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REMOTE SENSING AND GIS APPLICATIONS IN COMMAND AREA STUDIES

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1. INTRODUCTION

Development of agriculture depends on the development of irrigation. Availability of irrigation is the first and foremost requirement for promoting technologically superior agriculture. Wherever irrigated agriculture has been practised successfully, the population has increased, lived in better health and has made great strides culturally. However, in the present scenario of growing demand of food for the rapidly increasing population, the agricultural production has also to be increased. Irrigation water and cultivable land are the most important resource inputs into irrigated agriculture system.

Irrigation and agriculture projects cover large geographic area, involve a large number of users and such projects require large investments. Despite large investments made in the irrigation sector, the return from the investments in terms of the yields are not commensurate and there is poor utilisation of the potential created. Due to inefficient irrigation water distribution mechanism, excess water is used at the head end of the command area in the belief that more water increases the yield. The tail-end of the command area is deprived of irrigation facilities. By excess irrigation, the area in the command gets waterlogged resulting in salinity development. An estimate reveals that in India, 18% of 25 major command areas have become waterlogged in 13 states.

Modern irrigation aims at high efficiency of water application on farms so as to minimize the losses and to provide higher yield. Scientific improvements in irrigation management and agricultural practices are essential for increasing crop production and decreasing the menace of excess irrigation at some place and water deficiency at other place. A knowledge of soil-water-plant relationship is necessary for planning efficient irrigation. Too little water supplied to the farmer is as detrimental as excess water supplied in a cropping time. The farmers need correct quantity of water at specified times on an assured basis. This highlights the necessity of systematic command area development program.

Information is vital in reducing uncertainty, evaluating alternative courses of action and revealing new avenues. Availability of the right information at the right time to the right person and at the right cost is a crucial factor in decision making. For any command area development program, information on existing land use/cover, cropping pattern, soil characteristics and their spatial distribution is a prerequisite. These data and information need to be carefully, effectively and efficiently analyzed, stored and retrieved whenever required. The conventional procedure of storing, handling and updating records is slow, un-systematic, occupy large space and requires huge manpower. Further, such records are rarely updated. With the advent of remote sensing and GIS tools, it has become possible to prepare the dynamic resource maps at various levels of confidence. Remote sensing provides multi-spectral and multi-temporal synoptic coverage for the area of interest, while the GIS provide the facilities to integrate and analyze multi-disciplinary data. For natural resource management to be socially acceptable, decision-making must be a public and participatory process. The capability of GIS to express the information in maps and pictures, can make the general public more informed and can involve them in decision making activities.

2. WATER RELATED PROBLEMS IN COMMAND AREAS

History has shown repeatedly that excess water and salt must be removed from soils for irrigation to be permanently successful. Lack of adequate drainage has probably been the greatest single cause of failure of irrigation projects throughout the world. If irrigation is the science of survival it can be said that drainage provides the survival of irrigation. By excess irrigation, large areas in the command area get waterlogged due to rise in the subsoil water table. Waterlogging and inadequate drainage is detrimental for normal crop production. Continued waterlogging results in salinity development and in extreme cases renders the land completely unproductive. Some of the problems arising out of poor management of water resources in a command area are briefly discussed here.

2.1 Waterlogging & Salinity

According to the definition accepted by the National Commission of Agriculture (1978), a soil is waterlogged if the water-table rises to an extent that root zone becomes saturated, diffusion of air is curtailed and amount of oxygen is reduced with increase in carbon dioxide. It is a national problem in India and has been widely reported, especially in the head reaches of canal irrigation commands. A survey in 1983 of the Tungabhadra project in Karnataka found 33,000 ha of land severely affected by waterlogging and salinity, increasing at the rate of 6,000 ha annually. In Haryana where the waters of Bhakra canal were delivered, rising water table created a problem of salinisation. The rising water table in the command of the Mahi-Kadana project in Gujarat has been responsible for patches of salinity. Thus, there can be no question to the fact that waterlogging is a serious and threatening problem and needs to be addressed urgently.

2.2 Deprivation of Tail Ends

Tail ends of main canals, branch canals, distributaries and minors are deprived of the availability of right amount of water at the right time as the excess water is withdrawn in the head reaches. On minors in the Hirakud project, it was found that 70% of the water went to the head reaches with only 30% to the tail reaches. Deprivation is reflected in various indicators including water supply, irrigation intensity, crops grown, cultivation practices, yields and income. Higher valued and more water-intensive crops tend to be concentrated in the head reaches. Sugarcane in the north and west of India, and paddy in the south and east, often shows this pattern.

2.3 Development of Crop Stress

Crop stress is a comprehensive term in which the plant factors indicate when they are stressed. Since the actual spatial demands in a command area are not known, the supply of irrigation water is not supplied in accordance with the real-time demands. Rather, a rotatory irrigation supply system, such as warabandi, is resorted to. Because of this reason, it may happen that crops in an area are more water stressed but could not get water because of the prescheduled supply system. Development of stress results in lower yield and if it is not attended properly, the crops can wilt and get damaged.

3. REMOTE SENSING APPLICATIONS

Remote sensing implies sensing from a distance. Each satellite image is considered as representing a spatial distribution of energy coming from the earth's surface in one or several wavelength ranges of the electromagnetic spectrum. By using multi-spectral satellite data suitably, different ground features can be differentiated and thematic maps can be prepared. Satellite remote sensing measurements have been used to provide regular information on agricultural and hydrological conditions of the land surface for vast areas and have played vital role in developing and monitoring water management plans. The usefulness of remote sensing techniques to obtain information on land use, irrigated area, biomass development, crop type, crop yield, crop water requirements, salinity, and water logging etc. has been demonstrated in various investigations. Such information is potentially useful in water distribution planning, performance diagnosis, and impact assessment.

Remote sensing has several advantages over field measurements. First, remote sensing covers a wide area such as entire river basins/command areas whereas field measurements are often confined to a small pilot area because of the expense and logistical constraints. Second, the information is collected in a systematic way which allows time series and comparison between schemes. Third, the information can be spatially represented and analysed through geographic information systems, revealing information that is often not apparent from field measurements represented in tabular form. Before analysing the applications of remote sensing in irrigated agriculture, a brief presentation of characteristics of some currently available satellite/sensors and their suitability for various applications is also discussed here.

3.1 Satellite systems

Several satellites are now in earth orbit and are designated for measuring certain terrestrial processes. Each satellite has its own characteristics in terms of return period, local overpass time, pixel size and number of spectral bands etc. A fleet of different sensors (sensor is a radiometer that measures electromagnetic radiation in small and finite part of the spectrum) is required to make a range of applications feasible. Some sensors/satellites have only a few bands (IKONOS and IRS-1C/1D have 4 narrow spectral bands and 1 wide band) whereas others have many more bands that enable them to measure in a broader part of the spectrum (MODIS has 36 narrow spectral bands). Visible bands are found in the range between 0.4 and 0.7 μm. The blue band has the lowest wavelength (0.41 to 0.50 μm), followed by the green (0.51 to 0.60 μm) and red band (0.61 to 0.70 μm). The near-infrared bands measure in 0.71 to 1.5 μm range while thermal-infrared band measure between 8 to 15 μm region. Information on basic characteristics of some satellite systems is presented in Table - 1.

Table – 1: Basic characteristics of some currently available satellites

Platform	Sensor	Spatial resolution (m)		Temporal resolution (days)	Image dimensions (km)	Price (US$/km^2)
		Pan	Spectral			
IKONOS-1	-	1	4	3	15	39
SPIN-2	-	2 & 10	-	On request	40	30
SPOT-4	XS	10	20	26	60	1.14
IRS-1C/1D	WIFS	-	1100	5	806	0.001
IRS-1C/1D	LISS	6	23.5	24	141	0.25
LANDSAT	ETM	15	30	16	185	0.018
TERRA	ASTER	-	15, 30	4 to 16	60	Free
TERRA	MODIS	250, 500	1000	1	2330	Free
NOAA	AVHRR	-	1100	0.5	2800	Free
CBERS-2	-	-	80, 160	26	120	0.007

Panchromatic satellite data currently have spatial resolutions of 1 m (IKONOS), 2 m (SPIN), 6 m (IRS) and 10 m (SPOT) and these data are valuable to deduce the location of roads, canals, ditches, boundaries of individual fields, and for describing cartographical changes due to construction and encroachment of built-up areas or deserts. Crop identification at small farm plots (< 0.5 ha) can be done with multi-spectral images of sensors/satellites such as TM, IRS, and SPOT. NOAA-AVHRR is providing remote sensing data on a regular basis at 1.1 km spatial resolution at low costs which makes it suitable for land use determinations of large areas. This sensor allows fast delineation of a basin into major agro-ecosystems, though small-scale activities such as the cultivation of various crop types can not be captured with AVHRR images. A gist of use of various sensors for different aspects of agricultural management is given in Table – 2.

Table – 2: Suitability of current sensors/satellites for agricultural management

Purpose	*LANDSAT-TM*	SPOT	IRS	IKONOS	SPIN	TERRA-ASTER	TERRA-MODIS	NOAA-AVHRR	ERS-SAR
Cartographic information		√	√	√	√				
Irrigation/drainage Canals		√	√	√	√				
Micro-scale salinity/waterlogging		√	√	√	√				
Irrigated area	√	√	√			√	√	√	
Cropping pattern	√	√	√			√			√
Land use	√	√	√			√	√	√	
Leaf area index	√	√	√			√	√	√	
Crop coefficient	√	√	√						

Surface roughness									√
Crop yield	√	√	√				√	√	
Potential evapo-transpiration	√	√	√			√	√	√	
Actual evapo-transpiration	√					√	√	√	
Surface moisture									√
Root-zone moisture	√					√	√	√	
Soil salinity	√	√	√	√		√			√
Water logging	√	√	√	√		√			√

There are a variety of available packages for image processing of satellite data (Bos et al. 2001), ranging from low-cost and simple (MapInfo, IDRISI, ER-Mapper, PCI) to complete and simple (ILWIS, GRASS) and professional and expensive (Erdas-Imagine, IDL-Envi, ArcView-spatial analyst).

3.2 Major applications of remote sensing in irrigation

Advent of remote sensing technology and its great potential use in the field of agriculture have opened new possibilities of improving agricultural statistic system as it offers accelerated, repetitive and spatial–temporal synoptic view in different windows of electromagnetic spectrum. In last few years, remote sensing technology has been increasingly considered for evolving an objective, possibly cheaper and faster methodology for obtaining geographic information on various physical variables. In agriculture, possible applications of remote sensing are in the estimation of land use, irrigated area, crop identification and crop yield estimation, crop stress determination, soil moisture assessment, and estimation of crop ET. Potential applications of remote sensing in irrigation studies are briefly described below:

a) Identification of irrigated areas

Determination of irrigated area using spectral observations provided by MSS, TM, SPOT, LISS etc. has achieved a semi-operational status. The simplest way to discriminate crops and irrigated area is by relying on reflectance spectra (0.4 through 2.5 μm) as there is significant spectral contrast between crops and soils in irrigated and non-irrigated areas. Determination of yearly changes in irrigated areas can be a major remote sensing contribution for better irrigation management.

b) Cropping pattern

Irrigation water allocation is based on information about the irrigated area, crop types, and near-surface meteorological conditions that determine crop water demands. Actual irrigated area may deviate from the original estimates of irrigation command areas. Cropping patterns have been found to change over the years under the influence of price mechanism, infrastructure development, waterlogging, water scarcity, field irrigation and agricultural technology adaptation by farmers etc. Remote sensing has shown great potential in agricultural mapping and monitoring due to its advantages over traditional methods in terms of cost effectiveness and timeliness in the availability of information over larger areas. SPOT, IRS and Landsat multi-spectral data can be used for classifying cropped fields and the type of crop with an overall accuracy of about 85%.

Cropping patterns often comprise many crops which differ in terms of sowing date and phenology. Temporal evolution of amount and colour of foliage is a useful feature for crop discrimination, so multi-temporal sequences of satellite images can be used to measure spectral reflectance at different growth stages.

c) Crop water stress

Spectral reflectance of leaves is very sensitive to water absorption. Continuing water stress leads to observable changes in spectral reflectance of crops. Measurement of spectral reflectance in 0.4 to 12 μm region can be used to study land surface heat balance to obtain estimates of actual evaporation and other indicators of soil water availability. Radiometric temperature provides a measure of difference between actual and maximum transpiration which is related to crop water stress. This, however, applies to a relatively homogeneous canopy.

d) Soil salinity

Statistics about the extent of salt affected soils and the evolution of salinity with time are scarce. A simple combination of multi-spectral bands provides qualitative information about soil salinity, though a quantitative interpretation into salinity classes requires extensive field data. Maps of salt affected areas have been produced using Landsat MSS and TM imagery. For large single-cropped (wheat or maize) irrigated areas affected by salinity, reasonable correlations (with 60% accuracy) have been found between soil electric conductivity and spectral reflectance in visual bands.

e) Soil moisture

Spectral reflectance throughout the whole spectrum is low if water is standing at or near the land surface. A tendency of lower reflectance at increasing wavelength is usually witnessed for open water bodies which makes the classification of ponding layers relatively easy and reliable. Soil moisture can be determined in two manners:

- by means of a radar beam which penetrates through the vegetation and is scattered back after penetrating a few cm into the soil,
- root zone soil moisture as inversely related from the surface energy balance, which describes the moisture content related to root water uptake.

Optical remote sensing is sensitive primarily to the total amount of green vegetation while microwave remote sensing is sensitive to soil moisture, soil type, and salinity. However, active and passive microwave instruments probe only a small soil depth, so their use for irrigation water management is limited as many crops root up to 1 to 2 m depth.

f) Crop evapo-transpiration

Close dependence of surface temperature on actual evapo-transpiration makes thermal remote sensing suitable for crop consumptive use studies.

Bastiaanssen et al. (1998, 2000) have developed Surface Energy Balance Algorithm for Land (SEBAL) for determining actual crop evapo-transpiration for heterogeneous terrain. SEBAL does not require ancillary information on land use or crop type. The model uses NOAA satellite data and can be applied for diverse agro-ecosystems. Results have shown that the error at a 1 Ha scale varies between 10 to 20% and that the uncertainty diminishes with increasing scale.

g) Crop yield

In last few years, different approaches to compute crop yield using remote sensing data have been developed. Simple empirical relationships with spectral vegetation indices (spectral index that identifies the presence of chlorophyll) or the leaf-area index (LAI) have been derived.

Single date Normalized Difference Vegetation Index images acquired during heading stage of grain crops have shown to be closely related to crop yield. However, data from crop cutting experiments are necessary to validate these types of statistical relationships.

h) Performance assessment of irrigation schemes

Performance assessment is an essential component of effective irrigation management. Regular feedback of information from the field into decision-making can substantially improve the performance of water delivery services. However, obtaining repeated objective evaluations about actual field conditions is difficult. Remote sensing provides viable solutions in some situations, allowing repeated sampling of field conditions in units as small as 100 ha. By regularly monitoring field wetness indicators, irrigation manager can modify decisions based on field moisture depletion and evaporation deficit.

i) Miscellaneous other applications

In a number of countries, irrigation fees are assessed on the basis of irrigated area and/or crop type and these data are typically based on statements made by farmers to either Irrigation Authority or Revenue Service. Sometimes, the reliability of this information is not very high. Satellite data provide reliable and cost-effective estimates of cropped area. Estimates of crop coefficients can be obtained using spectral reflectance. The integration of hydrological simulation models with remotely sensed data is a rapidly growing area of research and applications.

To summarize, irrigation systems have received considerable attention for a broad range of remote sensing applications. Several inherent features of irrigated lands such as flat or gentle slope, significant contrast between irrigated and non-irrigated areas, serious water management problems tend to establish areas with open water and salt deposits which are clearly identifiable with simple techniques, and multi-spectral multi-temporal attributes of satellite data have led to the possibility of remote sensing applications. This potential is yet to be fully utilised.

Daily remote sensing observations are available at relatively low spatial resolution (NOAA-AVHRR, TERRA-MODIS), which can be used for large irrigation schemes. The scope of remotely sensed data can be significantly enhanced through integration with other types and sources of data in a GIS environment.

4. GIS Applications

Large amount of multi-disciplinary information pertaining to hydrological, hydro-geological, hydro-meteorological, soil, agronomic, and cropping pattern parameters are involved for irrigation management in a command area. Further, if the database is to handle spatial information, such as satellite imagery and thematic information of various important components of irrigation system, then the amount of data becomes enormous, particularly if the data pertains to a large geographical region. To handle such vast data, there is a need of efficient system by which data types can be stored, retrieved, manipulated, analysed and displayed according to the requirement. This is the purpose of GIS.

A GIS is a computer-based system designed to store, process and analyse geo-referenced spatial data and their corresponding attribute information. It has provided the planners with an inexpensive, rapid and flexible tool for combining earth related facts to create decision alternatives. GIS can assist in water resources management by efficiently handling spatial and temporal information of hydrology and water resources in a command area. Various distributed information relevant to irrigation management include maps depicting topography; soil type; cropping pattern, irrigation and road network; groundwater table; irrigable areas; water bodies cities, towns, villages, and forests etc. The GIS capability to integrate spatial data from different sources, with diverse formats, structures, projections or resolution levels, constitute the main characteristic of these systems, thus providing needed aid for those models that incorporate information in which spatial data has a relevant role. Some of the potential applications of GIS in command area studies are described below:

a) Topographical study

Topographical study for a command area can be easily carried out with the help of digitized contour maps. Digital elevation model (DEM), which is the digital representation of spatial altitudes can be generated in a GIS by interpolating the contour lines of different levels. DEM is one of the most frequently used input map in a GIS. They serve for a wide range of applications. The most important ones include: i) calculation of slope, ii) calculation of direction of slope, iii) calculation of slope convexity/concavity, iv) hill shading, v) generation of 3-dimensional view, vi) calculation of cut and fill (by overlaying two DEMs, and (vii) automatic catchment delineation and drainage pattern.

b) Water resources management

A large number of soil, climatological and crop parameters are involved in water management study of an irrigation command in different time and growth stage of crops. These different layers of information can be easily handled by a GIS. The water balance study, which can determine the real-time spatial demands in a command at any time, shows the stress condition of crops. By knowing the stress condition, type and area of crops, supplementary water requirement can be calculated and priority fixation process for irrigation becomes very easy. Knowing the stress condition, availability of canal water for irrigation, crop area, waterlogged and saline areas, the amount of water and the source of water supply (canal water or ground water) can be determined.

c) Waterlogging assessment

The ground water level at different time periods/season (e.g. pre-monsoon, post-monsoon), which are observed at different observation wells, can be interpolated and the temporal fluctuation of water table can be assessed. Same as for ground levels, Digital Elevation Model (DEM) of ground water levels also can be created. Knowing the grid-wise ground water levels and the surface levels, the depth of ground water at different locations can be determined. Thus, the area affected by waterlogging, or the area likely to be affected by waterlogging in future can be delineated.

d) Soil/Land suitability classification

Soil suitability classification depends mainly on the various soil parameters like effective depth, textural classification, permeability, available water holding capacity, salinity/alkalinity, presence of coarse fragments and stones and erosion status. Land irrigability classification depends on the physical and socio-economic factors also in addition to the soil irrigability classification. Different layers of information can be overlaid to come out with the final classification.

e) Participatory decision-making

For sustainable natural resource management, three components to management practices must occur simultaneously, i.e. they must be ecologically sound, economically feasible and socially acceptable. For natural resource management to be socially acceptable, decision-making must be a public and participatory process. Using GIS in a decision-making process can be extremely effective even in its basic form. The capability of GIS, to express the information in the form of maps and pictures, makes the general public more informed and involves them in decision making activities.

5. Development of an Irrigation System Simulation Model

The importance of conjunctive management of water resources in an irrigation command has long been felt in India. Further, the decision-making process for irrigation management in this country is handicapped with the non-availability of geographic information on real-time basis and the inability to process and analyze vast quantity of geographic data. With the advent of satellite remote sensing, it has now become possible to gather and update information of large areas at regular intervals. Using a (GIS), the spatial information can be efficiently stored, analyzed and retrieved.

There was a need to develop a comprehensive tool (geo-simulation model) that can integrate various processes of irrigation management from micro-scale (field level) to macro-scale (canal system) and can also integrate the real-time information coming from remote sensing observations and the spatial details provided by the GIS to help the irrigation managers in analyzing the system operation under current state of the system and analyze various decision alternatives. Recognizing the need of such a tool, a model [Simulation of Integrated Network of CHAnnels for Irrigation (*SINCHAI*)] has been developed at NIH.

5.1 Brief Description of *SINCHAI*

SINCHAI integrates the information about the actual irrigation demands in the command area, available surface water, canal system details, and the groundwater scenario in the command area and suggests a possible plan of operation of the canal system at weekly time step. The model uses the remote sensing observations for ascertaining the cropping pattern in the command and is linked to GIS database for utilizing the spatially distributed data of different variables (rainfall, soil type, crop type, groundwater conditions etc). By optimally using the canal water and groundwater, it is possible to keep the groundwater conditions in the command within the desirable range while simultaneously spending least amount of power for groundwater extraction.

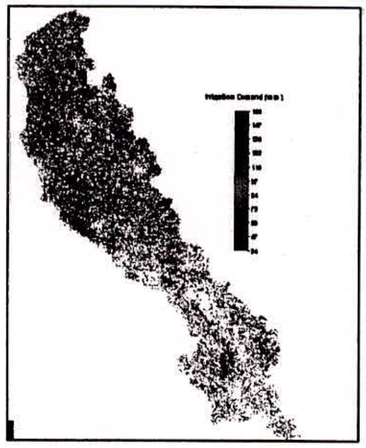

Figure – 1 Irrigation demand map

SINCHAI consists of two major distributed models [Soil Water Balance Model (SWBM) and Canal Network Simulation Model (CNSM)] and a number of sub-models for database generation and linkage. The purpose of SWBM is to simulate the moisture variation in root zone of crops for finding spatially distributed irrigation demands, groundwater recharge, water stress conditions in crops, and soil moisture content at the end of each week. Figure-1 shows the irrigation demands in a command in a particular week.

CNSM is used to analyze various scenarios of canal network operation on the basis of water demands, supply, and system characteristics. For generating revised groundwater conditions corresponding to different canal operation scenarios, an existing groundwater simulation model (Visual MODFLOW) is linked to *SINCHAI*. Figure – 2 shows the canal operation plan corresponding to the irrigation demands, canal water availability, and a specified policy of operation.

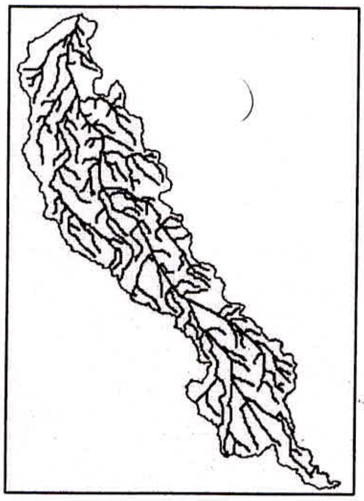

Figure – 2 Canal operation map

To analyze the performance and utilisation of *SINCHAI*, it is applied to Lakhaoti branch canal command (with a gross area of about 1956 sq. km) under the Madhya Ganga Canal System in U.P. State, India. Application of the model is demonstrated for one crop season of a particular year. It is found that under assumed scarcity conditions in one crop season, considerable amount of electricity can be saved under similar conditions of water supply to existing crops by judiciously operating the canal system. Maps corresponding to irrigation demands, groundwater recharge, water stress conditions in crops, various canal operation details, such as discharge and run-time etc. and performance indicators can be prepared with *SINCHAI*.

To summarize, integration of remote sensing and various other spatial ground inputs can be very effectively organized and analysed in GIS environment to find the optimum irrigation water delivery schedules. Remote sensing and GIS has great potential in the scientific and judicious management of water resources in a command area.

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