water resources (Mohile et. al., 1996).

The appropriate technology is satellite remote sensing (RS) technology which plays a major role in combination with the Geographic Information System (GIS) technology. Remote sensing has a great deal of promise for hydrology, mainly because of the potential to observe areas and entire river basins rather than merely points. In this review, the different hydrologic variables or processes related to the water and energy cycle: that is precipitation, snow, evapotranspiration, etc.using remote sensing and GIS and also the operational applications of remote sensing and GIS in hydrology such as Runoff and Hydrological modelling , Flood Management, Irrigation Water Management, Watershed Management, Drought monitoring, Reservoir sedimentation and Water Quality and also the scope of future direction.

Hydrologic variables or processes :	Operational Applications :
Rainfall, Snow & Glacial Studies	Runoff and Hydrological modelling
Infiltration / Soil Moisture	Flood Management
Evapo-transpiration	Watershed Management
	Drought Monitoring
	Reservoir Sedimentation
	Irrigation water Management
	Water Quality

HYDROLOGIC VARIABLES OR PROCESSES

Rainfall, Snow and Glacier studies

Recognizing the practical limitations of rain gauges for measuring spatially averaged rainfall over large areas and inaccessible areas, hydrologists have increasingly turned to remote sensing as a possible means for quantifying the precipitation input, especially in areas where there are few surface gauges. Direct measurement of rainfall from satellites for operational purposes has not been generally feasible because of the presence of clouds prevent observation of the precipitation directly with visible, near infrared and thermal infrared sensors. However, improved analysis of rainfall can be achieved by combining satellite and conventional gauge data. Useful data can be derived from satellites used primarily for meteorological purposes, including polar orbiters such as The National Oceanographic and Atmospheric Administration (NOAA) series and the Defense Meteorological Satellite Program (DMSP), and from geostationary satellites such as Global Operational Environmental Satellite (GOES), Geosynchronous Meteorological Satellite (GMS) and Meteosat, and Indian Satellite (INSAT) series. Whereas the visible/infrared techniques provide only indirect estimates of rain, microwave techniques have great potential for measuring precipitation because the measured microwave radiation is directly related to the rain drops themselves.

The GOES Precipitation Index [Arkin, 1979], derived from thresholding the infrared brightness temperature of cloud tops has been used to study the distribution of tropical rainfall. The university of Bristol [Barrett and Martin, 1981 and D'Souza and Barrett, 1988] has led the development of a cloud indexing [Moses and Barrett, 1986] approach, a thresholding [Barrett et al., 1988] approach. Thus rain rates must be established empirically or with cloud models but this method is not restricted to ocean backgrounds and may be the only feasible approach for estimating rain over land with microwave radiometry. Spencer et al [1988] have shown that the DMSP Special Sensor Microwave/Imager (SSM/I) data can identify rain areas and Adler et al, [1992] has used a cloud based model with 85 and 37 GHz SSM/I data to estimate rain rates. Ground-based radar, which is a remote sensing technique, has advanced to an operational stage for locating regions of heavy rain, and for estimating rainfall rates also.

Snow is one of the form of precipitation: however, in hydrology it is treated differently because of the lag between when it falls and when it produces runoff, groundwater re-charge, and is involved in other hydrologic processes. Remote sensing is a valuable tool for obtaining snow data for predicting snowmelt runoff as well as climate studies. Rango [1993] presents a good review of the status of remote sensing in snow hydrology. Depending on the need, one may like to know the areal extent of the snow, its water equivalent, or the ``condition" or grain size, density and presence of liquid water. The main properties which are used in snow studies are albedo and emissivity.

Currently using NOAA satellite images snow mapping in several regions of the world is in progress for about 3000 river basins in North America of which approximately 300 are mapped according to elevation for use in stream flow forecasting [Carroll, 1990]. Microwave remote sensing offers great promise for future applications to snow hydrology because it provides information on the snowpack properties such as snow cover area, snow water equivalent (or depth) and the presence of liquid water in the snowpack which signals the onset of melt [Kunzi et at., 1982].

Early use of remote sensing for snow melt runoff forecasting focused on empirical relationships between snow cover area or percent snow cover and monthly or accumulated runoff [Rango et al, 1977, Ramamoorthi, 1987]. On the other hand the Snowmelt Runoff Model (SRM) [Martinec et al, 1983] was specifically developed for using remote sensing of snow cover by elevation zone as the primary input variable. SRM has been extensively tested on basins of different sizes and regions of the world [Rango 1992, WMO 1992]. Although SRM is a degree day model that uses only snow cover as remote sensing derived input, energy balance models [Leavesley and Stannard, 1990 and Marks and Dozier, 1992] are able to use additional remote sensing data such as albedo and other energy balance parameters.

Infiltration / Soil Moisture

After the precipitation, infiltration is the phenomena where water percolates into the earth surface occurs. Conventional methods of measuring soil moisture includes tensiometry, neutron probes, gravimetric soil samples analysis, soil lysimeters and soil electrical resistance (Wheeler and Dun Can, 1984) as these field methods provide point data rather then areal values. Thus soil moisture measurements by remote sensing is advantageous for many applications. As infiltration is dependent on several factors such as soil texture, landuse, slope etc. it is essential to have the spatial information of all the parameters. As an example the infiltration process is described by the Philips Infiltration Model (Sullivan et.al., 1996). Field tests were conducted to calculate sorpitienty and hydraulic conductivity, and this point data is combined with the GIS database to develop map of the watershed which delineates areas of low and high potential infiltration.

Advances in remote sensing have shown that soil moisture can be measured by a variety of techniques. The remote sensing applications using the mid-infrared band (MIR) have been the main focus of research.(Moore et. al 1975; Curran, 1975; Knao et. al, 1985; Evertt et. al, 1989). Landsat MIR data may provide useful information for monitoring regional scale (1- 10^4 km^2) surface soil moisture conditions. (Sun F Shish et. al , 1992, Sun F Shish et. al , 1993, Hari Prasad, V, 1997). However, only microwave technology has demonstrated a quantitative ability to measure soil moisture under a variety of topographic and vegetation cover conditions so that it could be extended to routine measurements from a satellite system [Engman, 1990].

Currently, the European Remote Sensing (ERS-1) C-band and Japanese Earth Resources Satellite (JERS-1) L-band SAR and Canadian RADARSAT (also C-band) are operating. Although it is believed that an L-band system would be optimum for soil moisture, the results from the ERS-1 demonstrate its capability as a soil moisture instrument. Change detection techniques have been used to detect changes in soil moisture in a basin in Alaska [Villasenor et al., 1993].

Evapotranspiration

In general, remote sensing techniques cannot measure evaporation or evapotranspiration (ET) directly. However, remote sensing does have two potentially very important roles in estimating evapotranspiration. First, remotely sensed measurements offer methods for extending point measurements or empirical relationships, such as the Thornthwaite [1948], Penman [1948] and Jensen-Haise [1963] methods, to much larger areas, including those areas where measured meteorological data may be sparse. Secondly, remotely sensed measurements may be used to measure variables in the energy and moisture balance models of ET.

Radiometers aboard satellites measure the radiance in visible, infrared and microwave region and are able to monitor the reflected and emitted radiation components of irrigated lands. Attempts to transfer the spectral radiance into evapotranspiration maps of potential (eg. Meneti and Azzali, 1992) and actual (Jackson, 1977). The availability of low resolution satellite images such as NOAA-AVHRR and METEOSAT images with high temporal availability has made it possible to develop a physical process based Surface Energy BALance (SEBAL) (Bastiaanssen, 1998). Using the satellite data and ground measured meteorological data several parameters required for the model such as net radiation, sensible heat flux and soil heat flux are derived. The table 1 provides the requirement of the data for the components of energy balance.

Table 1. Data requirements Parameters Derived for Energy Balance Components.

COMPONENT	PARAMETER DERIVED	INPUT FROM	
		REMOTE SENSING DATA	METEOROLOGICAL DATA
In coming Short Wave Radiation	Atmospheric transimissivity		Sunshine hours
Out going Short Wave Radiation	Surface Albedo	VIS, NIR Images	
In coming Long Wave Radiation	Net emissivity		Relative humidity, air temperature
Out going Long Wave Radiation	Surface emissivity	NDVI, Surface temperature	
Sensible head flux (H)	Surface temperature	Thermal band image, surface emissivity	Air temperature, wind velocity
Soil head flux (G)		Surface albedo, NDVI	Air temperature

A schematic diagram representing the methodology of the SEBAL algorithm is shown in Fig 2.

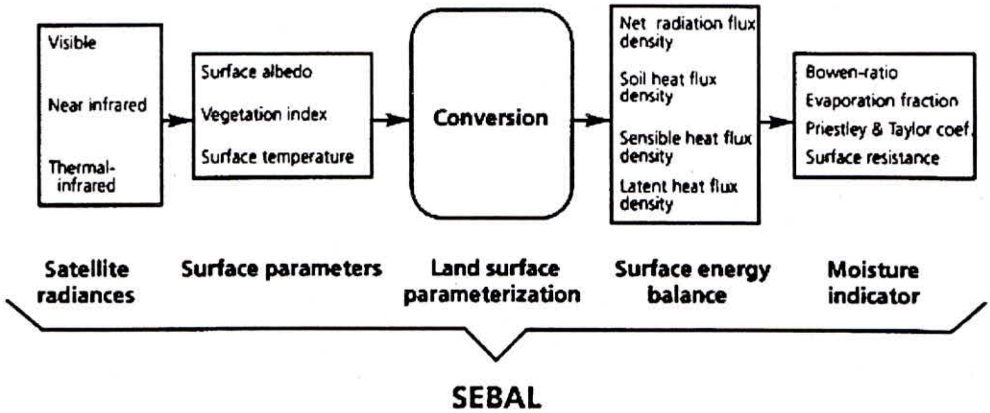

Figure 2. Principal components of the Surface Energy Balance Algorithm for Land (SEBAL) which converts remotely measured spectrally emitted and reflected radiance's into the surface energy balance and land wetness indicators.

The components of Energy balance calculated using the SEABAL algorithm in Nagwan watershed, Damoder Valley, Bihar State, India is shown in Fig. 3. (Personal communication).

OPERATIONAL APPLICATIONS

Runoff and Hydrological Modelling

Runoff cannot be directly measured by remote sensing techniques. However, there are two general areas where remote sensing can be used in hydrologic and runoff modeling: (1) determining watershed geometry, drainage network, and other map-type information for distributed hydrologic models and for empirical flood peak, annual runoff or low flow equations; and (2) providing input data such as soil moisture or delineated land use classes that are used to define runoff coefficients.

In many regions of the world, remotely sensed data and particularly Landsat, Thematic Mapper (TM) or SPOT MLA data, and Indian Remote Sensing Satellite data (IRS) is used for extraction of drainage basin areas and the stream network etc. Quantitative geomorphic information can also be extracted from Landsat imagery [Haralick et al., 1985]. Topography is a basic need for any hydrologic analysis and modeling. Remote sensing can provide quantitative topographic information of suitable spatial resolution to be extremely valuable for model inputs. For example, Panchromatic stereo imagery from IRS – 1C or IRS – 1D can be used to develop a Digital Elevation Model (DEM) with 5.8 m horizontal resolution. A new technology using interferometric SAR has been used to demonstrate similar horizontal resolutions with approximately 2 m vertical resolution [Zebker et al, 1992]. Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration. Distributed models, in particular, need spatial land use information. Most of the work on adapting remote sensing to hydrologic modeling has involved the Soil Conservation Service (SCS) runoff curve number model [U.S. Department of Agriculture, 1972] for which remote sensing data is used to derive the land cover maps [Jackson et al, 1977, Bondelid et al, 1982]. Mettel et al, [1994] demonstrated the recomputation of pmf's for the Au Sable River using Hydrologic Engineering Center (HEC-1) and updated and detailed land use data from Landsat TM resulted in 90% cost cuts in upgrading dams and spillways in the basin. Similar studies have been carried out using satellite data derived landuse information and GIS techniques for deriving the input parameters required for HEC- 1 model (Hari Prasad et.al, 1997) in Indian case studies.

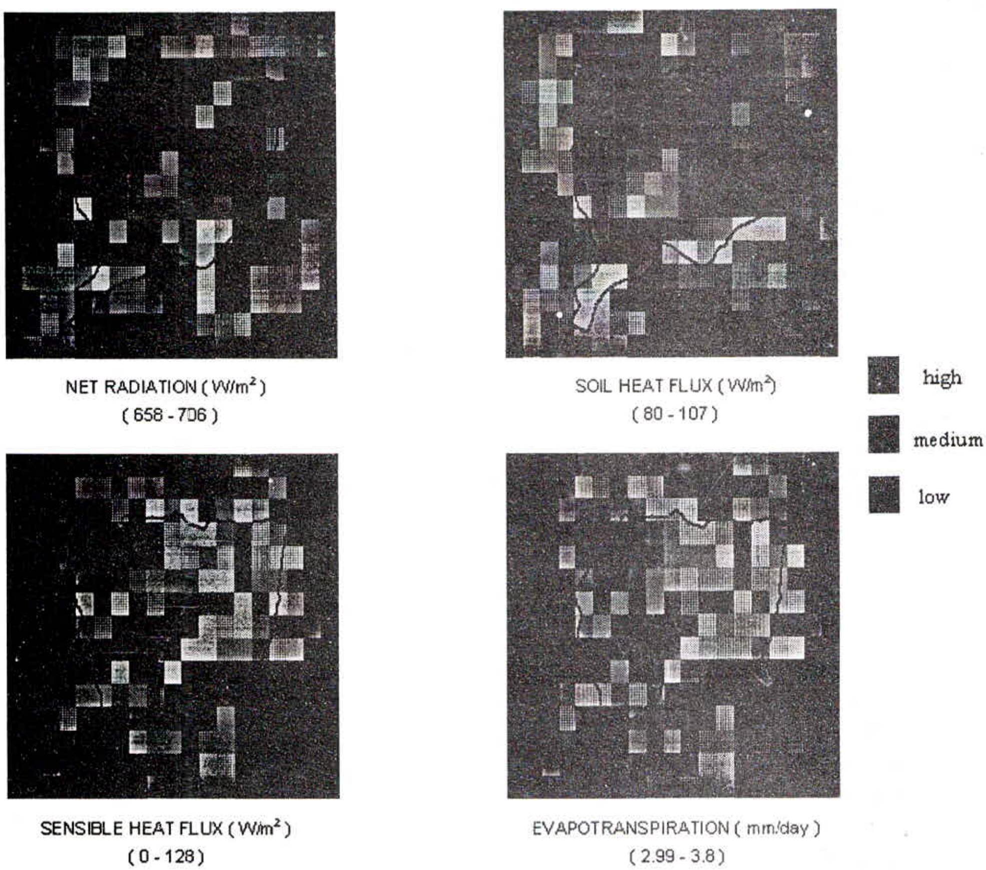

Figure 3. Energy balance components (26.1.95) Nagwan watershed, Damodar valley.

The GIS can be used to combine spatial data forms such as topography, soils maps as hydrologic variables such as rainfall distributions or soil moisture. This approach was demonstrated by Kouwen et al, [1993] where their Grouped Response Unit (GRU) included satellite based land use and lies within a computational element that may be either a sub basin or an area of uniform meteorological forcing. In a study of the impact of land use change on the Mosel River Basin, Ott et al, [1991], and Schultz, [1993] have defined Hydrologically Similar Units (HSU) by DEM data, soils maps and satellite derived land use. They also used satellite data to determine a Normalized Difference Vegetation Index (NDVI) and a leaf Water Content Index (WCI) which are combined to delineate areas where a subsurface supply of water is available to vegetation. Mauser [1991] has shown how multi-temporal SPOT and TM data can be used to derive plant parameters for estimating ET in a GIS based model.

Flood Management

India is one among the disaster prone geographical zone of the world and suffers losses worth more than $ 300 million as a result of flood and cyclone damage annually. It is also Worst flood affected country after Bangladesh. (Agarwal and Narain, 1991) and accounts for one fifth of global death count due to floods. About 40 million hecates (mha) or nearly 1/8 th of India's geographical area is flood prone and the country's vast coast line of 5700 km is exposed to tropical cyclones arising from Bay of Bengal and Ariabain Sea.

Space technology has made substantial contribution in every aspect of flood management such as preparedness, prevention and relief (Rao, 1994). Information acquired by remote sensing covers wide area, periodicity and spectral characteristics and especially in the easiness to compare the data before and after a disaster. The utility of the satellite remote sensing has been operationally demonstrated for mapping the flood inundation areas, major floods and cyclones that occurred in the country were mapped in near real time and information was provided to the departments concerned. Even partially cloud free data is acquired and analysed and interpreted and flood maps were prepared in near real time. During 1993 flood season attempts were made in advance to procure ERS-1 C band SAR which has got cloud penetration, covering flood affected areas and flood maps were prepared.

Watershed Management

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. The prioritization of watershed i.e. which needs to be paid attention is based on sediment yield potential so that the treatment would result in minimising sediment load into the reservoir. Satellite data have been extensively used in many watershed, namely Jurala, Asan and Ukai for deriving the parameters of the Sediment Yield Index (SYI) model to provide quantitative silt load estimates in watersheds developed by the All India Soil and Landuse Survey, Ministry of Agriculture, Government of India.

Spaceborne 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 socio-economic data in a Geographic Information System (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 carried out by the Department of Space, Govt. of India under a national level project titled "Integrated Mission for Sustainable Development (IMSD)". Implementation of appropriate rain water harvesting structures in selected watersheds under this programme has demonstrated the significant benefits by way of increased ground water 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 programmes.

Drought Management

Drought is one of the worst natural disasters affecting the social and economic life of millions of people every year. The World Meteorological Organisation estimated that in the quarter of a century since 1967 to 1991 droughts have affected 50% of the 2.8 billion people who suffered from weather related disasters.

Owing to the abnormalities in monsoon precipitation in terms of both spatial and temporal distribution, drought is a frequent phenomena over many parts of India. Out of net sown area of 140 million hectares about 68 % of the area is reported to be vulnerable for drought conditions and about 50% of the drought prone area is classified as severe where frequency of drought is regular. (Rao, 1999).

Timely and reliable information about the onset of drought, its extent, intensity, duration and impacts can limit the drought related losses of life, minimise the human suffering and reduce damage to the economy and environment. Remote sensing data from geo-stationary and polar orbiting weather satellites such as INSAT, NOAA and other global data is used as major inputs to all the three types rainfall and predictions such as long term seasonal predictions, medium range predictions and short term prediction. Vegetation index derived from remote sensing imageries are now being continuously used to monitor drought conditions on a real time basis.

National Agricultural Drought Assessment and Monitoring System (NADAMS) programme evolved by the National Remote Sensing Agency (NRSA), Dept. of Space, provides early warning on expected yields from major crops at district level by end of August, based on the relationship between vegetation index growth profile till end of August and yield. This information is updated by end of September and October with improved accuracy based on the relationship between total crop growth profile and the yield. The NADAMS uses daily NOAA AVHRR (1.1 km) and IRS WiFS (188 m) based biweekly/monthly vegetation index and provides periodic information on crop conditions at district and sub-district level in terms of drought bulletin and detailed reports. Crop Acreage and Production Estimate (CAPE) program is operational for providing production forecast before harvest from major crops in winter season, at district level using high spatial resolution IRS data and ground observed weather data.

Reservoir Sedimentation

Many reservoirs built with huge investment are undergoing rapid silting and loss of storage capacity and consequent reduction in economic life of reservoir. The analysis of sedimentation data of India reservoirs show that the annual siltation rate has been generally 1.5 to 3 times more than the designed rate and the reservoirs are generally losing capacity at the rate of 0.30 to 0.92 % annually. A broad estimate on soil erosion indicate that soil erosion is taking place at the rate of 16.35 tonnes/ha/year, which is more than the tolerance value of 4 -11.2 tonnes/ha/year. As a result, it is estimated that 20 percent of the live storage capacity of these reservoirs would be silted up by 2000 AD resulting in an average loss of 60,000 ha. of irrigation potential every year in India (Dhruva Narayana and Rambabu, 1983). Conventional hydrographic surveys to reassess reservoir capacity are both costly and time-consuming. Multi temporal satellite data have been used an aid to capacity survey of many reservoirs in India such as Hirakund, Bhakra, Pong, Tungabhadra, Malaprabha, Ghataprabha, Osmansagar, Niazamsagar, Himayatsagar and Sriramsagar. While this technique helps in revising capacity table between minimum and maximum draw-down level observed in satellite data, loss of dead storage capacity can be obtained only through conventional hydrographic surveys.

Irrigation Command Area Management

Irrigation tightens the intimate relationship of people (farmers, gate keepers, water policy makers), crops (irrigated areas, crop type, LAI development, yield) and water issues (crop water needs, crop water use, land wetness, water logging). Derivation of different object classes such as Cartography, Irrigated area (mono-crop and multiple crop), crop communities, land cover and use from remote sensing that are useful for irrigation water management. Using remote sensing several biophysical parameters are derived that are useful for irrigation management is given in table 2.

Table 2. Derivation of Biophysical parameters from Remote Sensing that are useful for irrigation management.

Biophysical parameters	Accuracy	Need for field data	Preferred Principle
Fractional vegetation cover	High	None	SAVI (Huete,1988)
LAI	Good	None	SAVI (Huete,1988)
PAR	Good	None	NDVI (Tucker, 1979)
Surface roughness momentum	High	None	Laser altimeter
Surface roughness heat	Low	High	Unresolved
Surface albedo	Good	Low	Two-way transmittance
Thermal infrared surface emissivity	Good	None	Valor and Caselles (1996)
Surface temperature	Good	Low	Single-way effective transmittance
Surface resistance	Good	None	SEBAL (Bastiaanssen,1998)
Crop coefficients :tabulated	Moderate	None	SAVI (Huete,1988)
Crop coefficients : analytical	Moderal	High	LAI (Cleavers, 1988,1989), albedo, roughness, displacement, minimum surface resistance
Transpiration coefficients	Good	None	LAI (Choudhury, et.al 1994)

Because productivity per unit of water is the focal point for evaluation of irrigation water management, regional yield data must be linked to regional consumptive use of water. The advantage of using remote sensing determinants is that they are based on standard international diagnostic techniques and that time-series measurements can be obtained from repetitive satellite coverage.

Water Quality

Nearly one million children in India die of diarrhea disease each year directly as a result of drinking unsafe water and living in unhygienic conditions, some 45 million people are affected by water quality problems caused by pollution, by excess fluoride, arsenic, iron or by the ingress of salt water. Remote sensing of water quality can complement ground efforts in mapping and monitoring point and non-point pollution sources, the influx and dispersal of pollutants in the aquatic environment and consequent impact such as algal blooms and weed growth (UNICEF, 1998). Point source identification call for high spatial resolution satellite data. Aerial surveys with multi-spectral scanners have demonstrated how the pollution influx and dispersal in riverine and lacustrine environment could be monitored. Salinity intrusion into estuary can be studied using airborne spectral measurements. Growth of aquatic weeds and algal blooms, as indication of eutrophication, have been mapped from satellite and aircraft data. The GIS technology provides enhanced capability for water quality modeling.

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