Integration of Remote Sensing Technology to Geographic Information System for Sustainable Planning of Water Resources

A.Nejat EVSAHİBİOĞLU, Prof. Dr.
The University of Ankara
Department of Agricultural Engineering
06110, Ankara, TURKEY
evsahibi@ankara.edu.tr

Egnar ÖZDİKİLİLER
Istanbul Technical University
Informatics Institute, Satellite Comm. and Remote Sensing
34460, Istanbul, TURKEY
ozdikililer@itu.edu.tr

Abstract — Remote sensing provides much of the information that is input to a GIS, from global scale vegetation and climatic data to the roof outlines entered into a municipal GIS. As with other fields, to make effective use of remote sensing technology requires technically skilled personal as well as the appropriate technology.

Remote sensing and GIS technology developed separately. In part this was a result of the use of different technical skills. While a user of remote sensing technology may develop expertise in sensor systems and image processing methods, the expert GIS user may become more familiar with principles of map projections, spatial analysis, and the design of spatial data bases. Although the technology may encourage different technical orientations, in both cases the user must understand the nature of the information being collected-the forestry, geology, building structures, roadway design and so on.

Ultimately, remote sensing and GIS technology are both used to collect, analyze, and report information about the earth's resources and the infrastructure we have developed to use them. The two technologies provide complementary capabilities. Remote sensing analyses are improved by the verification data retrieved from a GIS, and GIS applications can benefit from the information that remote sensing can generate. Often the image data are the most current spatial information available for an area. The use of digital image data offers the additional advantage of a computer compatible format that can be input directly to a GIS.

The integrated use of remote sensing and GIS methods and technology can not only improve the quality of geographic information but also enable information previously unavailable to be economically produced. Over the past few years manufacturers have developed more sophisticated technology for integrating remote sensing systems and geographic information systems. The effective use of these tools, however, depends on user sufficiently knowledgeable to apply them.

The objective of this paper is to examine geographical information system and its integration with Remote Sensing Technology for agricultural engineering applications in general but specifically related to water resources planning.

Keywords — water resources; sustainable planning; remote sensing, geographic information systems;

I. INTRODUCTION

The first operational computer-based Geographic Information Systems have started in North America in the middle of 1960 years. Canadian Geographic Information System (CGIS) and New York State Land-Use and Natural Resources Inventory Centers have been intensively using maps and aerial photos as resource data for Agriculture, Forestry, Wild-Life protection, Soil conservation and Geology. Geographic data were then converted into digital format for computer analysis. Although developments was commenced in the year 1960, due to availability of computer technology these systems have become functional in the beginnings of 1970 [47].

Harward Graphics Laboratories have been the most active research group for developing computer-based map analysis programs such as SYMAP, GRID and IMGRID for superimposing programs. Geographic information systems are computer-based systems for storing and processing of geographic data. Geographic information system (GIS) technology has an imperative potential from the more systematic and the wider range of disciplines point of view. GIS has to have four different capability related to store of geo-coded information;

1. Data Input; 2. Data Management (Data Storage and Retrieving); 3. Manipulation and Analysis; 4. Output information

On the other hand, Remote Sensing technology (RS) provides data layers to GIS system for several applications from global-scale crop and climate data to municipal practices.

Although both technologies (GIS and RS) have been developed separately, both technologies have been heavily used for collecting, analysis and publishing of data related to earth resources. Both technologies are complementary to each other. While remote sensing analysis is being confirmed by retrieving data from a GIS system, GIS applications have utilized information produced by remote sensing technology [4].

Integration of digital image data gathered by remote sensing system to GIS is one of the most brilliant ideas and it is called Geomatic technology. Geomatic technology has been extensively used for agricultural crop-pattern and crop-yield predictions, soil-surveys, flooding-impact analysis and water resources planning. Rapid word population increase and developing industrial sector have leaded heavy water requirements and as a result of this water crisis in many regions of the world may be expected. For this reason importance the RS and GIS technologies for sustainable planning of water resources has been revealed [15], [16].

Implementations of Geomatic Technology related to the planning of water resources and the management of irrigation systems are shown below;

1) *Agricultural Production*

a) Land-Use planning

b) Entomological and psychopathological analysis on agricultural lands

c) Crop-pattern and crop-yield predictions

d) Rural and Urban planning

e) Forestry works (timber predictions and forest fires)

2) *Hydrology*

a) Snow and ice volume estimates

b) Discharge rates of surface rivers

c) Erosion and sedimentation estimates

d) Flood impact analysis

e) Soil water content and drought analysis

3) *Water Resources Planning*

a) Water resource analysis for agricultural applications

b) High water tale levels and salinity problems

c) Dam and reservoirs location analysis

d) Leackage loses from canals and pipe-lines

e) Water Quality (Chemical, biological and thermal discharge control)

4) *Agro-meteorological Studies*

a) Evapotranspiration and irrigation scheduling

b) Early warning of natural disasters that can harm to plants such as storm and cold weather

c) Agro – meteorological measurements and weather forecasts.

5) *Energy Saving*

a) Energy loses control over agricultural buildings.

II. IRRIGATION SYSTEM MANAGEMENT

A system is defined as a set of objects, which act in a regular and interdependent manner. Inputs that may be controllable or uncontrollable, environmental factors and outputs that may be desirable, undesirable or neutral are the essential components of the system. An irrigation system as such defies a rational description, because it means different things to different people. Early (1983) described an irrigation system as an entire set of physical, biological, geographical, social, political and economic entities and objects, from the source of water through the conveyance to the farm and the land.

A. Irrigation System Framework

The irrigation sector may be represented as a set of nested systems as described by Small and Svendsen [43]. Each system in the framework of irrigation sector has its own particular set of objectives. They incorporate five systems (Figure 1) in their model:

- the irrigation system, which has its function the conveyance of water from the source to the farmer's field. The output from this system, water delivery at the farm gate, then becomes an input into
- the irrigated agriculture system where farmers use water and other inputs to produce crops; these crops becomes the inputs into
- the agricultural economic system that includes rainfed agriculture as well as irrigation: the value of the crops produced then forms part of
- the rural economic system that deals with the entire set of economic activities in rural areas that in turn form part of the highest level,
- the national political-economic system.

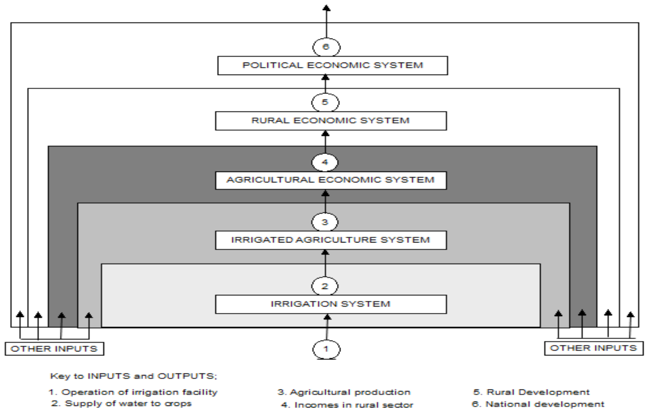

Figure 1. Irrigation sector as nested system

B. Performance Diagnosis Framework

Irrigation management is manipulation and use of water resources, canal systems, command areas, plants, soils and knowledge of technical disciplines to provide water to the root zone at the proper rate, time and place to produce food and fibre [12]. Some of the key elements of irrigation water management are:

- Performance monitoring and evaluation: monitoring and evaluation are the activities that estimate the performance of the irrigation system. In the context of this paper, monitoring may be defined as continuous or periodical surveillance of the implementation of necessary irrigated agricultural activities, including their various components. Evaluation may be defined as a process that determines systematically and objectively to the extent possible, the effectiveness and the impact of project activities in terms of their objectives [6].

- Diagnostic appraisal: this includes activities involved in identifying the interventions alternatives in the system and the consequences of such interventions in improving irrigation performance.
- Action research: action research involves validation of interventions meant for improvement on experimental basis in a project and their monitoring for purposeful evaluation.
- Peoples participation: farmers are the ultimate water managers in the real sense and their active participation will increase system performance by inculcating a sense of participation in decision-making. There is very little information available on the consequences of farmers' participation in irrigation performance, though the need is well realized.

C. Classification of Performance Indicators

On the basis of a review of the literature, Bos et al. [7] grouped performance indicators as follows:

- Water supply performance: this deals with the primary task of irrigation managers in the capture, allocation and conveyance of water from source to field by management of irrigation facilities and thus assesses the delivery subsystem.
- Agricultural performance: this addresses the direct impact of operational inputs such as areas actually irrigated and crop production. In other words, these indicators assess the performance of the application subsystem.
- Environmental, economic and social performance: this deals with the impact of both operational and agricultural inputs on the viability and sustainability of irrigated agriculture. The environmental performance indicators represent the state of the disposal subsystem, whereas economic and social performance indicators can be used to judge the overall performance of the irrigation system.

Delivery subsystem. The horizontal transport of water from storage reservoir or diversion structure to the fields is accomplished through the water conveyance and distribution system consisting of main canals, distributaries, minors and outlets. The performance objectives of good delivery management are equity, regularity, adequacy, reliability and productivity per unit of land per unit of water [25], [1].

Several studies have addressed performance assessment for the irrigation water delivery subsystem. Clemmens, Dedrick [11] and Palmer et al. [37] use the temporal coefficient of variation of instantaneous flow rate measured at farm turnouts to indicate the degree of water control of a water delivery system. However, no attempt has been made to address seasonal-scale variability in water deliveries or to explicitly relate the delivered flows to the scheduled or required flows. Ambast el al. [3] and Tyagi et al. [48] evaluated water delivery performance in terms of equity and seasonal regularity and adequacy for rotational supply of the Western Yamuna Canal and Bhakra Canal systems in India. Oad and Levine [35] and Oad and Podmore [36] defined a term called "relative water supply" as the ratio of supply to demand in order to evaluate how well water was managed to irrigate rice under various supply levels. Mohammed [29] presented adequacy, dependability and equity as performance indices. However, no clear distinction is made between the estimation of defined performance measures and the assessment of their values in light of multiple system objectives. Seckler et al. [41] used an index introduced by Theil [45] to measure the performance of the rotational delivery system in India. The index, however, does not allow an intuitive distinct assessment of performance relative to each objective separately. Molden and Gates [31] presented a comprehensive definition of performance measures assessable in terms of specific system objectives measurable in terms of structural and management contributions. Clemmons and Bos [10] proposed ratios to separate the overall performance into delivery schedule performance and operations performance. However, these indices can be generated from measurements taken of flow rate, duration, pressure, and frequency of delivery.

Application subsystem. The heart of irrigation is the water application or on-farm subsystem because it controls the environment within the crop root zone, where action for food production takes place. The function of the other two subsystems, i.e. delivery and disposal, is to support on-farm application in achieving the desired goal of food production.

The application of water is governed by a set of rules incorporated in the concept of crop irrigation scheduling. The three important components of crop irrigation scheduling are: (*i*) depth of application, (*ii*) rate and duration of application, and (*iii*) the frequency of application. The operational part of this concept revolves around the nature and properties of the growth medium, i.e. the soil, the crop water use pattern and its consequence for crop production, and the physical constraints imposed by the water delivery subsystem. The performance objectives of the water application subsystem are to distribute water uniformly over the entire field, with as little loss as possible; to ensure adequate moisture in the root zone to meet the crop water requirement and enough leaching to prevent soil salinization. The performance of an irrigation method can be evaluated by determining how well the irrigation meets the above requirements. Several parameters that describe the performance of an irrigation method have been identified, but effective evaluation of performance has been difficult owing to problems in identifying inadequacies in operation and design [17], [28]. ASCE [5] has proposed the actual application efficiency of low quarter (AELQ) to see how well the system is being used and potential application efficiency of low quarter (PELQ) to see how well the system can apply water, if management is at an optimum. Concepts developed by Hansen [18] which include (i) requirement efficiency, (ii)water distribution efficiency, and (iii) consumptive use efficiency dealing with the ability of plants to use stored water can also be used to evaluate irrigation method performance. Although a large number of field experiments have been conducted to evaluate the performance of irrigation methods, reliable and adequate data are generally lacking. There is an almost total lack of field data from measurements taken under actual farming conditions.

Disposal subsystem. Disposal is an integral part of irrigation system and it provides support to the application system in maintaining a favourable environment within the root zone as well as the irrigation basin as a whole. Here we are concerned with disposal of excess water and/or salts from the irrigated lands through the process popularly known as agricultural drainage. Agricultural drainage is defined as the establishment and operation of a system by which flow of water from the land surface/soil profile is enhanced so that agriculture can benefit from the subsequent reduction in surface water inundation or reduced water table and salinity (if salinity is a problem).

The performance objectives of the drainage system are to remove the excess surface water or lower the water table, to facilitate the leaching of salts if salinity is a problem uniformly over the entire area, at the desired rate in a given time span so as to maintain favourable conditions for plant growth. The performance of the drainage methods is evaluated by determining how well the above objectives are accomplished. Some of the possible indicators are (*i*) soil aeration, *(ii*) soil temperature, (*iii*) soil workability, and (*iv*) reduction in soil salinity [51], [9]. But in actual conditions these have seldom been used. The commonly used indicators are (*i*) the rate of removal of excess water or fall of water table, (*ii*) average water-table regime, (*iii*) average salinity and (*iv*) rate of salt removal [40], [49]. Lack of reliable data on crop performance as influenced by salinity and waterlogging is a serious handicap for performance evaluation results and thereby for the design of large-scale drainage.

III. Application of Geomatic Technology Related to the Management of Irrigation Systems

International Water Management Institute (IWMI) has reported that decision-makers and planners can decide efficiently for providing available water related to crop production and environment by using satellite-borne remote sensing data. On the watershed or agricultural land base this technology has provided benefits for information about how the water was delivered to the plants by revealing additional water resources provided, water-use efficiencies increased and water-requirements of user satisfied [21].

Management of irrigation water resources by using Geomatics technology are explained as,

A) Determination of storage capabilities of reservoirs

Multispectral satellite images and especially Near Infrared Band is highly effective for surface water delineation and mapping [34], [53].

B) Land-Use, Land-cover predictions over Irrigated agricultural Lands

Mapping of crop-pattern for land/use, land/cover is meaningful for crop-water requirements [19], [46], [20], [50].

C) Determination of Crop-patterns over Irrigated lands

Crop-patterns are needed for consumptive use of water [26], [14], [8], [38], [30].

D) Estimation of plant-growth and crop-yield

Estimation of crop-yields consisted of two steps: 1) estimation of crop acreages 2) yield predictions for each unit of land. By multiplying those steps it is obtained final production values [52], [24].

E) Estimation of Consumptive use of water and irrigation scheduling

Prediction of evapotranspiration rates by using satellite data can be managed by two approaches: 1) Instantaneous crop surface temperature measurements [22], [42]. 2) Instantaneous surface energy balance calculations [32], [44], [13].

F) Determination of Soil Salinity and high water level problems

High water table and soil salinity are the result of unsatisfactory irrigation system performance [39], [33].

G) Evaluation of Irrigation System Performance

Menenti et al. [27] have developed an irrigation system performance classification method based upon unit water necessity for unit cultivated land. The formula is given as;

$$Water\ Resource\ Efficiency = \frac{\begin{bmatrix} Actual \\ evaporation \\ for\ irrigated \\ circumstance \end{bmatrix} - \begin{bmatrix} Actual \\ evaporation \\ for\ nonirrigated \\ circumstance \end{bmatrix}}{Flow\ Discharge\ Rate\ of\ Water\ Resource}$$

IV. Future Perspectives

It is well known that water is a crucial and limited resource for crop production and would be even scarcer for irrigated agriculture. Management of irrigation systems is the key for efficient use of water, and application of remote sensing techniques is a viable means for management of such a vital resource in large irrigated areas. However, one can visualize the application of remote sensing up to the level of an agricultural economic system (the shaded area in Figure 2). The current state of remote sensing in terms of repetitive intervals of spacecraft and 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 is complex and requires significantly high processing time. There is a need to evolve simplified procedures for estimation of hydrological parameters. Modern tools like artificial neural networks may be explored to extrapolate input-output relationships (obtained from physically based models) in space to save processing time. Artificial neural network techniques may also be relevant to relate or model the input-output relationship between remotely sensed information and hydrological parameters, which is not fully understood.

Conventional methods of irrigation scheduling techniques utilize soil and meteorological data to determine the timing and amount of irrigation. As temperature is related to plant stress, and spectral reflectance from crops is related to plant cover and its density, which are measurable through remote sensing techniques, the response of the plant to its environment is determinable. Past research experience has shown that improvements in the present system of irrigation management can be made by combining remotely sensed crop canopy conditions with soil and meteorological information. Past experiments have indicated that a crop water stress index [23] is a promising tool for irrigation scheduling, particularly for grain and fodder crops.

Different types of hydrological models are available to be used as a decision support system for irrigation system management. In general, simulation of the water balance in the root zone is the main component of most models. Usually, one-dimensional water balance computations are used for each cluster of crops and the associated soil group. The water balance can be described by means of a simple steady-state model or by means of numerical integration of differential equations describing the transient water in the soil-crop system. A major constraint in spatial hydrological modelling is knowledge of the field-level soil and crop parameters. It is, therefore, important to integrate the various parameters, which can be obtained using remote sensing.

The integration of remote sensing and hydrological and/or hydraulic simulation models can be provided by a procedure called spatial hydrological processes for irrigation system management (SHISM). An approach for integration of remote sensing and simulation models for irrigation system management is shown in Figure 2 [2]. The SHISM is basically a database management system which enables the irrigation managers to introduce hydraulic network and field information to the extent of precision required. The building block 'A' in Figure 2 represents the hydrological components required for the soil water balance calculation for each plot or user-defined elementary area. The spatial information on ET, soil moisture and crop type can be obtained by image processing. The soil information can be obtained either by remotely sensed data or by rasterization of available soil maps. The spatial variation in precipitation can be obtained by the Thiessen polygon procedure for the meteorological stations falling in the irrigation area. The hydraulic network can be digitized in vector form and converted into raster form for further use.

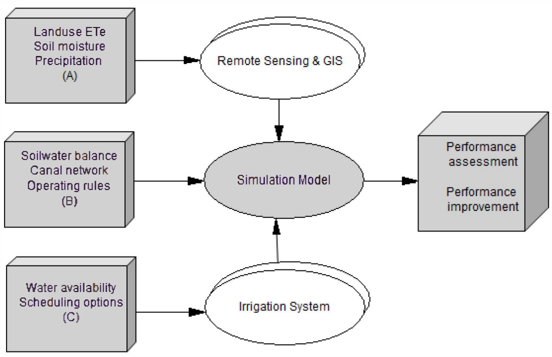

Figure 2. An approach for integration of remote sensing and hydrological modelling

Block 'B' is basically a core model that performs water balance for the command area of canal network under the given operating rules. The variables, which may influence the irrigation scheduling, can be incorporated to generate a scenario (Block 'C'). A procedure for evaluation of different performance indicators is the ultimate aim of the integration. If the performance of the system is well above the accepted efficiency criteria, the final flow requirement can be released. In case of underperformance, various options can be explored for improving irrigation system performance.

Forecasting of regional crop production under different agro-environments is another aspect. Application of remote sensing techniques for monitoring and evaluation of irrigation system performance is still at a very early stage. In large irrigation areas, particularly in arid and semi-arid areas, the problems of waterlogging and soil salinity pose a challenge to the sustainability of the system. The interseasonal and intra-seasonal dynamics of soil salinity may be studied in large irrigated areas. The impact from waterlogging and soil salinity on sustainability may be studied using temporal remote sensing data.

CONCLUSIONS

Satellite remote sensing has made considerable progress in the field of hydrology and irrigated agriculture. However, still more has to be done on operationalisation of satellite remote sensing techniques for irrigation system management. Many studies have been conducted in isolation, sustained efforts are needed to consolidate the results obtained so far to develop operational methodology packages. Integration of hydrological models with remotely sensed information is the need of the hour to manage our water resources effectively and efficiently It is also needed to integrate such methodologies with day-to-day working of irrigation organizations so that decision-making processes in the irrigation schemes improve substantially. The approach presented in this paper can be effectively utilized for effective irrigation system management on an operational level as it improves the decision-making process and enables the evolution of strategic management policies in a systematic manner.

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