Geographic Information System (GIS) Applications in Irrigation Issues

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INTRODUCTION

A Geographic Information System (GIS) is a holistic tool useful for synthesizing all information about farmers, their fields, and various development/conservation interfaces. This paper discusses the GIS applications for irrigation planning and management. One participatory approach to resource information systems using a GIS within the context of institutional and social organization is illustrated.

BACKGROUND

Agricultural productivity from finite land has to be raised to supply food for ever increasing populations. Besides intensive inputs to current agricultural practices, either new lands have to be developed for irrigation or existing irrigation systems have to be managed intensively. Any definitive actions, directed toward this have to be based on informed decisions both at grassroots and top level of concerned government and non-governmental organizations. The government is recognizing every day the importance of non-governmental organizations in funneling government resources to the local citizenry and they are also serving as agents of the local citizens to formulate people-oriented plans and programs. People at the grassroots do things intuitively based on past experience and social interactions within the limits of nature. Certain activities related to irrigation systems development planning and management whether centrally operated or operated by user groups, must rely on an appropriate information system. This paper will outline in an introductory approach, the potential roles of a GIS in irrigation development planning, management and institutional networking.

GEOGRAPHIC INFORMATION SYSTEM

Basically, a GIS is a decision support system which is comprised of a computerized set of powerful tools to capture, store, retrieve, analyze, manipulate and display of spatial (location specific) data to produce results in the form of maps and statistics. Burrough[2] defines GIS as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world. Earth features are represented by means of points, lines, polygons and continuous surfaces in a GIS using their geographic coordinates. Their associdata base development to address several issues. A simple example of examination of issues of siting irrigation potential areas and a GIS approach to address them will be presented in the following paragraphs. A general flow line of the procedures and key steps are presented on **Figure 1**. The flow includes all key steps from problem identification to "what-if" and alternative scenario generation. Each step will be dealt very briefly.

Problem identification

The important and frequently asked questions whose answers are sought to formulate policies of agricultural related development planning include: How much land is required for agricultural development for a given population growth rate in a region? Which are the lands for development that surpass conflicting conservation/development issues and policies? What will be the capability of the land in terms of production for an existing and alternative land management/farming systems scenario? Which are the potential lands for irrigation development?

Defining criteria

A set of criteria has to be defined to get appropriate answers. In addition to defining physical and environmental parameters and procedures, social issues and policy contexts, have to be examined. After a through and rigorous multidisciplinary approach of criteria definition, it becomes extremely important to examine data issues.

Information planning and data input

Based on the criteria, the data types are to be identified and planned for their collection. Answers to these simple questions could be obtained by use of numerous data sets describing the relevant phenomena. Data sets to answer the questions listed above include, for example:

- Land use/land cover
- Demography/settlements
- Topography
- Soils
- Land systems
- Geology
- Land capability
- Land ownership
- Land parcels
- Hydrography/drainage
- Infrastructure
- Meteorology
- Policy issues

After examination, it is apparent that issues of development planning requires dealing with a *large volume* of *multisectoral, multi-temporal spatial* data sets. To really use information for rational choice of options, it is important to build a spatially referenced multi-sectoral data over a period of time.

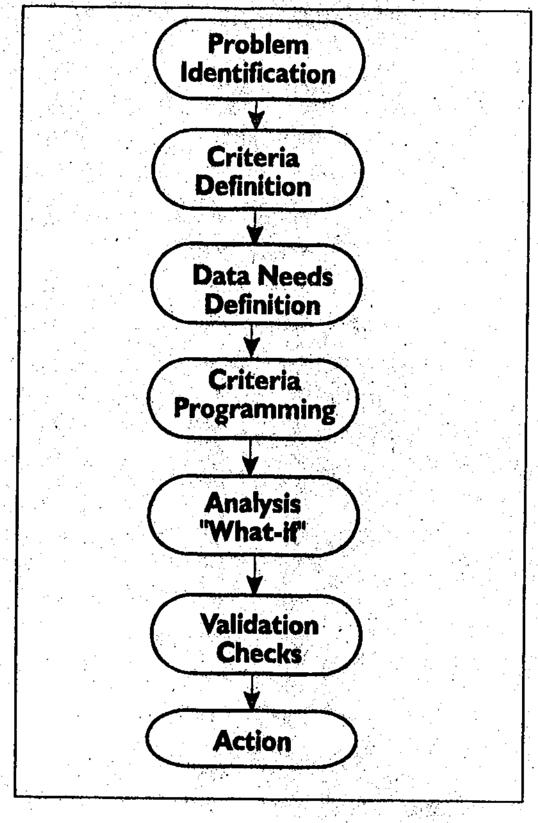

FIGURE 1 Flow chart of GIS procedures for general problems.

Other issue of planning is availability of useful data. It is necessary to examine whether the needed data already exists or it is necessary to collect them right from the start. Information planning could be a project in itself. Hence, it becomes important to include data aspects in the regular programs of the institution or projects. Some times, it is worth examining the objectives so that they are achieved with the existing information. If such information planning is carried on in a coordinated way so that the information is useful to every one, and a mechanism is developed to have access to such already existing data base, it is the GIS's strength to allow multi-sectoral coordination to take place and make information flow smooth. After finalization of data issues, the data identified to be useful are checked for their quality and maintained into a GIS data base.

Criteria programming

The topological graphics data linked to data base tables by a relational data base management system allows GIS operator to convert the pre-defined criteria into algorithmic models or spatial and relational query to get answers to a wide range of questions.

Analysis: "What-if"

What happens if a canal alignment is changed? What happens if a road is built connecting settlements and what would be the impact of growth centers on the agricultural land use? These kinds of conditional queries are examined and GIS offers a choice from a number of alternative options for informed decision.

Validity check

The existing policies, real world situations and the GIS analysis results are cross-checked and if needed the analysis has to be modified to suit actual requirements.

Policy formulation

The analysis results, such as "what-if" and alternative scenarios, help to guide appropriate decisions, and policy formulation.

How does this work? Unlike manual procedures, a computerized GIS avoids the need for reformatting of all the data into a common scale, on transparent sheets. All spatial data are brought into a common coordinate system and become free from scale but their quality and accuracy depends on the scales and quality of original source of data. The data sets are compared with each other for selecting the subset of information based on valid criteria. They are overlaid and appropriate areas are selected. The complexity increases as the information classes and the number of map sheets increase. It could take months or even years depending on the size of the study area. A computerized GIS can do the same thing in more convenient ways.

Text Box 3 contains a general outline of typical data sets dealing with irrigation issues. Text Box 4 lists some sample irrigation applications of GIS.

Data Category	Example Map Layers
Area data	Demographic areas, socioeconomic attributes
Basemap data	Topographic contours, ground control points
Environmental data	Soils map, flood plain map, stream and water bodies, land use/cover, geology/geomorphology, land systems, land capability
Cadastral data	Land parcel boundary, ownership, rights
Transportation data	Roads network, trails
Infrastructure data	Service centers, markets, energy, communication
Irrigation facility data	Intakes, canals, dropouts, diversion works etc.

BOX 3. Some typical data sets for irrigation issues.

Type of application	Example
Area mapping and reporting	Analysis and display of maps of schemes - inventory
Irrigation schemes ranking	Analysis of socio-economics, management, user involvement, productivity and display in map forms
Irrigation facility management	Support the planning and delivery of maintenance to canal, canal embankments, diversion work, river training, aqueducts etc, update, display and analyze facilities data, plan for facilities expansion
Irrigation project siting	Selection of optimum locations for new irrigation schemes (dams, canals etc)
Irrigation potential areas	Display of areas suitable for irrigation using water source, water conveyance, extent and nature of command area and demography.
Water rights, user contribution, land holding pattern	Segregation of water rights zone, assessment of water loads, assessment of user contribution to manage irrigation scheme
Productivity analysis	Analysis for productivity based on cropping pattern, farming system
Food demand supply analysis	Land capacity analysis to develop alternative land management/ farming scenarios, supply and demand analysis on region.

BOX 4. **Some examples of irrigation applications of GIS.**

WATER USE INVENTORY FOR MANAGEMENT AND POLICY

Objectives

The objectives and scope of irrigation inventory works would be concerned with first the "*What is where* ?" question which is most appropriately collected and processed by using integrated GIS tools. Text Box No. 5 outlines few basic questions to be answered for any irrigation management program. These questions yield location specific answers.

The inventory should be planned to provide for its further use other than just a listing, in the formulation of the solutions related to irrigation problems. Main objectives of the inventory could be as enquiry of (a) a particular irrigation system in terms of water management, water rights, water turns, user groups, cropping pattern, conflict resolution, productivity; (b) Source and quantity of irrigation water - current status, existing and planned use for water use; and (c) identification of potential sites for resource mobilization etc.

Depending on the scope, study of above nature can be investigated, in the preliminary stage, using existing information such as area maps, cadastral maps, aerial photographs and other sources which are best handled by a GIS.

Location specific and aggregate data

Figure 2 displays the difference between a site specific point information and their aggregates. It is now possible to collect most discrete information with the combination of integrated GIS tools, and the participation of the farmers themselves. If data collection is done at micro-level, GIS can generate aggregate information at any higher levels of regions. The first case in the figure is detailed micro-level information. The boundary of regions can be used to overlay on the detailed data and aggregate can be derived from the combination of two. Instead, if data were collected at regional level, the nature of first hand data itself is aggregate and there is not any possibility of making any decisions on site specific issues or micro planning.

Where are farmers / users?
Where is their land?
What are the characteristics (soils, productivity, cropping pattern) of their land?
Where is the source of irrigation water?
Where is headwork/intake located?
Where are regulatory works?
Where is the main canal?
How is distribution network laid out in relation to the land?
What is the total capacity of irrigation water supply?
How are those farmers / user groups related to each other?
What is the total command area of the irrigation scheme?
What is the total water demand and how is it fluctuating in relation to cropping pattern, soil characteristics and solar influx?
What are major land cover/use types in the catchment that may affect the discharge and quality of water, cause flood / siltation?
Where are all the irrigation schemes ?
In which irrigation scheme is a particular non-governmental organization involved ?

BOX 5. Few questions related to irrigation management.

Tabular and Spatial Inventory

Conventional tabular inventory is a simple list or a computer data base presented in a tabular format. This kind of inventory is oriented toward the analysis of aspatial (non-locational) data and lacks appropriate capabilities for spatial analysis[5] and modelling. The inventory of irrigation schemes and potential areas for irrigation development has to deal with all the aspects of location and conditions. In a conventional data base there may be various themes of information (conditions and quantity) about irrigation schemes, but nothing on location. This kind of inventory does not become as effective as it could be in a GIS. This case has been made self explanatory in **Figure 3**. In **Figure 3**, there is an example which compares traditional aggregate information, such as a conventional inventory of any irrigation scheme and the most desegregate information inventoried using a GIS. Information without describing them in terms of their discrete locations by coordinates lack the power to be visualized on space. Development or policy measures based on aggregate data, which lack spatial component, fail to address and encompass local conditions as a result of which program implementation and performance monitoring end up in very fuzzy terms.

Text boxes 6 and 7 outline the role a GIS can play in the information gathering, compiling, analysis, management and information presentation with respect to an irrigation/water use study.

Water use inventory study deals mainly with location specific information of water use by various users and potential users on a large geographic space. Use of GIS tools in such study

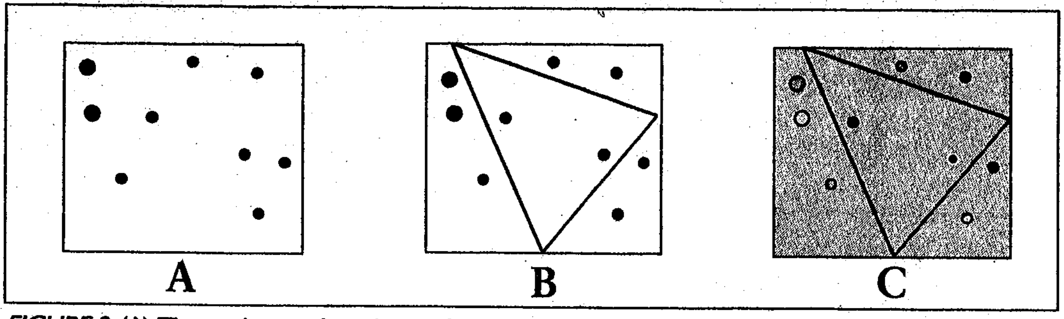

FIGURE 2. (A) The settlement based point features are the basic units of measurements free from changing boundaries; (B) If boundaries are available, they can be overlaid; (C) The micro level data can be aggregated at various levels of administrative units.

can make such information more effective. This can generate newer perspectives to our concerns as well as make information more manageable, with provision for required updates in the future.

MULTI-PARTICIPANT GIS FOR SHARING INFORMATION AND FACILITY

GIS is not a technology which is suitable for use by people who do not like to share information nor is it appropriate for those who do not believe that any other organization or discipline has anything to contribute to a solution of a problem (Rhind, 1990).

The top-down and centralized approach practiced so far has not been able to boost development at the grass roots. In a bottom up approach to development planning, people as individuals are directly involved to formulate local plans and activities. Sometimes it is hard for them to identify the right approaches or identify and solve their pressing social needs by themselves. To avoid manipulation by outside influences, the utilization of effective information system, can help NGOs in connecting grassroots organizations and government to speed up the development task. Various organizations involved in similar tasks will have some common information which can be shared. For example, an overview of water resources, irrigation facilities and distribution networks gives an excellent appreciation of an irrigation area's potential while highlighting certain types of problems. Regularly updated figures on comparative acreages under various irrigation schemes with and without user groups' involvement are vital inputs for the improved management of irrigation schemes and production. Data collected by one group can also be useful to others.

Information and its communication is one of the keys in the development process. It is important for both national and international organizations, to be associated and to share information through a compatible platform. A GIS can act as a catalyst to get organizations to communicate and work with each other based on the realization of the need for common data.

An institution can have a GIS of its own or many institutions can network and collaborate to form a "multi-participant" GIS facility in which data and operation cost sharing becomes a possibility. **Figure 3** is a schematic diagram for such a system. Such facility runs through the participants management as well as data contribution and the facility becomes a repository for all the information and its management can reply to a participant's query. If the GIS at the National Planning Commission (NPC) gains an appropriate institutional footing, this should employ a coordinating committee to eliminate all the bottlenecks of data sharing and discourage data hoarding. Proper coordination, cooperation, and communication among various data producers, archivers and users may alleviate data poverty, reduce duplication of efforts and increase efficiency. The GIS coordinating committee could devise all the data policies as required for the

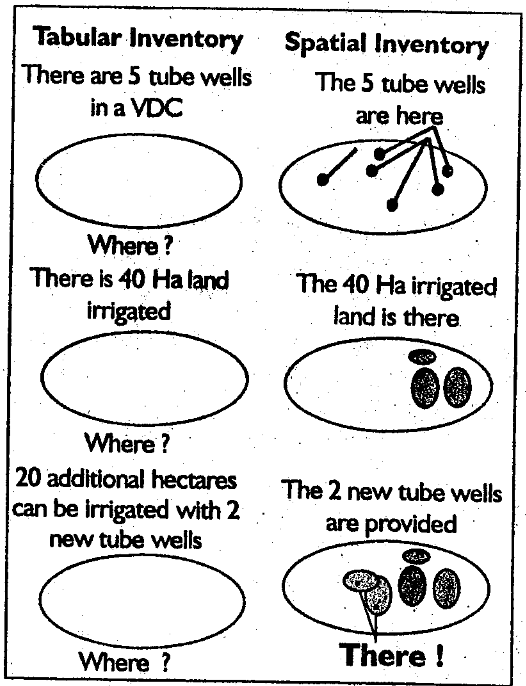

FIGURE 3. Comparative advantage of spatial inventory over tabular one.

Benefits of GIS use:

1. Preparation of data sets and inventory: All planning work for the study can be conducted at the desk most effectively. For this all relevant secondary information is inventoried. Provision for incorporation of any future data coming from the field, aerial photos, existing manuscript maps, survey and research is obvious.

2. Geo-positioning and geo-relating: Location of schemes and collection of their attribute information can be done by using GPS, geo-referencing the features of irrigation/water use on a base map. A field team can collect location specific data by use of a global positioning system (GPS) receiver. All the socio-technical information pertaining to a particular scheme or location can be linked to a base map.

3. Comparison: All land use and land capability information, along with irrigation related various other parameters can be examined simultaneously.

4. Adjacency and proximity analysis: Appropriately conducted, such functions yield information on potential irrigation development sites in relation to water sources for irrigation, command area, user groups/farmers and existing schemes.

5. Information enhancement: All information distributed on geographic space can be visually examined in terms of their relationships to each other.

6. Presentation: Most important of all, the results are presented in the form of maps which consist not only the locations, but also associated information.

7. Data exchange: An output from GIS can easily be passed on to a spreadsheet or any other data base program, and conversely, data from a spreadsheet or any other program can easily be linked with GIS.

Future uses

Once data is in a GIS digital form, its potential uses are numerous including the following:

8. Information sharing: The data is easily managed, can be shared among interested groups, including various government, non-government and international organizations involved in irrigation management. This avoids duplication.

9. Cross-relating and correlating: Multi-source, multi-temporal, multi-scale, multi-disciplinary and multi-scheme information (over a region) can be cross-related, correlated, thus enhancing the inventory information and invites various sectors, groups to participate to solve a problem from various perspectives thus promoting coordination.

10. Spatial query and interpretive/predictive modeling: Any information available about a scheme can be queried either on a basis of individual items or in combination with different others, at the user's convenience and interest. Once stored in GIS format, the data base would be able to serve as an input to various spatial modeling studies when required.

BOX 6. Some benefits of GIS use in irrigation issues.

Location and Display

A. Description of Agricultural System and Services on geographic space

(a) Main crops and their general conditions
(b) Cropping pattern
(c) Cropping intensity

B. Location of market and service centers (for agricultural inputs), transportation corridor

C. Location of user groups/farmers or social groups (ethnic composition in the command, settlement pattern), samitis

D. Location of water sources (tube wells, dug wells, etc), hydrography, catchment

E. Location of irrigation structures and facilities (intake/diversion, regulators, cross drains, aqueducts, siphons, drop structures, measuring devices, main turnouts), their operation and management schemes

F. Location of existing water rights of members within a system (permit, rent, prior appropriation, riparian), conflicting areas

G. Water distribution scheme (layout of main, branch and field canals in relation with the command area), and water source

Analyses

Yield (per crop, per unit area), change in agricultural land/command area or change in the boundary of the system over time.

Impact of markets, service centers and transportation on production, supply and food balance on a local and regional level.

Irrigation expansion and new development potentials.

Ranking of various systems according to selected decision rules.

Study of landholding pattern.

BOX 7. GIS applications in irrigation

country to have standard data produced and delivered. If GIS is not taken as a means to develop understanding of interagency, multi-sectoral interactions and if the host information organization favors the absence of communication and uncoordinated existence, it will symbolize the failure of information system.

The networked governmental, non-governmental and international institution involved in development endeavor, should have in mind the information system as one vital component and all the nodes should automatically form a coordinating body to facilitate smooth flow of information.

Acknowledgements: Mr. Paul A. Lundberg, Chief Technical Adviser, Decentralization Support Project, UNDP/Nep/92/027, for his support, review and comments.

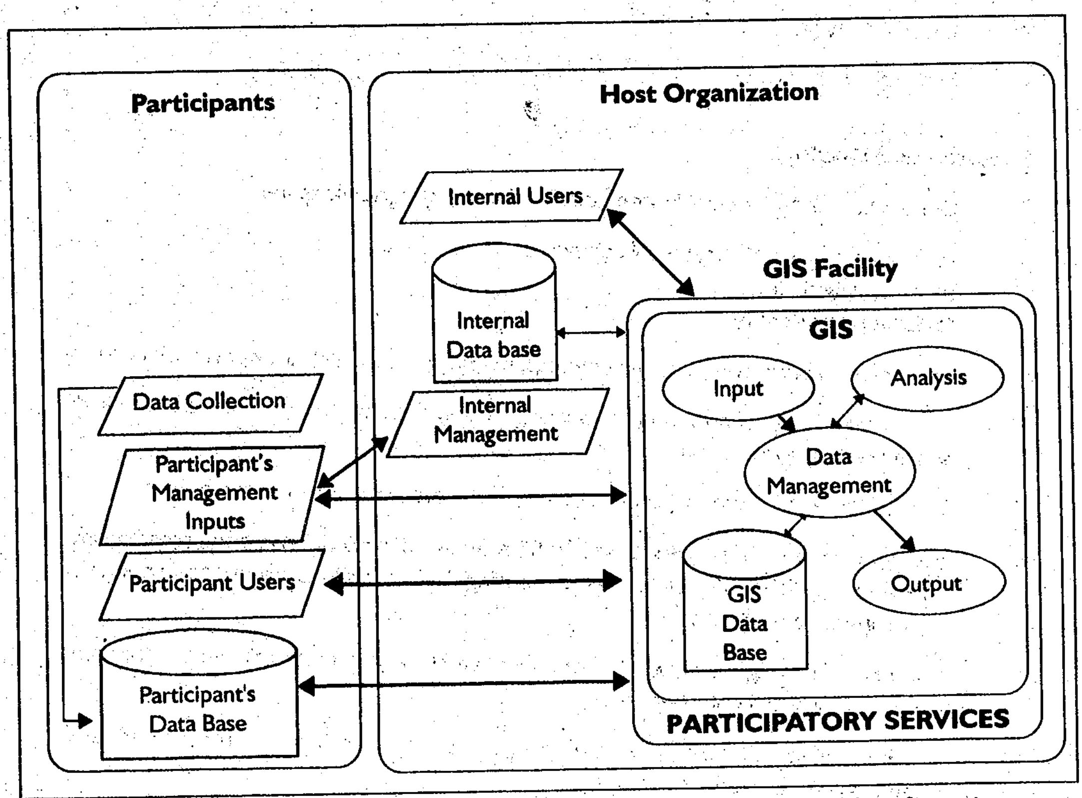

FIGURE 4. A mulit-participant GIS institution - encourages participatory approach to information sharing and management.

Notes:

[1] Sr. Spatial Analyst/GIS Specialist Decentralization Support Project UNDP/NPC GIS Facility, P.O. Box 107, Kathmandu

[2] Burrough, P. A. 1986.

[3] A system of linking geographic features with their associated information.

[4] Lundberg, Paul A. 1992.

[5] Spatial analysis is the process of examining the inter-relationship of variables in geographic space. It requires access to both attributes of objects under study and to their locational information.

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