ITIS

Information Techniques for Irrigation Systems

IIMI

November 1997 Vol. 4 No. 1

Network Newsletter Published by the International Irrigation Management Institute

Special Issue on RS and GIS

Introduction

Decision Support Systems for Efficient Irrigation Water Management

As we enter the new millennium, there are growing concerns and periodic warnings that we are moving into an era of water scarcity. With increasing demand for food and competing use within the water sector, the pressure is on irrigation professionals to manage water efficiently. The rallying cry is "more crop per drop." In response to this, strategic decisions and interventions would need to be made on a continuing basis. These decisions should cover the full spectrum of the irrigation water supply system from diversion and distribution, to on-farm application down to the crop root zone. Obviously, such actions require reliable and adequate information and data to ensure both precision and timeliness. Data and information for performance assessment are again wide-ranging and cover a multiplicity of parameters/ indicators.

We are all aware that conventional data collection has its limitations and constraints, which in some cases can be financially prohibitive considering excessive time, labor, and equipment costs. However, recent advances in information technology offer great potential for new and cost-effective ways of data and information management. Two such powerful tools, namely Satellite Remote Sensing (SRS) and Geographical Information System (GIS) promise wide application and are proving to be valuable assets to assist managers and decision makers involved in irrigated agriculture.

Satellite Remote Sensing offers many advantages in the field of data collection. It is a primary data source which can be utilized to increase the reliability and the confidence of conventional data collection

Inside ...

process. SRS is the only source of information bringing an exhaustive coverage of the space domain, either an irrigation system or the entire watershed. Another advantage is the ability to track historical evolution by using previously stored images. It thus allows going back into the past to describe irrigation system and water basin evolution possibly undergoing structural changes, physical or institutional, or both. Another important advantage is that SRS is able to cover inaccessible areas. In addition to the above-mentioned improvements in the collection of conventional data, SRS has the capability to describe land and water conditions (land wetness, consumptive use, leaf area index, vegetation cover, yield). These types of information open new avenues and methodologies for irrigation and water management. Cost-wise, SRS has also been favorable especially for large irrigation areas. Recent studies (IIMI Research Report No. 9) carried out on the Bhadra Project in India to map spatially distributed information on irrigation area, cropping pattern, and rice yield, have shown the cost of SRS application for this 100,000 hectare irrigation scheme works out at 0.1 US$/ha which cost could decrease to only 0.03 $/ha or less for schemes larger than 250,000 hectares.

Geographical Information System is a software system aimed at storing, processing, and displaying spatial data information. GIS offers extensive use in natural resources, agriculture, and environmental studies, where monitoring of the spatial distribution of variables is the main component of the management task. GIS is often associated with remote sensing (RS) because both can handle spatial information, and GIS is a sort of "natural" host of RS images linking them with other data sources. But the advantages of GIS go much beyond that. It is also very useful in interfacing several modern tools such as Database Management Software, Statistical Software, and Physical Hydrology Models. GIS may be regarded as an essential element data integrator for modern information techniques, and forms the interface with the user.

Given the good potential and promise for their application, the question may be asked why SRS and GIS have not been widely used. The topic has been discussed recently in regional and international fora organized by FAO, Cemagref, and ICID. Problems and constraints raised by participants range from lack of skills and training, cost of investment, cost-effectiveness, reluctance against high technology, and new information.

Understandably, some developing countries do not yet have easy access to remote-sensing data. Where these tools are available, there is lack of competent technical skills and resources. Capacity building ensures the site application and development of these techniques, appropriately supported through networking linking research and training institutes, RS laboratories, consultant companies, and irrigation managers.

Documentation and dissemination of information on the practical applications and benefits of SRS and GIS among the global community of irrigation managers go a long way in promoting awareness for their acceptance and wider use. I am pleased to introduce this special issue of the ITIS Newsletter covering various aspects of RS and GIS application thereby contributing to the process of transferring research findings and applications to the irrigation community.

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The Network

The Information Techniques for Irrigation Systems (ITIS) Network links the conceptual to the practical—the world of Decision Support Systems (DSS) to the world of irrigation. This newsletter is intended to serve as that bridge, to facilitate the dissemination of knowledge concerning the application of information techniques for improving the management of water in irrigation systems.

The IIMI-Cemagref Project in Kirindi Oya, Sri Lanka was the foundation on which ITIS was launched. Following the successful development and implementation of decision support tools in Sri Lanka, the Project has entered a new phase with work being initiated in Pakistan and Mexico. Work on the IIMI-Cemagref Project will progress for another five years. It is hoped that ITIS would have gained a sufficient critical mass by that time to sustain itself.

Cemagref

Cemagref is the French institute of agricultural and environmental engineering research. It is a parastatal organization supported by the French Ministry of Research and the French Ministry of Agriculture. It has a strength of more than 500 researchers and conducts research programs in the field of land and water management, environment, and agricultural engineering. Its irrigation division is located in Montpellier, France.

IIMI

The International Irrigation Management Institute (IIMI) is an autonomous, nonprofit international research institute supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of public- and private-sector donors that supports a worldwide network of 16 international research centers, including IIMI, conducting global research on agriculture, forestry, and fisheries. The CGIAR is sponsored by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP) and comprises more than 40 donor nations, international and regional organizations, and private foundations.

IIMI's mission is to improve food security and the lives of poor people by fostering sustainable increases in the productivity of water used in agriculture through better management of irrigation and water basin systems.

With its headquarters in Colombo, Sri Lanka, IIMI conducts a worldwide research and capacity-building program to improve water resources and irrigation management through better technologies, policies, institutions, and management.

Forum

Defining GIS and Remote Sensing Applications for Irrigation: A User-Oriented Approach

INTRODUCTION

Over the last few years, the generalizing of standard and relatively cheap computer hardware and software has enabled the development of information systems for irrigation and drainage in several countries. This development has often been successful, but sometimes the information systems set up are not used to their full potential, and have become obsolete or do not allow new functions to be integrated. This is often the result of the method used for setting up the system, which is often more concentrated on the tool itself rather than on the user's requirements. Though it is generally recognized that resources should be managed in a global way, this is very difficult to put into practice as their management involves a variety of actors whose objectives may differ and may even compete with one another, particularly when the resources are limited. Managers require very different types of information (qualitative, quantitative, administrative, etc.), both reliable and spatially distributed. In most cases, all management procedures need to be analyzed before an adapted information system can be set up.

Remote Sensing (RS) and Geographical Information System (GIS) are being included in such information systems more and more frequently, and their integration is particularly tricky, as they provide spatially distributed data that can be both consulted and manipulated. Therefore, within the framework of the International Committee of Irrigation and Drainage (ICID) work group on decision assistance systems for land and water management, the AFEID (the French Association for the Study of Irrigation and Drainage) created a working group on remote sensing and GIS in 1994. The objectives of the AFEID working group were to prepare the ICID Guide on the Use of Remote Sensing and GIS in Irrigation and Drainage, and in particular, to draw up technical and practical specifications to promote the integration of spatially distributed information in such systems. This paper summarizes the method recommended by the working group and presents an application of the method on a case study in the Punjab, Pakistan. More details on this approach can be found in Vidal, Laloux, and Lepoutre 1996 and Vidal et al. 1997.

METHOD

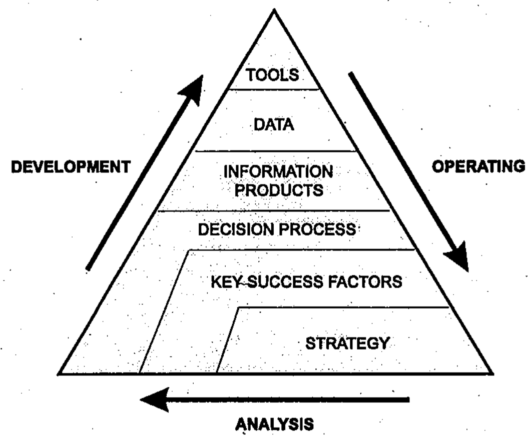
The chosen procedure, to be used by managers of irrigated and/or drained system, is based on the information system analysis application, more traditionally used for company audit purposes which/is illustrated in figure 1.[1]

This traditional analysis has been adapted to the specific constraints peculiar to geographical information, on the basis of a wide experience in consultancy and the setting up of decision support systems for public authorities managing large territories.

The process is as follows:

- Analysis of management strategy
- Defining of success and failure indicators and factors

Figure 1.
Information system analysis applied to geographical information.



- Analysis of internal decision procedures, including the description of the information system these procedures require
- Defining of information products, classified in five different categories according to when they are to be used:
  - * information-communication products
  - * products enabling strategic decisions (long and medium-term objectives, planning)
  - * products enabling tactical decisions (medium-term management)
  - * products enabling logistical decisions (short-term management, operating, maintenance)
  - * warning products
- Analysis of the use of these information products
- Gathering of knowledge of data, norms, and constraints for developing these products

[1]The logical procedure is to start at the base of the triangle (strategy), go up the left side for the analysis and down the right for setting up the information system. In some cases, the ascending part is neglected and a simple attempt to organize the available data (e.g., satellite images, surveys, bulletins) is made to set up the system. This is seldom successful.

- Analysis of tools to be used to obtain the information products

It must be pointed out that remote sensing and GIS will only be approached at the last stage in the proceedings.

The working basis of the AFEID remote sensing and GIS work group has been the decision process and function analysis grid used by a regional water distribution company, the SCP (Société du Canal de Provence). The analysis of irrigation-related techniques and the information products they produce has also been deepened by the comparison of experiences of different organisms such as research laboratories, planning companies, and service companies (both in France and in other countries).

AN EXAMPLE IN THE MANAGEMENT OF AN IRRIGATION SYSTEM

Now we consider the example of the management conducted by the Subdivision Officer (SDO) of the 70,000 ha Chistian Irrigation System in the Punjab, Pakistan, on which the International Irrigation Management Institute (IIMI) and Cemagref have been working for several years. This is a fictive example, since no real demand in terms of implementation of an information system has been formulated, though some demands were expressed concerning better communication means. The analysis briefly presented above leads to the following issues:

- the SDO's strategy is to monitor water distribution, but it is limited by institutional and technical rigidity
- the key factors of success mainly concern the productivity of the work which can be measured through water levels of secondary canals and the quality of water distribution service
- decision processes concern water distributions and devices operations, water police, and maintenance of the canals

Table 1.
The identified information products and their characteristics.

Level	Mission	Description	Product of information	Spatialized nature
Strategic	Planning of the maintenance	To establish a file of request for the planning of maintenance for the coming year	File, planning of the maintenance	Yes, for the requests
Strategic (or tactical)	Evaluation of the production operations	To evaluate and analyze the water distribution in determining the water levels at key points	Indicators of functioning	Yes
Tactical	Control planning	To plan the dates and places of control of the irrigation (irrigation practices, state of the devices)	Control planning	Yes
Tactical	Training for the regulation	Use simulation to test different alternatives of regulation	Simulation	Yes
Logistical	Network management	To ensure and control the distribution with functioning indicators (water levels at the head and tail) and the discharges delivered to the subdivision (anticipation)	Instrument panel and data storage	Yes
Logistical	Control and verbalization	Monitor (and update) the files of control and verbalization	Control map, database	Yes
Logistical	Followup of the maintenance works	Store and followup the works of maintenance	Table of intervention and monitoring of works of maintenance	Yes

CONCLUSION

The aim of the methodology proposed by the ICID working group is to help managers who wish to widen their management methods to embrace new technologies to:

- analyze their requirements in terms of information products rather than of data
- think in terms of decision processes beyond the information products themselves
- think in terms of management and organization beyond just the tools
- develop a geographical type information system, designed to meet their requirements, rather than a database that is both too general and unadapted

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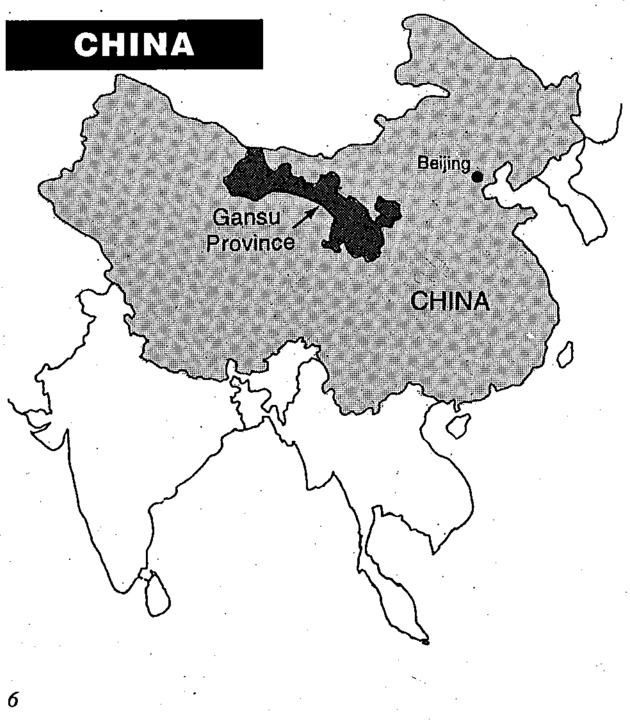
ITIS in the Field: Performance

CHINA



Remote Sensing Estimates of Crop Water Consumption in Oasis-Desert Systems of China

INTRODUCTION

Snowmelt rivers are an important source of water for agricultural production in the arid Northwest China. The geomorphology of the Gansu Province consists of mountains with permanent glacier caps, river basins at the foot of the mountains, and dry deserts forming the transition to Mongolia. The alluvial soils in the flood plains of the river basins are suitable for irrigated agriculture and the 400 km long strip of land between the mountains and the desert in the Gansu Province is known as the Hexi Corridor. China's food production relies on the agricultural productivity of the Hexi Corridor among other areas, and the irrigation intensity is still expanding.

The Heihe River basin is non-closed and the excess river water flows into the Gobi Desert. Irrigation is practiced in a 40,000 square kilometer area. New irrigation command areas are planned and are under construction to minimize water excess which is neither utilized by agriculture nor by nonagricultural users. The collaborative Sino-China HEIFE project was launched to support the planning and management of water resources in the Heihe River basin. The HEIFE project focused on water consumption of crops growing in the irrigated oases and evaporation from the deserts. It aims to gain better insights on the balance of water inflow from rivers and rainfall, and outflow through evapotranspiration and river runoff.

The project results showed that the spatial variations of evapotranspiration in an oasis-desert system were significant and that a regional average value could not be accurately estimated from a selected number of detailed on-site field measurements. Remote sensing has been used to get a better impression of the regional evaporative conditions. The objective of this note is to demonstrate that remote sensing can be applied to study the regional water consumption which is a key element for assessing the future planning of irrigation activities in non-closed river basins.

EVAPOTRANSPIRATION FROM REMOTE SENSING

The Surface Energy Balance Algorithm for Land (SEBAL) model has been applied using visible, near-infrared and thermal infrared data from the Landsat Thematic Mapper. The spatial resolution of one pixel was 30 m being sufficient to locate the detailed field measurement sites. The average root mean square error between measured and estimated fluxes from SEBAL was 23 W m^{-2}. The relative error of actual evapotranspiration for deserts and oases was 33 percent and 8 percent, respectively. Four field measurement sites were equipped with three different systems to measure the actual evapotranspiration: (i) weighing lysimeters, (ii) bowen-ratio surface energy balance systems, and (iii) eddy-correlation measurement systems. It is generally accepted that eddy correlation fluxes provide a better assessment of the field scale heat fluxes than the other measurement methodologies. It should be noted that a difference of 37 percent existed between the various measurement techniques, which demands a more careful interpretation of field measurements on consumptive use.

The regional crop water stress has been expressed in terms of the evaporative fraction (latent heat flux/net available energy). The summer conditions show that the evaporative fraction in the oases of Linze and Zhangye was 0.82 and 0.79, respectively, exhibiting optimal soil moisture conditions (crop stress emerges if the evaporative fraction is less than 0.75). The autumn conditions indicate an evaporative fraction of 0.81 for Linze and 0.85 for Zhangye. The spatial variation in crop water stress, with a standard deviation/mean of 5 percent was extremely small, implying that the alluvial soils are, without exception, sufficiently moist everywhere. Probably, much irrigation water can be saved by the construction of reservoirs. More irrigation water can be made available at the downstream side of the Heihe River if water saving techniques are applied at the upstream side. The evaporative fraction which is representative for the river basin, including various oasis-desert systems, varied between 0.48 in summer and 0.61 in autumn. These extremely useful figures can be used to calculate the actual regional evapotranspiration.

RIVER BASIN MANAGEMENT AND REMOTE SENSING

Although not operationally established, the planning of irrigation water application in the Hexi Corridor can benefit from remote sensing data. The integration of flow records of the Heihe River with the amount of water evaporated on an annual basis (thus by time integration of remotely sensed actual evapotranspiration) provides a sound basis to divert river water to the various oases systems found along the river course. The basin-wide evapotranspiration is 1,215 million cubic meters per year. The total inflow of surface and subsurface sources is independently estimated as 2,155 million cubic meters per year. Hence, an amount of 940 million cubic meters per year is in excess and, therefore, utilizable, if commitments with downstream users do not exist. Besides this quantity, it appeared that much irrigation water can be saved for downstream users as the oases seem to receive more river water than required by the crops. It is expected that river basin management can profit from remote sensing, especially if the costs of the images will decrease and images can be obtained with a short repetition time.

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Space Observations on Uniformity of Irrigation Water Distribution

INTRODUCTION

Allocation of irrigation water can be based on several principles. Equal water supply to all beneficiaries is the main principle practiced in the warabandi systems of Northwest India. The principle of equity implies that all farmers receive a fraction of the crop water needs, preventing the crop from complete failure. This is also known as protective irrigation. The scheme objectives can be evaluated against the uniformity of irrigated land and crop water consumption using remote sensing measurements. In the Nile Delta (Egypt), water supply is based on anticipated cropping patterns and their associated water needs. Evaluation of the systems' performance can be achieved by the uniformity of crop water stress. The irrigated alluvial fans in Argentina supply irrigation water on the basis of historical water rights. Farmers have to pay levies for the right to receive canal water. Crops with high evaporation can be detected from space and compared against administrated rights. The present note aims to show some major different observations between these schemes by a generic remote sensing technique based on Landsat Thematic Mapper measurements.

REMOTE SENSING OBSERVATIONS OF IRRIGATED REGIONS

India—Haryana has insufficient water resources available for irrigating all the agricultural land. Farmers receive irrigation water according to their landholdings and the amount is insufficient to meet crop water demands. The fractional vegetation cover has been computed from Landsat Thematic Mapper's red and infrared channels (30 meters resolution) for an area stretching from the Punjab to Rajasthan. The concept of the minimum and maximum Soil Adjusted Vegetation Index (SAVI) has been applied. The Punjab has a contiguous pattern in vegetation cover. The Hisar and Sirsa districts in Haryana indicate more spatial contrast in vegetation cover (standard deviation/mean = 0.25) revealing less contiguous irrigation practices. The latter may be caused by less canal water availability per unit land or by the lower density of tube wells due to the presence of saline groundwater in Haryana as compared to the Punjab. The nonuniformity of the vegetation cover and consumptive use from irrigated plots cause a more than tenfold water consumption from irrigated fields than from non-irrigated fields. The water distribution does not conform to equity (standard deviation/mean varies between 0.2 and 0.25, see table 2). Hence, the objectives of uniform irrigation are not met.

Egypt—The Nile Delta receives sufficient water to irrigate the clay soils in the Delta at full demand. The objective of unstressed growing conditions can be verified by looking at the crop water stress determined from space measurements (evaporative fraction = actual/potential evapotranspiration). It seems that only the fringes of the Delta adjacent to the desert respond with crop water stress. Either this area is not receiving a sufficient quantity of water, cropping intensity due to farmer decisions is reduced, or the coarse textured soils lack water-holding capacity. The spatial variation of actual evapotranspiration in the central part of the Delta is remarkably low (standard deviation/mean is between between 10% and 15%, see table 2). This homogeneous water consumption can be attributed to cyclic use of water as many farmers pump irrigation water from the surface drains. Considering an evaporative fraction of 75 percent to be satisfactory, it may be concluded that irrigation objectives are met for 48 out of 53 irrigation districts. If the target value for evaporative fraction is higher, water allocation to maize and the desert fringes should be corrected.

Argentina—A vineyard conglomeration of 75,000 ha is irrigated at the foot of the Tunuyan River in the Mendoza Province. The spatial delineation in actual evaporation and evaporative fraction reveals that the central part of the irrigation scheme receives more water than the secondary canals located at the northern and southern edges surrounded by the desert and hills. The eastern edges receive a sufficient quantum of irrigation water. The differences among the secondary units are rather reduced. Table 2 shows that the evaporative fraction is much lower than found in Egypt and India and is caused by the image acquisition at the end of the irrigation season.

Table 2.
Area-average conditions and spatial variation of irrigation determinants obtained from Landsat Thematic Mapper data for three irrigation schemes: Bhakra Canal (India), Nile Delta (Egypt), and Rio Tunuyan (Argentina).

Location	Date	Vegetation cover-		Latent heat flux-		Evaporative fraction-	
		mean	cv	mean	cv	mean	cv
India, Haryana	4th December, 1995	0.4	0.25	246	0.20	0.70	0.25
Egypt, Nile Delta	27th July, 1987	0.8	0.10	407	0.10	0.86	0.15
Argentina, Tunuyan	5th March, 1990	0.6	0.20	220	0.06	0.47	0.06

Note: cv = standard deviation/mean.

CONCLUSIONS FOR SYSTEM OPERATION

Improper and local information on aspects related to the actual irrigation condition can jeopardize decision making with respect to the uniformity of canal water distribution. The examples have shown that uniformity in irrigation practices can nowadays be computed from remote sensing data to evaluate uniformity in irrigation processes at the regional scale. The information can be explored to enable irrigation systems evolve towards decision making on canal water distribution on the basis of concurrent satellite monitoring.

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Announcement

ICID-FAO Guide on the Use of Remote Sensing and GIS in Irrigation and Drainage

ICID is preparing, in cooperation with FAO, a Guide on the Use of Remote Sensing and GIS in Irrigation and Drainage, which will be issued by late 1997/early 1998. This guide will be available in both English and French, and will be organized in chapters as follows:

1. *Principles of Remote Sensing and Geographical Information*
2. *Methodological Guide on the Use of Remote Sensing and GIS in Irrigation and Drainage*
3. *Examples of Applications in the Areas of*
   - *evaluation of irrigation potential*
   - *management of irrigation systems*
   - *drainage and salinity monitoring*

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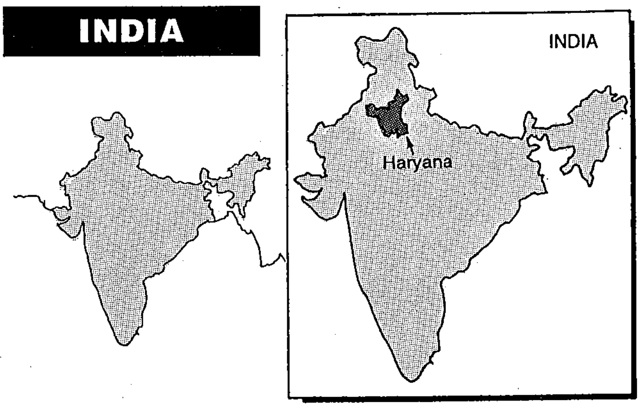
Performance Analysis of a Wheat-Based Irrigation System Using SRS and GIS Techniques: A Case Study from India



INTRODUCTION

The study was undertaken by IIMI in close collaboration with the National Remote Sensing Agency (NRSA) of India and the Irrigation and Water Resources Department (IWRD) of the State of Haryana, India. It aims to inventory the Bhakra canal command area in the State of Haryana.

The main objective of the study is to test the application of a total package of SRS and GIS techniques to evaluate the performance of a wheat-based system and to demonstrate the utility of these techniques as an operational tool for system improvement. The specific objective of this study are:

- the generation of desagregated statistics on total irrigated areas, area under major crops, and wheat productivity
- the integration of satellite-derived statistics with other relevant ground measured data to identify factors constraining agricultural performance and to develop strategies for improved water distribution and agricultural productivity

THE BHAKRA SYSTEM

The Bhakra system has a cultivable command area (CCA) of 1.2 m ha partitioned into 3 operational systems, 13 divisions, and 41 subdivisions. In this command, area irrigated by groundwater through shallow and deep tube wells is almost equal to that irrigated by canal water. The surface irrigation system is operated according to warabandi principles. The Bhakra canal system has been in operation since 1955-56. Presently, most of the irrigated area is occupied by high yielding varieties of rice, wheat, and cotton.

The average minimum temperature fluctuates around 5 °C and the maximum around 45 °C. The average annual rainfall in the command varies from 750 mm in the northeastern to less than 400 mm in the southwestern parts. During rabi, rainfall varies from 100 mm to less than 50 mm. Evapotranspiration is estimated to vary between 1,250 mm and 1,650 mm per year, being equivalent to an average of 4.5 mm per day.

SATELLITE INVENTORY OF THE BHAKRA CANAL COMMAND AREA

The Bhakra command area is covered by two paths of the IRS IB satellite. Keeping in view the cropping pattern and crop calendar, five dates of satellite overpass (21/22 November 1995; 26/27 January 1996; 17/18 February 1996; 10/11 March 1996; and 01/02 April 1996) were obtained. The above data-supplemented by LANDSAT TM data of December 1995 cover the whole period of the rabi crop season of 1995–96.

Field visits were carried out for collecting information on crop cultivated, crop calendar, crop condition, groundwater quality/utilization, and locational position of crop-cutting experiment (CCE) plots (latitude and longitude) for development of the wheat yield model. The accuracy of crop classification was also validated during this field visit.

Due to staggering in the crop calendar across the command area, satellite data of any one overpass date could not achieve complete classification of crops and hence satellite data of 5 dates during the growing season were analyzed. An innovative classification methodology was developed by combining supervised (maximum likelihood) and unsupervised (clustering) techniques.

The crop classification was validated against sample areas identified during the field visits but not used in classification, as well as randomly selected area observed during the field visit. An overall *kappa accuracy* of 95 percent was obtained.

Ground-harvested wheat yields in 270 plots were obtained from the Agriculture Department of the State of Haryana. The latitude and longitude of CCE plots were measured through a hand-held GPS receiver. The NDVI of 17/18 February 1996, representing the maximum value corresponding to the heading phase of wheat, was used as the independent variable in the regression. The wheat yield model is computed as yield = 3.75 + 0.043 NDVI with coefficient of determination of 0.85 and a standard error of estimate of 0.217 t/ha. The regression coefficient is significant at 99 percent confidence level. Using the linear regression model, the yield in t/ha was estimated for every wheat pixel, to enable aggregation over any desired aerial unit such as distributary/minor command, canal subdivision, division, and water circle.

GEOGRAPHICAL INFORMATION SYSTEM

To enable more comprehensive spatial analysis and to integrate more ground data which are in different scales and information levels, all relevant data have been organized in a GIS environment using IDRISI. Information integration analysis was attempted through union and intersection techniques.

The GIS application covered two main aspects in this study:

- characterization of command area in regard to agricultural productivity, canal supply, and groundwater regime and their interrelationships to help identify policy issues on the long-term sustainability of the irrigation system

- answer specific queries on location-specific corrective management, such as areas with potential waterlogging problems, areas for reclamation, areas of soil limitations to wheat productivity, etc.

RESULTS OF ANALYSIS

The wheat yield and wheat production across the command area for rabi 1995-96 were obtained. The spatial variability of irrigation intensity (cropped area to cultivable command area), wheat as percent of total cropped area, and oilseed as percent of total cropped area were also obtained. Average wheat yield over the command area is estimated to be 4.09 t/ha. Distributaries/minors having less than 90 percent of divisional mean wheat yield are considered poorly performing distributaries/minors. Based on this criterion the names of distributaries/minors of poor wheat productivity were listed out for taking corrective measurers.

Based on the RS and GIS study, two main observations were made:

1. In canals having fresh groundwater, mean wheat yield is high; percentage of wheat area is also high; and surface water supply is low. Wheat yield, percent wheat area, and canal supply remain constant along the channel length. The groundwater depth is around 10 m and is falling moderately over the years.

2. In canals having marginal and saline water, mean wheat yield and percent wheat area are low; surface water supply is high. Wheat yield and percent wheat area decrease along the canal length while surface water supply remains constant or increases. Groundwater level is fast rising and in many places, the groundwater depth is less than 3 meters.

The above two observations have been used to draw the following conclusions:

CONCLUSIONS

1. This study has demonstrated the utility of SRS and GIS techniques to assess the irrigation system performance of a wheat-based irrigation system.

2. The present practice of allocating and distributing the surface water leads to high productivity of water, but the sustainability of maintaining such high productivity seems to be questionable due to marginal and saline groundwater levels rising fast while the fresh groundwater level is receding. This unsustainable situation can be corrected through proper planning of surface water allocation and distribution.

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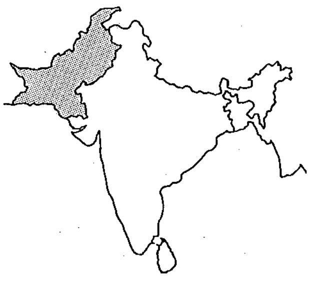
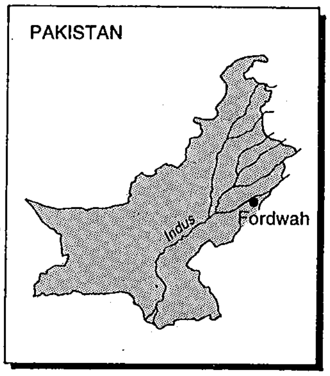
ITIS in the Field: Water Quality

PAKISTAN





Remote Sensing Applied to the Assessment of Salinity in Irrigation Systems: Some Results Obtained in Punjab

INTRODUCTION

Among the 270 million hectares of irrigated surfaces, it is admitted that 100 million have been, or will soon be, brought out of cultivation due to waterlogging, or soil salinization, or both, as a result of irrigation (Smedema 1995). Accurate information to assess the magnitude of these problems for specific irrigation schemes and to identify solutions for improvements is rare. Thus, satellite remote sensing represents a great potential for salinity assessment, especially in large irrigation systems such as those existing in Pakistan.

Since 1994, Cemagref and IIMI have been cooperating to develop an integrated approach to assess the impact of changes in irrigation management on agricultural production and salinity. The approach is currently developed and tested in a large irrigation system in Pakistan, a country with 17 million irrigated hectares, where there are soil salinization concerns around 20 percent of the area. The irrigation system selected for testing the integrated approach is the Chishtian Subdivision of the Fordwah/Eastern Sadiqia Irrigation System, South Punjab. With a command area of 69,000 hectares, the Chishtian Subdivision is fed by the Fordwah Branch Canal, and includes a mix of perennial (receiving canal water the year-round) and non-perennial (receiving canal water during the kharif or summer season only) secondary canal or distributaries. Surface water is complemented by groundwater of lower quality (higher salt content), pumped by more than 4,400 private tube wells installed by farmers in the command area of the Chishtian Subdivision.

This article briefly presents the first results obtained in the assessment of soil salinity using remote sensing techniques.

SOIL SALINITY MAPPING

Several studies have already been completed on the assessment of soil salinity using remote sensing, but they have not been very successful. The original method developed by Tabet (1995) relates the vegetation and brightness indexes derived from SPOT XS to visual observations of salinity indicators.

The obtained classification enables to identify mainly the areas of high salinity (66% of well classified fields), and non-saline areas (80% of well classified fields). The areas with low to medium salinity are more difficult to identify. Current studies try to improve these results by using several SPOT and Landsat-TM images on the same cropping season, and by validating visual observations with soil analyses undertaken in laboratories. This classification provides a first map of salinity on the irrigated area.

ANALYZING THE DISTRIBUTION OF SOIL SALINITY IN RELATION TO OTHER SPATIAL FEATURES

When the limits of the watercourse tertiary command areas and the topography are displayed along with SPOT-derived salinity maps, it is possible to obtain preliminary information on some of the causes of salinity. Though it would be necessary to model transfers of salts from tube well water to fields, two trends have been identified for two sample watercourse command areas:

- *Primary salinity* is related to local morpho-pedogenetic conditions, and, in the present case, located in micro-depressions with more clayey soils corresponding to old meanders of the Sutlej River. Spatial and temporal dynamics of this salinity type are not well explained yet, but they may be due to the proximity of the water table with vertical and lateral salt transfers and due to seasonal climatic conditions (Tabet et al. 1997).

- *Secondary salinity* is related to irrigation practices, and, in the present case, to the use of low quality groundwater, more saline than canal water: salinity then appears where canal water is rare or even absent (for example, the tail of the watercourse), and/or where groundwater represents an important part of irrigation water.

PRELIMINARY CONCLUSIONS

Though these first results are encouraging, they are mostly limited to areas where salinity and/or sodicity is already high enough to yield salt crusts on soil and/or salinity patches with vegetated areas, corresponding to a poor crop growth. The detection and the assessment of lower levels of salinity/sodicity within vegetated fields are difficult, mainly because satellite images of common spatial resolution of 20 meters do not allow to get precise information from small fields of 1 acre (0.4 ha), and also because the impact of salinity, and particularly of sodicity, on crop growth and electromagnetic properties needs to be further explored to understand how it can be derived from remote sensed information.

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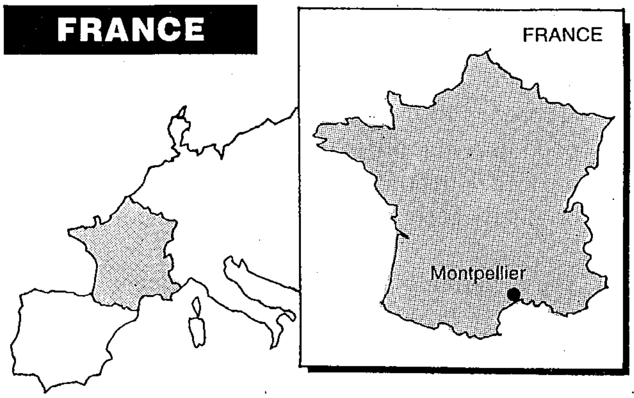
FRANCE



A Regional GIS Model for Water Quality Assessment in Irrigated Areas in France

INTRODUCTION

Following decades of highly intensive agriculture, nonpoint source pollution from agricultural areas is becoming an increasing concern in western Europe as chemical loads are increasing in both surface water and groundwater. This pollution is added to the untreated components of waste water from urban areas. Altogether it contributes to increasingly jeopardize the natural eco-system and the domestic water supply. European authorities have recently been driven to enforce strict standards for domestic water quality and promote better watershed monitoring and management. In the low lands along the Mediterranean coast in the southeast of France, the situation of lagoons is worrisome in that regard. An average increase of nitrate content of 2 mg/l per year has been measured during the eighties in the groundwater connected to the Mauguio lagoon, east of Montpellier. Some wells for water domestic supply are now temporarily or permanently abandoned as they do not match the quality standard for nitrates. In 1991, a survey made by Cemagref showed that:

- 448 tonnes/year of nitrates are contaminating the lagoon and its aquifer, out of which 50 percent is estimated coming from urban areas, and 36 percent from agricultural areas

- 68 tonnes/year of phosphorus are pouring into the lagoon, out of which 80 percent is from urban areas
- 80 percent of the nitrogen and phosphorus pollution from urban areas is located downstream of sewage treatment plants which were not originally designed to treat those components

These alarming figures motivate regional authorities to:

- develop a regional model to monitor the agricultural practices and the resulting pollution within the watershed
- invest in tertiary treatments to reduce nitrogen and phosphorus from sewage water

The regional model for agriculture was developed in 1993–94, on a pilot area (2,300 ha) of the Mauguio lagoon watershed totaling 357 km^2. It has been used essentially to assess the spatial variation of the vulnerability and the risk to nitrate and phosphorus pollution. A second unexpected application of the regional model has been the identification of possible sites for reuse of waste water in agriculture as an alternative to tertiary treatment.

REGIONAL MODEL FOR VULNERABILITY AND RISK TO NITRATE AND PHOSPHORUS POLLUTION

The regional model has been developed as a combination of a GIS (ARC-INFO) and a semi-deterministic distributed model: CREAMS (Knisel 1981) and also with the upgraded version GLEAMS. The CREAMS model is composed of several sub-models: Hydrology - plant growing - nitrogen leaching - erosion - phosphorus production. It calculates the daily runoff, erosion, deep percolation, and chemical fluxes from time-dependent parameters at a daily time step (rain, crop growing information, data of chemicals applications, and irrigation inputs). It requires some macroscopic calibration (lumped level). CREAMS was interfaced with ARC-INFO using a special linking program.

APPLICATION TO NONPOINT SOURCE POLLUTION ASSESSMENT

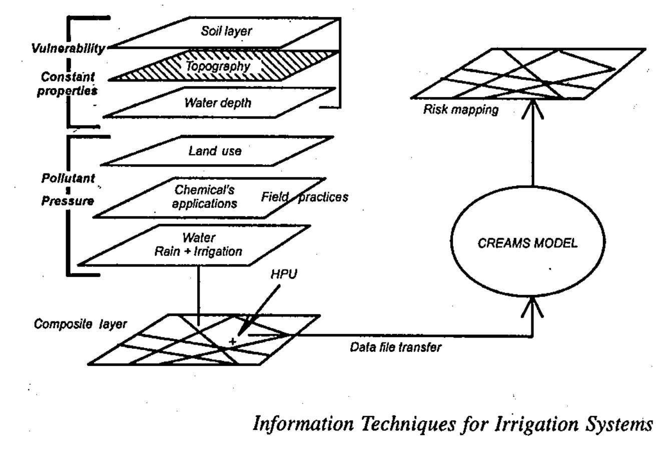
The definition of "sensitive area" to pollution, includes both vulnerability and risk notions. Vulnerability is defined as the propensity of an area to be impacted by a specific threat. This is a general concept depending only on the permanent land characteristics (soil, topography, etc.) and the physical and chemical behavior of a specific pollutant. For example, nitrates are mostly leached towards groundwater while phosphorus is carried along by runoff. Vulnerability does not change over time.

The notion of Risk is derived by combining the vulnerability of a given area, with a "pollutant pressure" representing in that case, specific land uses, and agricultural and irrigation practices (quantity and frequency of inputs). The notion of Risk varies in time as practices can change.

In the first stage, an overlay weighted process was used to identify a homogeneous unit for vulnerability from soil, topography, and water depth layers of information. The resulting vulnerability map allows to identify particularly areas for which soft practices should be highly promoted. In a second stage, the homogeneous production unit (HPU) combining vulnerability and pressure layers of information (land use, field practices, and water budget), is identified as shown in figure 2. Each HPU has specific land use, soil type, general slope, tillage, fertilization, and an irrigation scenario. Except in a highly contrasted situation, practical consideration has led to retain existing fields as the frame for the HPU.

For each HPU, CREAMS Model computes the daily amount of nitrate leached below the root zone and of phosphorus that has drifted away from the field. The output is a risk map displaying the load of pollution per time. It allows to simulate the current

Figure 2.
Mapping vulnerability and Risk.



situation and evaluate the performance of any alternative scenario of agricultural practices in reducing the pollutant load.

APPLICATION FOR DESIGN SUPPORT SYSTEM FOR REUSE OF WASTE WATER IN IRRIGATED AREAS

The regional model and particularly the GIS abilities, appear to be also very useful for site identification and the design of management rules for reuse of waste water in agricultural areas. This study was motivated by the fact that for small and medium communities, the cost of classical tertiary treatment is somehow prohibitive and reuse of water on agricultural lands after primary and secondary treatments appears to be an interesting potential alternative.

The methodology was developed in several steps (i) exclusion of areas with regulation constraints: identification of sensitive entities (household, water withdrawal points,....), building of protected areas around them (buffer), and identification of the remaining fields; (ii) identification of the more suitable irrigated fields, combining distance to the treatment plant, vulnerability to erosion and percolation; (iii) identification of the system layout, by testing manually or automatically different layouts; (iv) identification of fields for a low duty system (water supply limited to evapotranspiration); (v) identification of fields for high duty system (duty greater than evapotranspiration) for nonirrigation season; and (v) management scenario and performance of the elimination.

The results showed that the scattered urban area development around the greater treatment plant (10,000 inhabitant equivalents), leaves no place for waste water reuse in agriculture. For the two others, 700 and 3,000 inhabitant-equivalents, several scenarios were proposed to the partners of the project. The flexibility of the GIS regional model was found to be a paramount property, as it can be adjusted to any change in the negotiation process between local authorities and farmers. And in sensitive issues such as reuse of waste water, this was felt to be of great importance.

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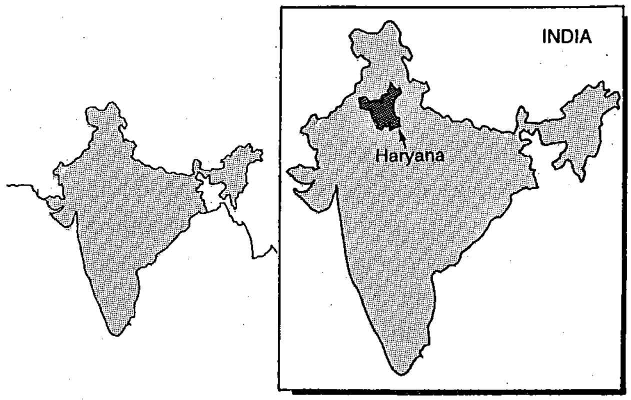

Regional Water and Salt Balances Obtained from GIS and Hydrological Models

INTRODUCTION

The rapid expansion of irrigated lands in Haryana, India, during the last two decades has led to a destabilization of the regional water and salt balance. Although irrigation water is scarce, Haryana is afflicted by large-scale waterlogging. Improved on-farm water and salinity management is conceived as the cornerstone for the development of a better and sustainable agricultural irrigation system. On-farm water losses at micro scale affect the meso scale buildup of water and salts. Micro scale field experiments conducted in the framework of the Indo-Dutch project at Hisar focused on studying the response of the soil-crop-atmosphere continuum to various irrigation regimes at a set of given boundary conditions. The experiment indicated possibilities to halt the imbalance between inflow and outflow of water at field scale by means of water management interventions such as reduced water supply at shallow water tables, installation of subsurface drainage systems, and lower application depths to prevent groundwater recharge. These results from small-scale experimental pilot areas should, however, be envisaged as being site-specific.

The canal command area of the main canal Bhakra system serves more than 1.2 million ha comprising a variety of climatic conditions of the overlaying atmosphere, soil types, and subsurface hydrological conditions. The findings from experimental fields generally reflect specific combinations of soil and climate, and recommendations may not be made generic. New extrapolation techniques between farm plots and the Bhakra Canal command area were therefore deemed necessary. GIS information has been used to describe the environmentally distributed conditions at the regional scale. Based on the GIS and hydrological models, a Decision Support System was developed to compute longer-term water and salt balances, which guides water policy makers in the allocation of canal water amounts. This article shows how GIS techniques can contribute to the process of hydrologically quantifying farm-plot conditions under different environments.

GIS PROCEDURES TO INFER GEOGRAPHICALLY IDENTICAL UNITS

The required amount of canal water depends on crop type, soil type, potential evapotranspiration, tube well water supply, leaching requirement, and capillary contribution from the soil matrix. These properties exhibit a distinct spatial variation in Haryana and a straightforward water requirement computation cannot be compiled. Basic maps of soil, depth to the water table, groundwater quality, rainfall, and potential evapotranspiration were digitized from available maps being prepared by several governmental organizations in Haryana. An overlay procedure of these maps has been applied yielding to units having geographically uniform information, i.e., geo units. After leaving out units of less than 10 ha, Haryana could be classified in 67 geo units. These units have reduced internal spatial variations of the environmental conditions mentioned. Physical properties of soil such as water retention characteristics and unsaturated-saturated hydraulic conductivity have been assigned to the geo units after having identified their textural properties. Also crop properties such as root depth development, leaf area development, and sensitivities to moisture and salinity stress are assigned for the dominant crops in given geo units.

HYDROLOGICAL MODEL

The GIS database has been employed to compile input data for hydrological on-farm management models. All 67 discerned geo units were modeled to study the response of canal water supply on crop and environment. The water and salt balances were obtained from the transient moisture-solute transport model SWAP. This column model simulates the transport of water and salts with depth increments of 10 cm and time increments of minutes. The model output comprises information on the number of days that the water table has been in the root zone, the pace of water and salinity buildup and reveals all necessary information to compute the actual crop yield.

The leaching requirements and capillary contribution varied substantially across Haryana, and as a result, a nonuniform canal water supply is necessary to meet demands of crops and soil environments. The canal water quantum necessary to reach a long-term sustainable irrigation system in Haryana with crop yields being more than 75 percent of the local maximum attainable crop yield has been computed for each of the 67 geo units. All data on irrigation and the response of crop and environment are stored in the Haryana Irrigation and Drainage Compendium. The latter compendium not only contains the theoretically desired amount of canal water, but also contains the effect of different canal water and drainage scenarios on crop growth and water table fluctuations. The canal water scenarios tested consist of full canal water supply according to crop water demands, reduced supply and pre-sowing water supply only. The drainage options are composed of subsurface drains at shallow and deep depth, besides the absence of the drainage system. Table 3 demonstrates some selected results if interventions in irrigation and drainage are made effective for an arbitrary selected geo unit. The power of GIS can be utilized to create graphical output of selected hydrological parameters such as moisture saturation and actual/potential transpiration.

IMPLICATIONS FOR CANAL MANAGEMENT

As the geo units and the canal water conveyance network are both spatially referenced and stored in a GIS, agricultural water management of geo units can be aggregated up to the scale of canal command areas. The fusion of geo units with the canal conveyance network allows the possibility to compute the required canal water quantities for the head of distributaries.

Table 3.
Effects of irrigation conditions on the hydrological conditions of a geo unit containing loamy sand, a water table of 2 m, a groundwater solute concentration of 2 dS m-1, and a wheat-cotton rotation scheme.

Parameter	Full irrigation and drainage	Reduced irrigation and drainage	Pre-sowing irrigation and no drainage
Irrigation (mm)	830	430	190
Moisture storage change(%)	+1	+2	0
Moisture saturation (%)	62	48	36
Actual/potential transpiration (%)	86	77	55
Critical/actual salinity (%)	10	40	52
Salt storage change (%)	-3	+5	+4
Drainage (mm)	236	2	0

The distributaries and minors in Haryana are gated which enables the Irrigation Department to adjust the number of running days per year. This not only saves valuable canal water but diminishes the waterlogging problem simultaneously. This water should be added as extra water to those distributaries which need additional good quality canal water to leach the soil.

The socio-political dimension of canal water allocations in the present GIS model study has not been considered and this was realized from the onset of the project. A systematic inventory of the problem areas and the profitable technical interventions to alleviate the environmental deterioration received first attention. By using the Irrigation and Drainage Compendium, water planners can get a better idea on how canal water should be theoretically distributed, taking farmer preferences into consideration. The database can help them in negotiations with irrigation engineers and water user associations to define a solution which is acceptable to and satisfactory for all parties to halt the rise of the groundwater table.

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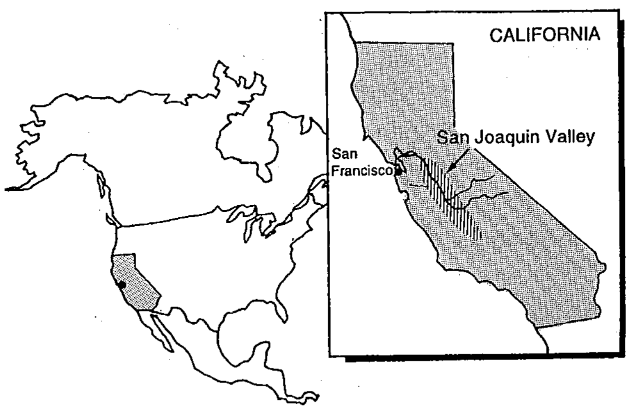
Spatially Distributed Water and Salt Balances Using GIS: Panoche District, California

CALIFORNIA



BACKGROUND

The west side of the San Joaquin Valley, California is one of the most productive agricultural regions in the world. However, agriculture in this region is threatened by shallow water tables, salt accumulation, and selenium-tainted drainage water. These problems are interrelated and solutions addressing one often affect the others. Shallow groundwater within 1.6 meters of ground surface affects nearly 400,000 ha of land in this region. The presence of a shallow water table creates problems for deep-rooted plants and makes soil salinity control difficult. In response to these problems, subsurface drains have been installed to control water table elevations and enable salt leaching. However, these drains collect naturally occurring selenium mobilized by water moving trough the soil profile. Selenium toxicity has been observed in wildlife coming in contact with the drainwater. Because of this, the reduction in volume and disposal of drain water have become primary concerns for the Valley's agricultural industry.

The occurrences and causes of these problems are not spatially uniform, and attempts to address them require analytical tools that account for this variation. Recent improvements in data collection within a centrally located water district have allowed for the calculation of water and salt balances at a finer scale than was previously possible. The study was undertaken in the Panoche Water District (15,000 ha), located on the west side of the San Joaquin Valley. It lies on two alluvial fans and is generally flat with land slopes of no more than 1 percent. Predominant crops in the district are cotton, melon, and tomato which cover over 70 percent the land area. Mean annual rainfall is 230 mm.

SPATIALLY DISTRIBUTED BALANCES

Spatially distributed water and salt balances were calculated for the Panoche Water District for the year 1.10.1995 to 30.9.1996, using GIS. The spatial resolution of the control volumes within the district was limited by the spatial resolution of the known water balance components. Rainfall, evapotranspiration, and fallow season bare soil evaporation were calculated as a depth and therefore they were not factors in determining spatial resolution. Data on infiltrating applied water and drainage were collected as water volumes applied or originating in a particular area. The spatial resolution of the infiltrating applied water was determined by the area served by a canal turnout. This resulted in 100 individual polygons ranging in area from 0.12 km^2 to 14.58 km^2 which represented areas as small as one field to as large as one ranch. A map containing polygons representing the area served by each drainage sump was also obtained. As drainage polygons did not correspond with the applied water polygons and also because of the partial coverage of the district by drainage polygons, the applied water polygons were used as the balance control volumes. A method for spatially disaggregating drainflows was then developed. Ultimately, the water balance was calculated for 98 control volumes.

ADVANTAGE OF THE GIS-BASED APPROACH

The developed methodology, i.e., water balance process and GIS, shows promise as an assessment tool that yields valuable insights into the spatial variability of water fluxes throughout an entire water district. The accuracy of the water balance approach was verified by results in agreement with those reached during groundwater modeling efforts. However, the water balance approach is conceptually more straightforward and practically easier to implement than a groundwater model. After the initial expense and effort in creating the database, updating the balance on an annual basis requires relatively little effort. The products, in the form of maps showing water fluxes throughout the district, will be useful to ranch and district management and the research community.

OUTPUTS OF THE STUDY

In absolute terms, the accuracy of the computed drainage output appears to be low due to the subtraction operation used in the process. Improving the accuracy of the inputs data should concentrate first on the main terms, i.e., evapotranspiration and irrigation.

In a more relative view, water balance calculations revealed that groundwater is recharged in upslope, undrained regions, and discharged as drainage and evaporation in downslope regions. Average depths of deep percolation in undrained areas were over twice those of drained areas. This difference in deep percolation suggested a difference in irrigation management correlated to proximity of the shallow water table. The salt and selenium balances revealed that the geology of soil materials plays a large role in salt and selenium leaching and accumulation rates. Also, salt and selenium accumulation in some regions suggests that anticipated future restrictions on drain water volumes or selenium loads will have a detrimental impact on the region's agricultural productivity.

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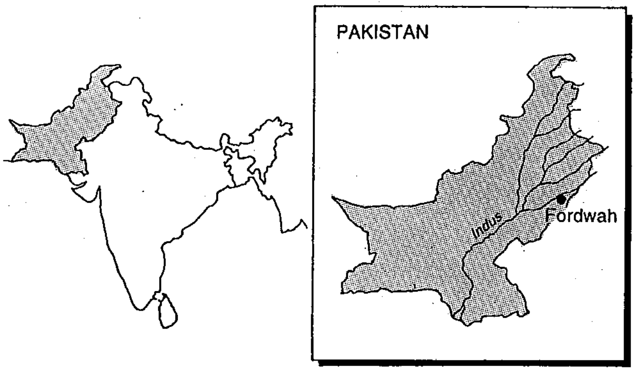
ITIS in the Field: User Perspectives

PAKISTAN



Using GIS and RS to Monitor and Evaluate Irrigation and Drainage Projects: Example from IIMI Pakistan National Program

BACKGROUND

Irrigation system performance has received increasing attention during the last decade as a result of poor performance of projects and policy interventions.
In large-scale irrigation and drainage projects in Pakistan, assessing performance requires a large amount of information that is currently scarce and whose accuracy is, often, less or unknown.
In this context, Remote Sensing (RS) and Geographical Information Systems (GIS) offer a high potential for obtaining and structuring information to improve monitoring and evaluation of irrigation and drainage projects and related policy decisions.
To address these issues, the International Irrigation Management Institute (IIMI), Pakistan National Program, started a research program in 1994, in collaboration with Cemagref, a French research institute for agricultural and environmental engineering, and the Watercourse Monitoring & Evaluation Directorate (WMED), Water and Power Development Authority, Pakistan.

OBJECTIVES

The main objectives of this collaborative research are:

- to assess the potential for GIS and RS to monitor and evaluate irrigation and drainage projects in Pakistan
- to identify appropriate methodologies to estimate selected performance indicators using RS

Based on research results, the final goal is to operationalize GIS and RS as part of the regular monitoring and evaluation activities of WMED or other potential partners. To assess performance requires a clear identification of the performance indicators, the scale at which performance is to be assessed, and the level of accuracy required by the potential users of this information. In terms of the use of satellite imagery, it is important to identify the appropriate combination of the number of satellite images, resolution, dates, bands, and ground truth information required to obtain a given indicator at the right scale and with the right accuracy. This article concentrates on the estimate of crop-related indicators such as area under different crops and cropping intensity.

INITIAL ACTIVITIES

Activities on the use of satellite imagery for estimating area under different crops and cropping intensity started in April 1994 in the context of the collaboration between IIMI and Cemagref. SPOT images from October 1994 and March 1995 were acquired for the Chishtian Subdivision (67,000 ha) that is part of the Fordwah/Eastern Sadiqia irrigation system, South Punjab. Supervised classification was performed independently for both images to obtain cropping pattern and cropping intensity for the *kharif* (summer)

1994 and the *rabi* (winter) 1994–95 seasons. An overall accuracy of around 95 percent was obtained for land use (i.e., cropped area versus other areas), but confusion remained between different crops (overall accuracy of 80-85% only).

METHODOLOGY

Based on the lessons from these initial activities, a collaborative research effort between WMED and IIMI with support from Cemagref was developed. This research is focused on the development of appropriate methodologies to identify crops and estimate cropping intensity and cropping pattern in irrigation systems in Pakistan. The sensitivity of classification results to specific elements that are part of the methodology development is being tested.

These elements include:

- different sample sizes for ground truth information, from 1 to 7 percent of the total command area
- different sampling methods, using square segments or tertiary unit command area as sampling units
- different combinations of dates, resolution, and number of bands of satellite images
- different intensity of ground truth data collection, from rapid surveys to more detailed monitoring of sample areas

The research effort is undertaken in the command area of the 3-R secondary canal of the Fordwah/ Eastern Sadiqia irrigation system with a command area of 28,000 ha.

PROGRESS AND EXPECTED RESULTS

Activities started in May 1997 for the kharif 1997 season. Initial output will include the production of primary agricultural statistics for the command area of the distributary. The comparison between these statistics and statistics obtained by WMED using their traditional sampling plans will lead to the identification of improvements in these sampling plans. The next step will be the production of secondary statistics using classification results and satellite imagery. A sensitivity analysis will be undertaken on the elements described above. Costs will be estimated for each option to identify the appropriate methodology required to assess the cropping pattern or cropping intensity at various scales of the irrigation system using various accuracy levels. Appropriate methodologies will then be implemented by WMED on a regular basis in various monitoring and evaluation projects.

FOLLOW-UP ACTIVITIES

The direct follow-up activity that will involve WMED and IIMI will consider the full area of the Fordwah/ Eastern Sadiqia (South) irrigation and drainage project. The operationalization of the methodologies identified will lead to the production of crop-related information that will be used in the preparation of the second phase of this irrigation and drainage project. Other follow-up activities will investigate other performance indicators such as actual evapotranspiration (using NOAA-AVHRR satellite) or crop yields. Such activities will start in October 1997.

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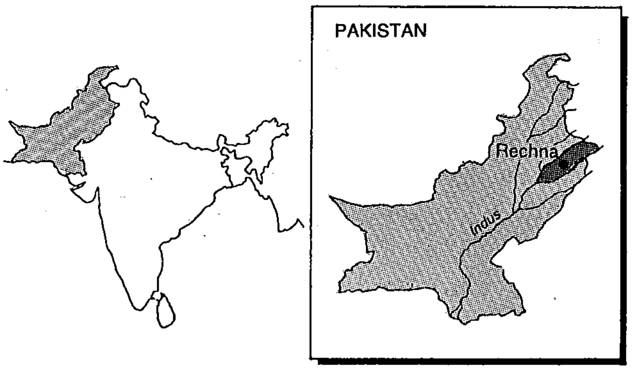
Announcement

Update on the World Water and Climate Atlas

Version 1 of the World Water and Climate Atlas developed by IIMI and covering Asia was released in March, 1997 and is available on CD Rom or through the Internet. This initial version of the atlas was released for illustration purposes and for seeking recommendations and suggestions for its improvement. A second version of the Atlas for Asia with improved maps and software will be available during the first part of 1998. The remainder of the World Water and Climate Atlas is due to be completed thereafter. To obtain the atlas, visit the Internet address http://atlas.usu.edu/. For further questions, contact Atlas@cgnet.com

PAKISTAN



GIS Framework for Salinity Management across Large Irrigation Systems: The Rechna Interfluve in North Central Pakistan

A COMPLEX AND HETEROGENEOUS IRRIGATED DOMAIN

The operational complexities in the use of the spatial information systems primarily derive out of the three-dimensional matrix comprising units in space and time and their qualitative or attributive profiles. An increase along any of these dimensions multiplies the complexity and handling of the respective constituent representations in space. In the context of large area inventories, such as across irrigated landscapes, these considerations become profound due to variations in physiography, cropping pattern, farming practices, and productivity changes over time. One such example could be quoted from the Punjab Province of Pakistan where the regime between the Ravi and Chenab rivers constitutes a bar upland interfluve that is under extensive canal irrigation comprising a total of 2.4 million hectares. Much of the system, irrigated by three major canals offtaking from an equal number of barrages/headworks along the length of the Chenab River, is more than 100 years old and has had a documented history of problems related to high water tables and buildup of soil salinization. The distribution system itself, comprising branch canals and secondary channels, is designed for equity. However, due to a host of physical and social reasons this objective is not globally realized. Incidentally, this aging system has also remained the focus of much of the past public sector investigations and land reclamation efforts; hence, the wealth of information is considerably more than on other parts of the Indus Basin.

INTEGRATION OF SCATTERED INFORMATION THROUGH GIS

Under a mandate from the Government of Pakistan, much of IIMI's past 10 years of research into the management of the irrigation system has remained confined to units comprising the secondary and tertiary level commanded regimes. This was essential to the understanding of the causes underlying emergent constraints to productivity. However, the absence of mechanisms for extrapolation of the results across successively larger geographical locales has prevented consolidated analyses encompassing areas of the size of a canal command or larger. For the Rechna *Doab* (interfluve) in particular, the challenge towards integrated assessment of multi-spatial and temporal data derived from different sources was considerable. Accordingly, the prerequisites of base stratification of public sector archives and IIMI's own data across a consistent reference in space called for an indispensable reliance on a GIS. This would facilitate not only the aggregation, and in many cases spatial resampling of existing mapped data but also the derivation of useful information pertaining to the geographic distribution of the sustainability rankings for crops, surface and profile drainage conditions, and three-dimensional variations in surface topography and groundwater quality.

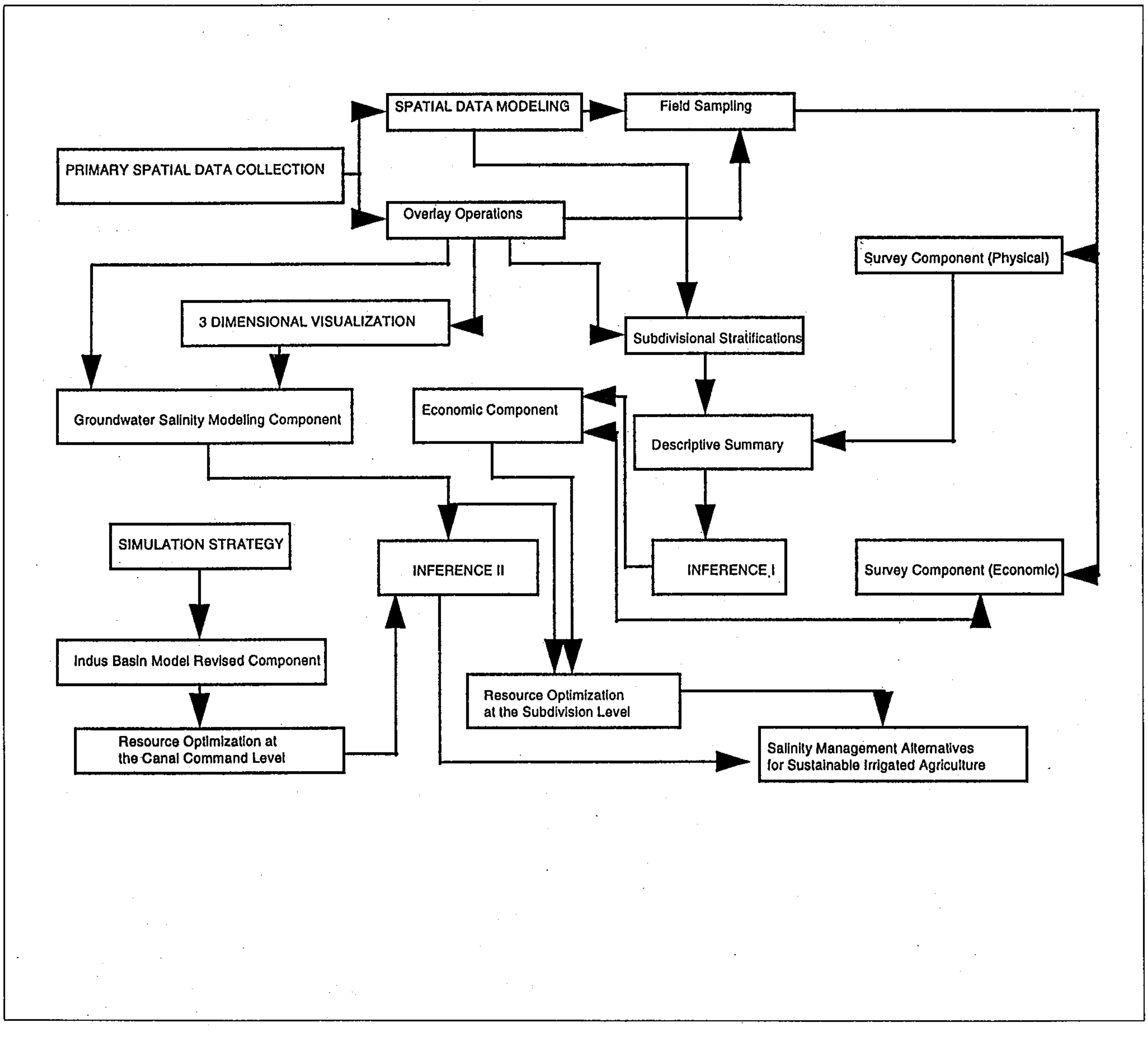
A MAJOR CONCERN: SALINITY MANAGEMENT

The multidisciplinary study, titled Salinity Management Alternatives for the Rechna Doab, Punjab, Pakistan formed a subcomponent of a larger project, Managing Irrigation for Environmentally Sustainable Agriculture, that has been funded by the Government of the Netherlands for the period 1994-1998. The study, begun in late 1994, was completed in June 1997, and comprises an 8-volume report that follows a sequential flow of information summarized in the Process Flow Chart given in figure 3. The objective definitions called for an evaluation of the existing physical and economic resource base across the multiple canal commands of the Doab that would facilitate deployment of strategies to combat land degradation. The intent was not to evaluate specific land reclamation strategies, such as the ones effected by the government in the past, but to explore options that are primarily management-oriented and coincident with realistically achievable targets. The ultimate goal of the overall evaluation process is to maintain the best returns at the farm gate.

GENERATED ALTERNATIVES

The GIS-generated thematic comparisons involving soil salinization, variations in surface texture, and their associative definitions (drainage and crop suitability), quality of groundwater for irrigation, and fluctuations in subsurface water levels together lent credence to the

Figure 3.
Process flow chart for the study of Salinity Management Alternatives in the Rechna Doab, Punjab, Pakistan.



selection of sample sights for in situ substantiation of the land degradation trends. Across the sample domain, 164 sites were monitored totaling 15,200 measurements of salinity taken through the EM 38 device. These measurements coincided with 443 farmer interviews recorded on a separate questionnaire. The questionnaire information helped establish the critical parameters for the generation of the production functions specific to the major crops grown in the area. These functions represent the economic slide rule for higher crop yields within their respective definitions of physical constraints that can be geographically accounted for, to arrive at cumulative production potential. Variations to the functional inputs would then constitute partial evaluations leading to the salinity management alternatives.

Towards comparative assessment of the salinity management alternatives at the canal command level for the years 2000 and 2010, the use of the Indus Basin Model has been indispensable. This model was developed by the World Bank for the Government of Pakistan to evaluate the economic costs and benefits of alternative water allocation strategies across the Indus Basin. For the study, the Model has allowed estimation of the productivity, costs, and profits that would be realized, given the options for extensive (land-related) and intensive (input-related) reliance on irrigated agriculture. In arriving at these comparisons, infrastructural adjustments towards augmentation of the irrigation supplies have been forsaken in favor of reallocation strategies. The conclusions are clearly drawn in favor of intensive inputs to irrigated agriculture to redeem the farm-level economies. Recommendations support a farm-level management program together with improvements to the hydraulic performance of the canals and institutional steps for groundwater management. The remediation has to be supported by the renewed commitment to the investigation of the current physical resource base that allows research activities to remain focused on coordinated salinity management.

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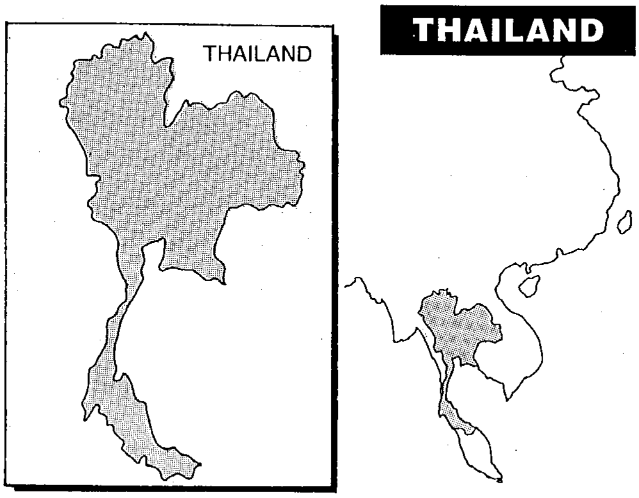
THAILAND



NAGA—A GIS-Based Software for the Monitoring and Diagnosis of Irrigation Projects

A large number of computer tools have already been developed with the aim to improve water management or irrigation projects management. Except for a few examples of automated irrigation projects in the most developed countries, their introduction has generally not been very successful. Too heavy data collection, poor data quality, lack of incentive or insufficient skills of the staff, difficulties in enforcing management rules at the lower levels of the scheme, and insufficient hydraulic regulation structures are some of the constraints commonly experienced by these programs.

The NAGA program is deliberately aimed at using existing data without demanding heavier data collection than is usually done. NAGA allows the manager to *visualize* the current situation in his scheme through the use of a GIS interface, and to analyze it by displaying time series of relevant data. In its first version, NAGA is designed to strengthen (or restore) the control upon what can be considered as the minimum and basic requirement of water management: the monitoring of water allocation in the different hydraulic units and the monitoring of the water level in the main canals. In fact, it is assumed that these two functions are a necessary first step in daily monitoring and water management, and that their mastering is a prerequisite to any further improvement. NAGA is, therefore, designed to allow easy and visual assessment of these variables, with little or no change in data collection.

(Existing) DATA

NAGA

- ➡ store and manage digital information
- ➡ visualize the current situation (discharges, water levels, settings, etc.)
- ➡ analyze, to improve decision making (in-season, post-season analyses)

NAGA is written in the MapBasic® language and is run under Mapinfo®. A "NAGA" menu appears in the main task bar and provides several facilities:

Monitoring of water allocation. Water allocation is shown on a map by assigning different colors to the hydraulic units. These colors indicate the status of current water deliveries compared to requirements. The hydraulic units are defined by the user according to existing flow data (a unit can exist if its inflow and outflow are recorded). They can be as small as a plot or can cover the command area of the main canals. The current water allocation (corresponding to the last data collection) can be displayed as the supply/requirement ratio (rainfall being taken into account) or in terms of discharge (l/s/ha, mm/day, cm). Alternatively, the same maps can be requested for a cumulated period (of "n" days, n being specified in the menu), which allows one to directly identify areas with water shortage.

Monitoring of water levels. A menu offers a selection of main canals whose longitudinal cross sections are available, showing current water levels and the elevation of the sill of the secondary canals branching from them.

Monitoring of one structure. By selecting (clicking on) a canal reach or a hydraulic unit, a menu is made available which proposes the cross section of the regulator which controls the inflow in the unit, with its current gate opening, upstream and downstream water levels and discharge, or a graph of the evolution of one (or all) of these four variables over the last "n" days.

"Times Series Analysis" offers a retrieval facility to graph or map any variable over a specified period. "Post-Season Analysis" is under development and will at once create a comprehensive set of maps, tables, and graphs giving a complete balance of one given season.

Other sub-items of the menu include "Creating Maps," which allows one to choose layers from a set of 15 basic layers, in order to create a custom map very quickly; "Maintenance Management," which can display the current status of maintenance of all canals, drains, and structures, as well as the past and planned operations; "Data Management," which retrieves data such as land use, rainfall, or yield series from normalized spreadsheets to display them as maps or graphs; "Build Canal Network," a utility used to create canal profiles; "Setting," which gives access to some parameters which can be customized.

Daily data are keyed in and managed in a separate Excel spreadsheet provided with several macros accessible through buttons. Data (discharge, water level, gate opening, rainfall) can be checked automatically and stored into separate spreadsheets which are read by NAGA.

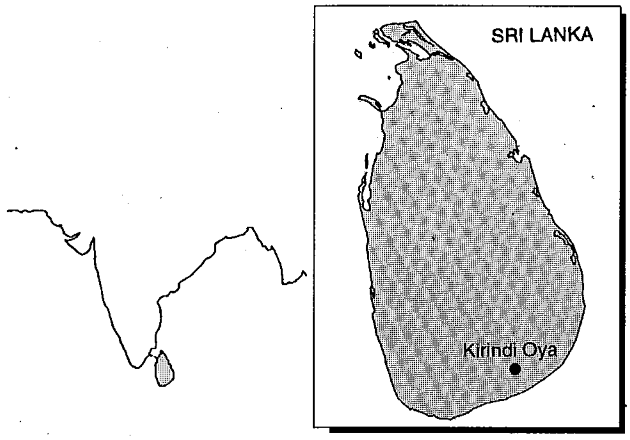
NAGA has been designed to be quickly adapted to a new irrigation project. All the normalized files have a fixed name, the first two letters being indicative of the project (KPcanal.tab, for example, is the canal layer of the Kamphaengsaen Irrigation Project). By simply changing this code in the settings and creating the normalized files, NAGA will work with another project.

However, no decision support systems can be built on weak data collecting and, like in any other Decision Support System, the quality of the information produced by NAGA is obviously related to the quality of the weakest link in the information chain. Poor data will generate poor information and the incentive to use the software will vanish very quickly.

Some of the expected benefits of the application of NAGA are: improved stability of delivery at the secondary level by an almost "real time" monitoring; monitoring of the global indices of efficiency and identification of mismanagement; digital storage of the project's data (often registered in books, with little possibility of analysis) alongside diagnosis facilities; control of data collection (imaginary readings will be revealed when compared with information on other adjacent structures); upgrading of the "visualization capacity" of the staff by resorting to geographic representations; easy weekly assessment of performance, and quicker and improved responsiveness to changing conditions allowing, in particular, better use of rainfall.

Continued on page 25

SRI LANKA



GIS for Irrigation Schemes Management: Sri Lanka Experience

INTRODUCTION

Management of irrigation systems demands the handling of large amounts of data. As most of these data are spatially distributed, one can expect that the quality of decisions made by irrigation managers could be promisingly improved by applying Geographic Information Systems.

Continued from page 24

Purposely simple, generic, and user-friendly, with a geographic interface allowing direct visualization of the current situation, NAGA is intended to be a first step tool towards improved water management, by upgrading monitoring capacity and by organizing daily data for any further time series analysis and diagnosis. It is currently being tested in Thailand and will be tested soon in Vietnam.

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The stage of the application of GIS capabilities to irrigation water management is at its infancy, at least as far as Sri Lanka is concerned. Therefore, the IIMI-ITIS unit, together with the Irrigation Department of Sri Lanka launched a pilot study in mid-1995 in the Kirindi Oya Irrigation and Settlement Project (KOISP). The main objective of the study was to develop an appropriate information system to improve the decision making in the operation and management of the irrigation scheme.

The studied irrigation scheme presents a high degree of complexity in the water flowing paths which go with good opportunities for improving water use efficiency. Therefore, the case appears to be interesting in developing a GIS approach addressing:

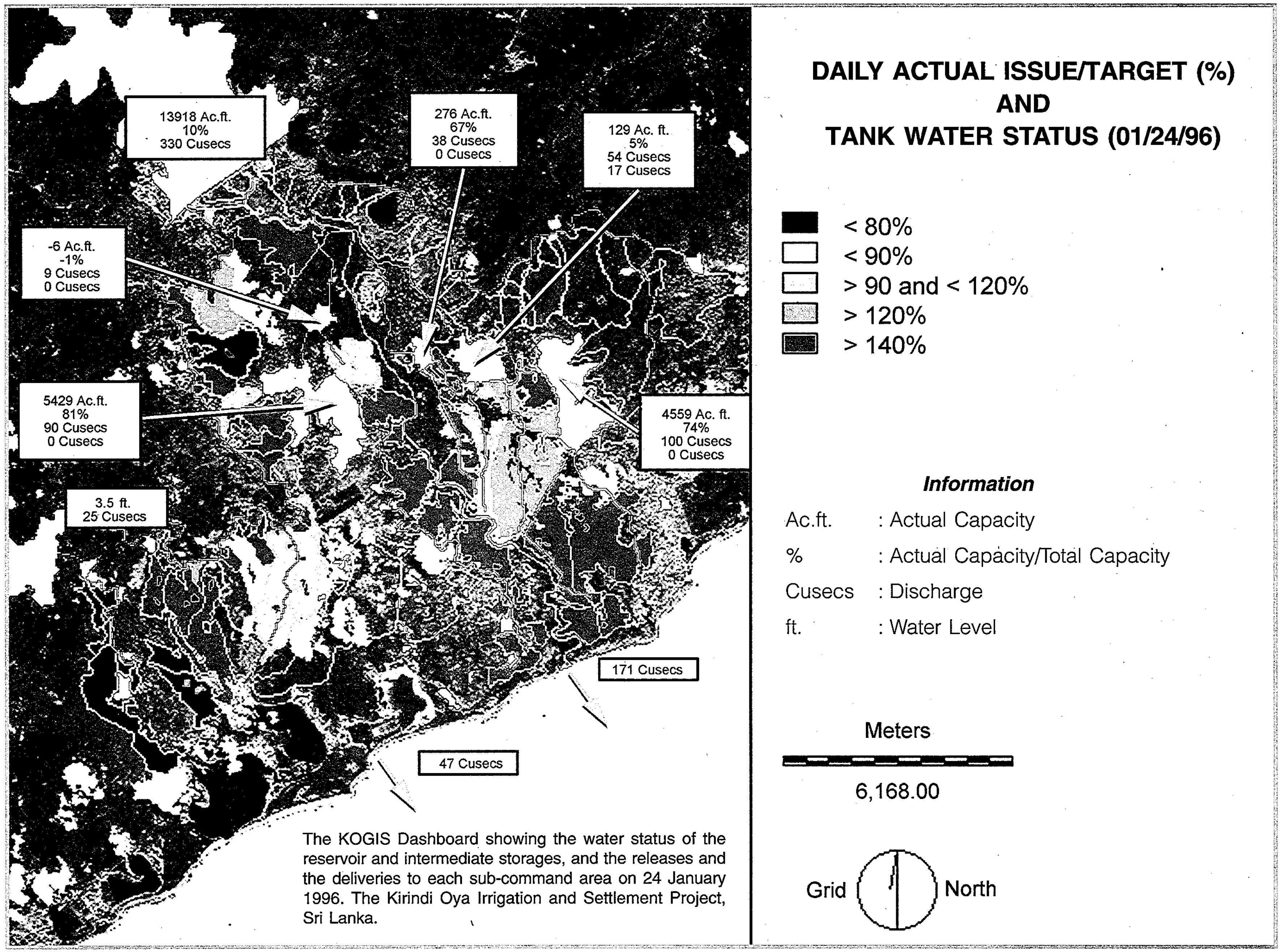
- strategic decisions in mobilizing and allocating resources throughout the area (water, human, etc.)
- tactical decisions in operating the infrastructure

As it was the first study of this nature, the manageable size of data, required spatial scale, cost of implementing such a program, and the training requirement of the project staff for a GIS-based information system were also attempted to be understood.

KIRINDI OYA IRRIGATION AND SETTLEMENT PROJECT

The study took place in an irrigation scheme located in the southern part of the island. This project, commissioned in 1986, is one of the largest agriculture-based development undertakings of the Government of Sri Lanka. The project area is about 20,000 ha, with an irrigated extension of 10,000 ha, covering old irrigation areas and newly developed areas. The infrastructure is composed of one large reservoir used as the main supply, seven intermediate tanks, and two main canals.

KOISP is a complex irrigation system as it is always associated with many technical, social, and political problems. Therefore, the system managers frequently face many difficulties in managing the system.



The KOGIS Dashboard showing the water status of the reservoir and intermediate storages, and the releases and the deliveries to each sub-command area on 24 January 1996. The Kirindi Oya Irrigation and Settlement Project, Sri Lanka.

CONSTRAINTS AND OPPORTUNITIES

Three main characteristics of KOISP are fundamental with respect to constraints and opportunities for water management:

- It is a cascade system common in Sri Lanka. It implies that runoff, overflow, and drainage coming from upstream irrigated areas, are, for the most part, collected and stored in downstream reservoirs.
- It is a basin open to the sea which means KOISP is the last user of water before it reaches the ocean. Hence, these water savings in the area are 'true savings.'
- It is a multiple use water scheme, which means that water resources are used for purposes other than seasonal field crops: domestic consumption (water network for the new areas, recharging of the groundwater in old areas); use of water by the environment (wetland sanctuary, downstream wildlife park, and lagoons); bathing facilities in tanks and canals; fishing in downstream lagoons as well as in inland tanks; and consumptive use for perennial vegetation (homestead garden and natural trees).

PROJECT IMPLEMENTATION

Basic maps were digitized on Arc-Info software and later converted into IDRISI files. The whole GIS was built on IDRISI (for windows version 1.1) platform, mainly because of its low cost and the availability of spatial analytical tools. Basically, spatial information regarding command areas, soil distribution, irrigation storage tanks and distribution network, drainage network and other related map data such as roads, lagoon areas, rainfall station locations, etc., were digitized. All layers of information were built with the available maps and later corrected using a satellite image.

FINDINGS AND ACHIEVEMENTS

Spatial Diagnosis for Strategic Decisions

GIS appears to be very useful to partition the irrigated area in homogeneous units based on hydrological properties relevant to the managers. In particular, it has been possible to map the sensitivity of the infrastructure with respect to operation by overlaying several layers of information. Command areas for which drainage flows are recycled, are separated from those having no recycling facilities and for which more inputs for operation are required. Furthermore, the drainage network was mapped with respect to different types of drainage (rice field spilling, rainfall streams, overflow from irrigation canals etc.).

Current discussions with the managers are bearing on the allocation of 'efforts' for operation according to the sensitivity map (more care in operation, on-farm enhanced techniques, implementation of recycling facilities, etc.).

Another output of the GIS approach was to design an enhanced information system network based on a limited number of recorded points within the irrigation scheme.

Dashboard for Tactical Decisions

GIS had been used as a data visualization tool, 'a dashboard,' by connecting the existing database with all the water releases to the GIS interface.

The pictorial presentation of the water status of the reservoir and intermediate storages, the releases and the deliveries to each sub-command area in the KOGIS dashboard give a very comprehensive knowledge of the whole project area in an attractive manner. The color codes used in the dashboard were very easily understood and interpreted by the manager at a single glance. Therefore, with a minimum time he is in a position to give orders to his operating staff.

Despite the initial success in introducing the GIS dashboard at manager level when supported by IIMI staff, it is felt that GIS software may not be the most appropriate and sustainable tool for this particular function. Hence, it is planned to test another version of the dashboard developed on a spreadsheet software, with which managers are more familiar.

LESSONS LEARNED

As this was the first attempt in using GIS-based tools for the management of irrigation systems, many practical problems arose during the initial stages. Lack of data and reliable maps was a shortcoming and not surprisingly, the investment for creating numerical layers of information is important. However, with many field verification studies, it was possible to overcome most of these difficulties. It was found that, maps available at the Irrigation Department and field visits would give fairly accurate information to correct the digitized map layers. These map layers are accurate enough for the building of a GIS-based information system for irrigation scheme management and operation.

A simple dashboard, summarizing the key information required for the day-to-day management of a complex irrigation project appears to be a very practical decision support tool.

It is worth noting that the Irrigation Department officials were highly enthusiastic in grasping the essentials of new technologies for the management of irrigation systems.

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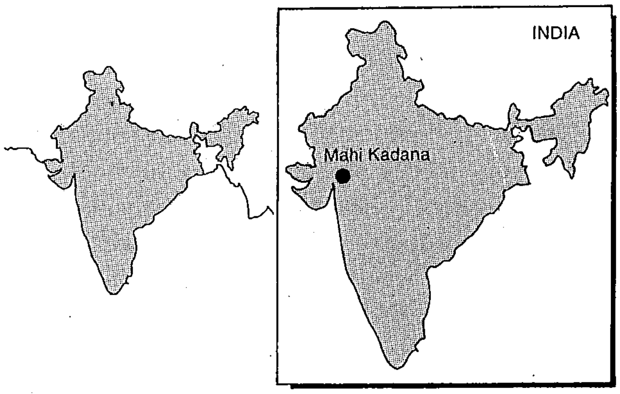
GIS in Water-Related Environment Factors and Malaria Transmission

INDIA



The importance of the spatial and temporal dimensions in the relationship between malaria incidence and water-related environmental factors has been long recognized though difficult to quantify. Studies seeking to examine the relationship between malaria and irrigation have revealed a complex picture with a high degree of site-specificity. In some situations, incidence of malaria is increasing while in others it is decreasing, or remains unchanged following irrigation development. In some areas, irrigation may only have a seasonal effect by extending the transmission season into the dry season, while the contribution from irrigation during the rest of the year may be limited in comparison to the mosquito breeding habitats created by rainfall precipitation. Variations in irrigation water management practices and differences in the design of irrigation infrastructure will also create very different breeding opportunities.

Today, GIS offers a good opportunity for researchers in the field of health and irrigation, in facilitating the integration of spatial dimension in the analysis. The advantages in using GIS in that field will be illustrated through two case studies carried out by IIMI in 1996.

MALARIA TRANSMISSION IN THE MAHI KADANA IRRIGATION SCHEME, GUJARAT INDIA

The studied area is located in the Bay of Cambay, with an average rainfall of 780 mm, a population of 1.2 million, and a cultivable command area of 212,000 ha. Malaria incidence was recorded at 15 parent primary health care centers (PPHC). Water-related factors included in the study were: rainfall recorded at 7 stations within the area; rice intensity and irrigation density for the 39 distributaries in the command area; depth to groundwater recorded in 1988. Analysis of the relationships was run for the entire area on an annual basis for 1981 and 1991. A timely (seasonal) analysis was also run for the Nadiad thaluka, one of the seven administrative units within the area, from July 1990 to June 1993. Ultimately, data analyses were performed on a specific statistical software package, after being prepared on the GIS software.

Results of the analysis are somewhat mixed. In brief, the variability considered in this study cannot explain the variation in malaria incidence between different PPHC catchment areas. Although rainfall, in some years, explains variation, the inconsistency in the findings makes this parameter less conclusive. It was only for the Nadiad thaluka that factors under irrigation management control were found to be of importance in explaining the variation in incidence.

Regarding the methodology followed in that study, GIS appears to be very useful in many instances:

- spatial interpolation of data recorded on limited points (rainfall)
- spatial visualization of the variables within the area and visual comparison of the environmental factors and malaria incidence, before working on correlation analyses
- overlay process in multi-criteria analyses to create a composite environmental indicator
- identification of catchment around primary health centers to spatialize the incidence levels
- aggregation of environmental data at catchment level around each health center

PROGRESSION OF MALARIA FROM WATER BODIES IN A VILLAGE IN SRI LANKA

Environmental and socioeconomic risk factors for malaria were studied in a village in Sri Lanka. Over a period of a year all 49 households in the village were visited every other day to obtain information on malaria episodes. In this survey, 280 residents participated. The buildup of populations of Anopheles culicifacies (the major vector of malaria in Sri Lanka) before the start of the transmission season had taken place in a stream near the village.

The use of GPS (Global-Positioning-System) on-site was of great importance to locate the houses of malaria patients. Then GIS was used to create a series of maps of the disease cases within the area at different time intervals. It showed a clear progression of malaria from the stream throughout the village during the first month of the transmission. It also showed that the second water body, a tank on the other side of the village, was of little importance. This visual interpretation on GIS was confirmed later on by statistical analyses.

GIS was found useful in many ways:

- to calculate distance from homestead to areas presenting high risk, such as streams, tanks, cattle sheds
- to identify spatial clusters of diseases not distinguishable by classical analyses
- to visualize the progression of the malaria incidence throughout the area

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IPTRID Database on Research in Irrigation and Drainage

The IPTRID Database on Research in Irrigation and Drainage, developed and managed by Cemagref since 1994, can now be accessed and browsed through the Internet. It provides detailed information on more than 300 research projects in 14 countries, and will be extended by late 1997 for reference from most country members of ICID.

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AFEID Web Pages

AFEID, the French ICID National Committee, opened its Web pages by early 1997. These pages offer information in French and English on AFEID working groups and activities, as well as on numerous links towards other worldwide Web sites in the area of water and agriculture.

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RS and GIS: A Fistful of Promises We Have to Make Real
A Letter from the ITIS Network Coordinator

Dear Colleague,

Though the potential of RS and GIS is estimated to be high in the field of irrigation and drainage, while many diversified experiences are accumulating, these technologies are currently not widely used by professionals of irrigation on a routine basis.

This special issue was planned with the purpose of gathering and sharing the different types of experiences and knowledge in this field. Although the reader will discover the variety of themes and the various levels of intervention they imply, I am quite sure we are not covering the entire picture. I earnestly hope that readers will react by sending further contributions on important points and aspects they feel are missing in this newsletter.

Dato Ir. Shahrizaila Abdullah in his introduction pleads for the strengthening of the use of Decision Support Tools for a better water management. With high level of professional experience, he comes to the conclusion that the key point for the use of information technology lies in capacity building. I am pleased that this aspect will be further tackled in some of the papers presented.

Vidal and Belouze first remind us that tools have to be developed in a user-oriented approach. Before addressing the questions of the means or the tools, the "information" has to be fully analyzed in the management process of the agency. I am inclined to add that the question of information is also a multiagency issue, which does not make the analysis and the diagnosis of the management process very easy.

Other contributions are gathered into 3 main domains, although in most cases, papers deal with more than one area.

The first section focuses on the performance of irrigation. The first contribution by Jiemin Wang and Yaoming Ma focuses on water consumption computed from satellite images in oasis-desert systems of China. Uniformity of irrigation in water distribution is then analyzed through several national cases by Wim Bastiaanssen. Finally, Sakthivadivel, Thiruvengadachari, and Mutuwatte address the performance of a wheat-based irrigation system, looking at yields and water management.

The second section deals with the important issue of water quality within irrigation schemes. Vidal, Tabet, Zimer, and Strosser report from their experiences in salinity assessment in the Punjab, Pakistan. My contribution emphasizes what has been done for irrigated areas in southeast France in the field of regional modeling for non-point source pollution. The other two contributions focus on water and salt balances, one by Schakel and Bastiaanssen in the State of Haryana, India and the other by Wallender and Young in the Panoche District of California.

The third section of this newsletter focuses more on the potential users of RS and GIS, and capacity building and transfers of those technologies. The first contribution made by Asif, Chemin, and Ali is a good illustration of what can be done between a research center and a planning agency to validate and favor the use of RS and GIS for monitoring irrigation and drainage projects. Next, Rehman deals with irrigation in Pakistan focusing on long-term planning for irrigation management on a very large scale, and also addresses an important issue related to information: the networking of several agencies providing information. The next two contributions by Molle and Pongput, and Renault and Hemakumara deal with the use of GIS as decision support tools for irrigation managers on a daily basis. Finally, the researcher as the user of these tools is also addressed through the contribution by Konradsen, Renault, and Mutuwatte, on health issues related to water and other environmental factors.

I hope you will enjoy reading this issue and once again look forward to your comments and additional contributions in this field.

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