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Remote Sensing: A Miracle in Irrigation Management

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Abstract **:** ***Managing water for multiple benefits & between competing demands is occupying the minds of irrigators, catchment water managers & policy-makers. Remote sensing techniques are becoming powerful tools for efficient management of irrigation systems in large irrigated areas. This overview of the studies to date indicates that remote sensing-based monitoring of irrigation is at an intermediate stage of development at local scales. Remote sensing applications in irrigation management range from water availability studies in the catchment to the salinity studies in the command area. The objective of this research paper is to present the state of the art on applications of satellite remote sensing that support, management of irrigation systems & to identify emerging approaches that focus on future perspectives of research which may pave the way to operationalise the remote sensing techniques in practice.***

Keywords — RS, Irrigation Management, Precision farming, UMAC model, Future perspectives. IIS, AS, WWD

I. Introduction : World's population figure crossing the six billion mark & expectation of the figure to cross the nine billion mark over the next five decades, have placed the world's food scenario under challehge. Arable land resources being limited, the pressure on current productive land is greater than before. Irrigation produces 30 to 40% of the world's food crops on 17% of all arable land (Seckler et al., 1998). To meet the future demands for food with an increasingly scarce water supply, management of water resources is paramount. When water supplies are abundant & environmental pollution & degradation is no issue, water managers can afford to be lax in its management. Population growth & the effects of cyclic droughts on irrigated agriculture have put pressure on the available water resources. Such prevailing conditions have the effect of creating an imbalance between the increasing water demand & limited available water supply. Under this perspective, effective planning & management can only be obtained on the basis of reliable information on spatial & temporal patterns of farmers' water demand on farming irrigation practices & on physical & operational features of large-scale irrigation systems. It is necessary to employ modern methods of surveying, investigations, design, & implementation. Remote sensing & GIS are viewed as an efficient tool for irrigation water management. The task of providing reliable & accurate information from scales of farmer fields to entire river basins, encompassing millions of hectares of irrigated land, is far from trivial. Space-borne remote sensing measurements can, however, provide regular information on agricultural & hydrological conditions of the land surface for vast areas. It is important to understand that integrated water resource management should not merely imply the maintenance of an inventory of different activities to be undertaken within a hydrological unit. Since a watershed is considered as the smallest unit of drainage basin, a hydrological framework that can keep track of the inter-connection of these units is essential. The impact from action taken at the watershed level will be experienced at a higher level within the drainage basin & the assessment of these impacts will require the availability of the framework which will require regular maintenance & updating to reflect fully the infrastructure requirements for planning & management of the relevant planning departments.

Chowdary et al. (2008) demonstrated that satellite remote sensing coupled with GIS offers an excellent alternative to conventional mapping techniques in monitoring & mapping of surface & sub-surface waterlogged areas. El Nahry et al. (2011) found that for center pivot irrigation under precision farming, remote sensing (RS) & GIS techniques have played vital roles in the variable rate of water applications. Crop water requirements were determined using SEBAL model with the aid of FAO, CROPWAT model. Hatzios & Kriton (2000) used the information from soils recompiled from an uncorrected aerial photographic base to a USGS topographic base map. Soil data were added to numerous other data layers & images. Xiaopveng et al. (2011) developed an irrigation scheduling method by integrating the 'checkbook irrigation method' into a GIS-coupled soil water & nitrogen management model. The soil water & crop information required by the checkbook method & previously collected from field observations was estimated by the soil water & nitrogen management model.

Remote Sensing (RS) & Geographic Information System (GIS) with their capability of data collection & analysis are now viewed as an effective tools for irrigation water management. Remote Sensing is the acquisition of information about an object or phenomenon without making physical contact with the object & thus in contrast to on site observation. The term generally refers to the use of aerial sensor technologies to detect & classify objects on Earth (both on the surface, in the atmosphere & oceans) by means of propagated signals. Locations or extents in the Earth space–time may be recorded as dates/times of occurrence & x, y, & z coordinates representing, longitude, latitude & elevation respectively. Comprehensive reviews on remote sensing applications for agricultural water management are presented by Choudhury et al. (1994), Vidal & Sagardoy (1995), Rango & Shalaby (1998), Bastiaanssen (1998) & Stewart et al. (1999).

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II. Methodology :

Remote Sensing (RS) with GIS in Irrigation Management Recent advances in Remote Sensing (RS) technology offers potential improvement in various disciplines along with water resources management through important water resource related information. This information is potentially useful in legislation, planning, water allocation, performance assessment, impact assessment, research & in health & environment-related fields (Bastiaanssen & Bos, 1999). The remotely sensed data in conjunction with other traditional data provides valuable information on topography, land use/cover, geological feature useful in irrigation planning & management. The space & time based earth observation in remote sensing provides unique opportunity in handling spatial & temporal irrigation data for better irrigation management. Remotely sense data can be used by two ways regarding irrigation management, first accessing land cover in different cover & other is through estimation of water requirement parameters. When we deal with relatively large area/surface, remote sensing is more useful & there is always large area, when dealing with irrigation management. Remote Sensing data to determine actual evapotranspiration & crop water stress for managing irrigation systems was started during the eighties (Bastiaanssen & Bos, 1999).

Remote Sensing has been able to provide information with varying degrees of success & accuracy on : irrigated area, crop type, biomass development, crop yield, crop water requirements, crop evapotranspiration, performance diagnosis, salinity & water logging (Choudhury et al., 1994; Bastiaanssen & Makin, 2000). Available remotely sensed data remain underutilized by practicing water resource managers, although remote sensing has several advantages which can be complementary to field measurements. Spatially distributed information on soil water availability of crops can contribute to enhance the statistics on water availability in space & time. Remote Sensing techniques & its data use in India for irrigation management has been suggested by previous researchers (Ray & Dadhwal, 2000; Ray et al., 2002).

Remote Sensing technique can be used for assessment of water availability in reservoir for optimal management of water to meet the irrigation demand. It can also be used in determination of irrigation water demand over space & time, water logging & salinity problems in irrigated land. Further it can be used for performance evaluation of irrigation system through identification, inventorying & assessment of irrigated crops. Ray & Dadhwal (2000) used Remote Sensing & GIS for estimating seasonal crop evapotranspiration. The methodology can be used for estimating weekly evapotranspiration & correlating with it to a real-time irrigation scheduling. The integration of RS data & GIS tools can be used to compute performance indices (Ray et al., 2002). The regular computation & monitoring of performance indicators could provide irrigation managers with the means for managing efficiently the irrigation system. Bastiaanssen & Bos, (1999) as described in his paper, 'quantified irrigation performance indicators' based on remotely sensed data in a cost effective manner. He suggested irrigation experts to use Remote Sensing techniques in evaluation of irrigation performance indicators for better irrigation management.

Benchmarking (BM), using a set of defined indicators to determine the performance of various components of irrigation system is very important to evaluate the irrigation performance & the applied management for the irrigation project. Suresh et al. (2012) used various components of irrigation systems namely Irrigation Infrastructure (IIS), Agricultural System (AS) & Water Delivery Dynamics (WDD) as performance evaluation indicators for benchmarking study of the Nagarajuna Sagar Left-bank Canal (NSLC) using geospatial approach. Remote Sensing techniques can provide benchmark dataset of cropping, water distribution, baseline data & other data for comparing among the fields to evaluate the performance of irrigation or other management input.

Geospatial approach for benchmarking of irrigation systems could be useful to evaluate the performance of irrigation through different performance indicators & compare the performance indicators within the command to identify the problem for better management (Suresh et al., 2012). The geospatial approach for Benchmark study in irrigation management enables the improvements in data collection methods over time consuming conventional field survey of large area providing alternative mechanism, diagnostic analysis, spatio-temporal visualization of BM indicators. Thus, the use of satellite data combining with field data on water deliveries could be an alternative to the conventional non-spatial approaches for BM study useful for decision making for better management of irrigation projects & further, better water resources planning & management.

Precision farming & Remote Sensing (RS) :

Precision agriculture is a production system that promotes variable management practices within a field according to site conditions. This system is based on new tools & sources of information provided by modern technologies. These include the global positioning system (GPS), geographic information systems (GIS), yield monitoring devices, soil, plant & pest sensors, Remote Sensing (RS) & variable-rate technologies for application of inputs. Analyzing the results of the USDA's 1998 Agricultural Resource Management Study survey, Daberkow & McBride (2000) concluded that in the United States the highest rate of adoption was found in corn & soybeans in the Mid-West (Heartland) region, while the lowest rate was found along the Southern Seaboard. By crop type 13.7% of the grains & oil seeds sector used precision technologies, while only 1.6% of the livestock sector had adopted them. The Northern Great Plains region ranked second in the US for precision agriculture technology showed adoption with a rate of 5.8%. The shorter growing seasons & large farm sizes are considered to be reasons why some of the country's early adopters reside in the region.

Possible applications of Remote Sensing (RS) :

General :

Remote Sensing (RS) has the possibility of offering important water resource-related information to policy makers, managers, consultants, researchers & to the general public. This information is potentially useful in legislation, planning, water allocation, performance assessment, impact assessment,

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research & in health & environment-related fields. Remote sensing, with varying degrees of accuracy, has been able to provide information on land use, irrigated area, crop type, biomass development, crop yield, crop water requirements, crop evapotranspiration, salinity, water logging & river runoff. This information when presented in the context of management can be extremely valuable for planning & evaluation. Remote Sensing covers a wide area such as entire river basins's information can be aggregated to give a bulk representation or disaggregated to very fine scales to provide more detailed & explanatory information related to spatial uniformity. Information can be spatially represented through Geographic Information Systems (GIS), revealing information that is often not apparent when information is provided in tabular form.

Water use & productivity

With competition for water increasing daily, it is important to understand patterns of water use. Water accounting studies are used to identify the various users of water in the context of basin

Table 1: Remote sensing products for water management

Remote Sensing deliverables	Water use/ productivity	Performance diagnosis	Strategic planning	Water rights	Operations	Impact assessment
Land use	✓		✓			
Irrigated area	✓	✓	✓	✓	✓	✓
Crop type	✓	✓		✓	✓	✓
Crop yield	✓	✓	✓			✓
Daily ET		✓				
Seasonal ET	✓	✓		✓		✓
Crop stress		✓			✓	
Salinity		✓				✓
Historical data		✓	✓	✓		✓

wide water use & the productivity of each use. Although these questions can be solved through the framework of water accounting (Molden, 1997; Molden & Sakthivadivel, 1999), the results rely substantially on proper input data. To better understand irrigation in the context of basin wide water use, a water accounting study was carried out at Kirindi Oya sub basin in Sri Lanka (Bakker et al., 1999; Renault et al., 1999). Water resources in the area were primarily developed for irrigation. Initial studies pointed out that the amount of water evaporated from non-crop vegetation was in the same order of magnitude as that for rice, field & vegetable crops grown in the area. Remote Sensing was used to carry out a more in-depth analysis to classify land types, & then to estimate evapotranspiration by land type & classify the same. The results reveal that evapotranspiration of non-crop vegetation is significant & needs to be taken into consideration in the operations & performance assessment of cascade-type irrigation systems in the humid tropics. The International Water Management Institute (IWMI) has developed a set of indicators focusing on productivity of land & water resources (Molden et al., 1998).

Performance diagnosis

Ideally, managers of irrigation systems should include regular performance monitoring in their management techniques. Occasionally, the nature or complexity of a problem requires a more detailed diagnosis. On such occasions, consultants or researchers are called to identify constraints to performance. Satellite Remote Sensing, especially in large complex areas, can be a cost effective tool in diagnosing & establishing the performance of irrigation, especially when consultants are familiar with the opportunities. The performance of the Bhakra Irrigation System in Haryana, India was assessed using Remote Sensing. (Bastiaanssen et al., 1999b; Sakthivadivel et al., 1999). Spatial variations in land & water productivity were presented & explanations for their differences forwarded through linkage with field observations & a hydrological model in a GIS environment were observed. It was found that differences in productivity were ascribed more to the hydrological setting than to water delivery performance. Additionally, it was demonstrated that while productivity remains at reasonable levels, sustainability is in question with the build-up of salts & rapid rise in groundwater levels in some areas & fall of groundwater levels in other areas.

The opportunity to rapidly compare the performance of different irrigation systems measured with the same satellite sensor is provided in Table 2. The 'coefficient of variation' **(C_V)** in cropping intensity, evapotranspiration & conditions of crop stress for climatological different regions are presented. This is usually applied to express equity in access to water resources & irrigated land, being essential for water scarce environments & in disadvantaged regions where progress in socio-economic development is central. All schemes were analysed with 30 M resolution 'Thematic Mapper' data calculated with the same energy balance algorithm, to make sure that sampling, measuring & interpretation techniques are similar. The results have, therefore, a more indicative character, but never the less demonstrate that systems can be potentially compared. Examples of other performance assessment studies incorporating Remote Sensing data are presented in, for instance, Moran, 1994, Menenti et al., 1995 & Roerink et al., 1997. A review of irrigation performance literature is provided in Bastiaanssen & Bos (2000).

Strategic planning & water rights :

It is essential to develop & rethink long-term strategies to meet challenges. Strategic or long-term planning is implemented through legislation & policies. Studies on irrigated areas taken from governmental water agencies & satellites in Turkey, Argentina & Spain have indicated differences ranging from 40 to 70%. Farmers usually adapt their cultivation practices to overall water availability, including groundwater & the actual situations can differ from the planned situation. Here remote sensing provides an excellent means to fit into this process of strategic planning at regional level. Two basic problems of setting up a system of water rights are (i) the definition of the right to water & (ii) the adjudication of that right. When setting up a system of water rights, water use as determined by Remote Sensing can be extremely useful in assessing which individual or group is presently or historically using water & after identification of

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water rights, water use can be checked. This can be done through remote sensing estimates of vegetation cover combined with a geographical database on water rights. Parodi (1999) used spectral vegetation indices for the recognition of the irrigated areas & compared this information with the official cadastral ownership & list of water rights. Remote sensing offers possibilities in the collection of fees & enforcement of regulations. Water charges are sometimes based on crops & area under each crop; items readily discerned by Remote Sensing.

Table 2. Coefficient of Variation or C_V (standard deviation/mean, expressed as a percentage) of crop & water parameters in seven different command areas. (All calculations are based on Landsat Thematic Mapper data)

Location	Date	Cropping intensity, C_V	Evapo Transpiration C_V	Crop stress, C_V
Nile Delta, Egypt	July 27, 1987	10	10	15
Rio Tunuyan, Argentina	March 05, 1990	20	6	6
Heihe River, China	July 09, 1991	30	76	52
Niger River, Niger	September 18, 1992	30	26	17
Haryana, India	December 04, 1995	25	20	25
Kirindi Oya, Sri Lanka	June 19, 1995	15	37	30
Gediz River, Turkey	August 29, 1998	25	26	39

Impact assessment

Huge amounts of funds are invested in irrigation & drainage infrastructure with different approaches to irrigation development (Horst, 1998). Remote Sensing offers a huge advantage in this area as archived images (Landsat from 1972 to date & NOAA-AVHRR from 1982 to date) can be used to track these changes. Project impact assessments require comparisons of the irrigation conditions before & after project execution. Thiruvengadachari & Sakthivadivel (1997) performed a study on cultivated areas, area under paddy & crop yields after turn-over of the Bhadra irrigation project in Karnataka, India. By repeating the satellite data analysis before & after project completion, they quantified the impact on irrigation performance. Productivity per unit of water increased from 0.36 kgm^{-3} of water delivered to 0.57 kgm^{-3} in 1994, an increase of 64%. Archived satellite data provides the opportunity to reconstruct longer & continuous time series of irrigation conditions.

The UMAC model :

Recognizing the special needs of Remote Sensing for precision agriculture, the Upper Midwest Aerospace Consortium (UMAC) used a learning community approach in promoting the use of Remote Sensing among the farmers & ranchers of the Upper Midwest. The objective of this paper is to show how a learning community approach integrates training data delivery, & application development to provide precision farmers with management tools derived from Remote Sensing technologies

III Results :

Background of Remote Sensing achievements in water resources research :

Thematic object classes

Panchromatic satellite data currently have spatial resolutions of 2.0 (SPIN), 5.8 M (Indian Remote Sensing Satellite, IRS) & 10 M (Satellite Pour' Observation de la Terre, SPOT) & these data are valuable to deduce the location of roads, canals, ditches & boundaries of individual fields & small command areas. The 'National Oceanic Atmospheric Administration Advanced Very High Resolution Radiometer' (NOAA-AVHRR) is providing vegetation indices on a regular basis & at low costs. Chakraborty et al. (1997) for instance, identified four major types of lowland cultivation practices prevailing in West Bengal (India) with a 90% classification accuracy using three-date, C-band data of the European Remote Sensing Satellite, ERS-1.

Crop yield

The concept of assimilating Remote Sensing data in mathematical/physical crop yield models (Bouman, 1992) is attractive to modelling crop growth concurrently. Moran et al. (1995) used LAI & evapotranspiration from Remote Sensing data to update the model parameters of a physiologically based crop yield simulation model at field scale.

Evapotranspiration

Jackson et al. (1977) performed pioneering work on 'thermal infrared applications' for a wheat mono-cropping system. Crop Water Stress Index (CWSI) (Jackson et al., 1981) & Water Deficit Index (WDI) (Moran et al., 1994) are the Crop Stress Indicators to circumvent the need to solve the surface energy balance explicitly.

Soil moisture

The results for two large-scale field campaigns dedicated to soil moisture-evaporation-biomass interactions, FIFE (Smith et al., 1992) & EFEDA (Bastiaanssen et al., 1997) are depicted in Fig. 1.

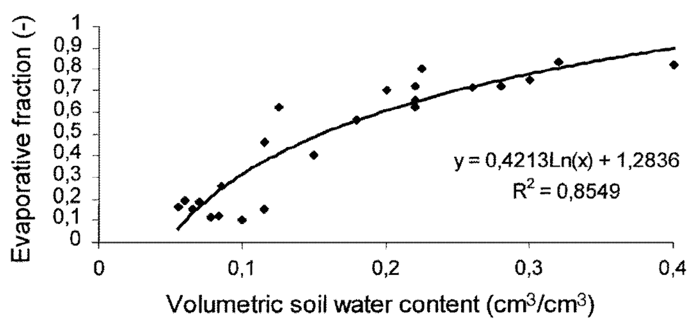

Figure 1.

Runoff

Imhof et al. (1987) mapped flood boundaries along the lower Ganges River by using L-band radar data in association with

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Landsat MSS data. Smith (1997) also demonstrated that C-band radar data with a spatial resolution of 12.5 M could be helpful. Smith provided a non-linear relationship between river width & river discharge so that they could interpret the estimated width into discharge. Vorosmarthy et al. (1996) & Choudhury et al. (2000) used passive microwave data from Nimbus (37 GHz) with pixels of tens of kilometers to estimate the span width of the Amazon & the Rio de la Plata, respectively. These pixel sizes are only applicable for larger rivers. Research on this issue is still continuing & has to go a long way before yielding substantial results.

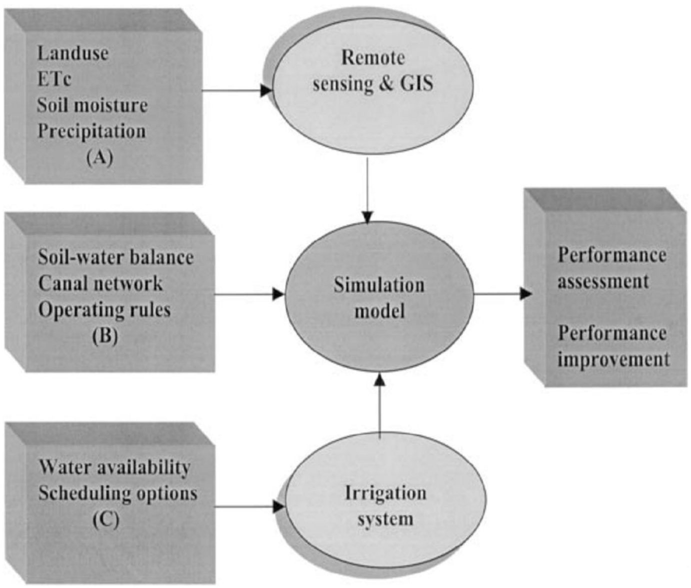

Figure 2
An approach for integration of Remote Sensing & ydrological modelling

Future Perspectives :

The current state of Remote Sensing in terms of repetitive intervals of spacecraft & range of sensors for measuring hydrological variables will continue to improve in the coming years. Presently, the physically based models for estimation of hydrological parameters at a regional scale are complex & require significantly high processing time.

There is a need to evolve simplified procedures for estimation of hydrological parameters. The integration of remote sensing & hydrological &/or hydraulic simulation models can be provided by a procedure known as□'partial hydrological processes for irrigation system management' (PHISM). An approach for integration of Remote Sensing & simulation models for irrigation system management is shown in Figure 2 (Ambast et al., 2000). In large irrigation areas, particularly in arid & semi-arid areas, the problems of waterlogging & soil salinity pose a challenge to the sustainability of the system. The inter-seasonal & intra-seasonal dynamics of soil salinity may be studied in large irrigated areas. The impact from waterlogging & soil salinity on sustainability may be studied using temporal remote sensing data.

IV Conclusion :

Increasing accessibility :

The use of satellite measurements of ET on an operational basis requires more expertise & costs more than the use of simple tables. In some overseas countries, groups of irrigators have formed consortia to share the costs of acquiring customised satellite data for their irrigation requisites. The consortia contract specialist organisations to interpret the satellite Remote Sensing data & tailor it to specific paddocks for each irrigation enterprise. Work is on-going to raise an awareness amongst irrigators & other water managers, about the value of using information from satellite Remote Sensing of ET to improve water use efficiency on-farm. Adoption by irrigation managers, at farm & district levels, of estimates of actual ET derived from Remote Sensing has the potential to improve irrigation water use efficiently & contribute to more efficient use of water resources.

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