Use of Geographic Information Systems for Planning and Management of Smallholder Irrigation and Drainage

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Introduction

As the world moves into the information age, meaningful data are becoming the major currency. The value and use of data, and their ultimate form "information" are becoming basic necessities. For any development to take place or for it to be recognized as such, the available data and those that can be collected must be put together in a form that can be easily accessed and understood by users and stakeholders. The price of information can be high, as it encompasses the sum total of investments such as people, facilities, machinery, effort and time needed to process it. Perhaps even higher is the cost of no information, as we may pay dearly for such ignorance. Despite the high costs, information offers an excellent investment, considering its value. In a developing country such as Kenya, the need to put in place spatial databases that assist in planning and management of development programs, such as irrigation, is not only crucial but also a good investment. However, the success or otherwise of such a venture may be based, to some extent, on the available infrastructure. For Kenya, a look at the background information provides a basis for formulating these developments.

Development of Irrigation and Drainage Databases in Kenya

Kenya lies within the tropical regions where rainfall is characterized by erratic and unreliable patterns, and where rain-fed agriculture is unsustainable for 80 percent of the country. The scarcity of water and reliability of its supply are major constraints for agricultural development. While the average amount of water available to a country remains constant, the demand for water is steadily increasing. As Kenya is a strongly agrarian country, the rapid population increase has pushed the demand for more agricultural land for food production as well as for economic purposes. Two scenarios have emerged: one, where previously protected water catchment areas, such as forests, are opened for agricultural production, resulting in detrimental environmental impacts; and two, semiarid lands previously used as rangelands are cultivated (Kilewe and Thomas 1992), where crop yields under rain-fed agriculture are poor or fail altogether. This has prompted many small-scale farmers to seek irrigation as a solution, to ensure and improve crop production, as well as for raising farm family incomes.

Irrigation development started in isolated parts of Kenya about 400 years ago, but formal irrigation started in the mid-twentieth century, when several irrigation projects were developed. The creation of the National Irrigation Board (NIB) saw the development of large-scale public-settlement schemes. With time, small-scale irrigation development emerged as an important

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subsector. Irrigation has been identified (IDB 1999) as a possible option to increase food production in the arid and semiarid lands (ASALs) of Kenya, which account for 80 percent of the total land area as well as for intensified land use in high potential areas. However, data on irrigation and drainage in Kenya are scarce and only irrigation schemes of the NIB are well known. Private commercial irrigation, both smallholder schemes and large estates, are less well documented (Republic of Kenya 1990). Hence, more information is required for policy makers as well as administrators. Previous attempts to put together a database of irrigation and drainage in Kenya have relied on ad hoc studies, which provide detailed information for specific projects. Perhaps the most comprehensive database of irrigation and drainage in Kenya was compiled in 1990 (Republic of Kenya 1990). However, even this database was not spatially geo-referenced to permit easy access, analysis and updating of new information. Later work by the Irrigation and Drainage Branch (Republic of Kenya 1995) of the Ministry of Agriculture to put together a database resulted in about 45 reports. These are bulky and are not easy to access by users. Therefore, there is a need for a more flexible and reliable database, such as a Geographic Information Systems (GIS).

Irrigation development revolves round the development of water resources. The major challenge facing planners and managers is that the physical availability of water and land is fixed; yet their demand is growing (Biswas 1990a). Accordingly, the problem is how to balance demand and supply under these increasingly difficult conditions. For many countries, the only solution, therefore, is to manage the available land and water resources in the country in an efficient and sustainable manner. To achieve this, a reliable information base is necessary, which can identify the resources available, their allocation and use (or misuse), the actors involved, their abilities and limitations and the infrastructure available at the national, regional and subregional levels. Such a database is most useful, if it has spatially referenced data, in which the information can be easily displayed on a map. This calls for a Geographic Information System.

Geographic Information Systems

A GIS has been defined (Burrough 1986) as a set of tools for capturing, storing, manipulating, analyzing and displaying spatially referenced information. Thus, a GIS is not a system which automatically answers all questions, but a set of computer hardware and software which helps the user in the analysis of data (Peccol et al. 1996). GIS technology is nowadays used by millions of people throughout the world, in a wide range of applications. The use of GIS has accelerated in recent years due to the availability of more user-friendly and cheaper computers capable of handling large volumes of data. This is in addition to the availability of data sources in digital formats as well as a clientele with ever-increasing demand for more cost-efficient and timely tabular and spatial information (Mellerowicz et al. 1994; Aalders and Morrison 1999). GIS allows for vast amounts of information on different themes and from different sources to be integrated and displayed in a format that end users can utilize.

Compiling the Irrigation and Drainage GIS Database for Kenya

Data Sources

In 1994, the Irrigation and Drainage Branch (IDB), Ministry of Agriculture and Rural Development (MARD) compiled one of the most comprehensive databases on smallholder irrigation and drainage (SID) development in Kenya. District Irrigation Engineers (DIEs), with the technical staff of their respective District Irrigation Units (DIUs) collected these data through field surveys. In addition, the Ministry of Water Development assisted with the collection of streamflow data. These data are available at the IDB in 45 volumes referred to as "District Profiles" (Republic of Kenya 1995).

An example of a District Profile, Homa Bay (Ministry of Agriculture and Livestock Development 1995) provides a 125-page document, which weighs nearly 1 kilogram. Some hard copy maps have been provided, while a page of codes is necessary to permit reference to distances to irrigated areas (potential, actual, proposed), market locations, etc. The District Profile contains maps of administrative units, agro-ecological zones, soils, rural access roads, and average annual rainfall. In addition, there is a map of irrigation and drainage project sites, grouped by size of irrigated area. With about 45 such reports, access to irrigation and drainage data can be tedious, slow and inefficient. A GIS database can significantly improve the accessibility to these data.

Preparing the Baseline Data

For the preparation of the GIS database on smallholder irrigation and drainage (SID) in Kenya, it was necessary to update the District Profiles, as new districts have been created since the preparation of the original data in 1994, and also to update them with new data. Thus, the IDB in collaboration with the International Water Management Institute (IWMI) organized a series of three workshops, covering eastern/coast/central Kenya, Rift valley, and Nyanza/western Kenya. The DIEs were invited to these meetings, where they presented their activities, including updated irrigation and drainage databases for their districts. They were also given basic training in GIS and provided with topographic maps, which they used to estimate the respective Global Positioning System (GPS) of each irrigation and drainage scheme in the district as point data, obtaining the easting and northing coordinates for each scheme. Ideally, it would have been better to have the geo-referencing of the schemes done using portable GPS units at each scheme. However, because of fiscal and logistical constraints associated with such an exercise, the methodology described here was the most practical. Even then, there is still a need to do a more thorough geo-referencing exercise using modern technologies, such as a GPS unit. It should be noted that that database does not include data on the NIB, commercial or large-scale private irrigation schemes.

Preparing the GIS Thematic Data

The updated baseline data from the District Profiles and the GPS were put in a spreadsheet (Excel). For each district, the following data were compiled for each scheme: Scheme name, easting, northing, total irrigable area (ha), actual irrigated area (ha), ratio of irrigated area (%), water demand (m^3/s), water supply (m^3/s), number of farmers per scheme, name of the river or water source, crop types and current status (whether the scheme is operational or not, the types of water conveyance and any special notes). The data for each district were put in a separate file, and a text file created for it. This was the file put into the GIS.

ArcView GIS (ESRI 1996) was used to prepare maps of irrigation and drainage data. ArcView is one of the leading software products for desktop GIS and mapping, which enables the user to visualize, explore, query and analyze data geographically. One advantage of ArcView is that it allows extensions and add-on programs that provide specialized GIS functionality. Its easy adaptability with text files created from spreadsheets makes it especially useful for interfacing data, especially by inexperienced users. Thus, this software was considered useful in the current project, as well as for long-term day-to-day management of the irrigation and drainage database by the IDB, where it will be used by a wide cross section of personnel.

Preparing the Maps

In preparing maps of irrigation and drainage, five base maps of Kenya were digitized. These were a) administrative districts as polygons, b) major rivers/streams, c) contours, d) major roads as lines, and e) towns as point data. Only the district map was really necessary for this work. However, the other thematic layers were used for integrity assessment of the data. The map of Kenya showing districts was opened in ArcView and zoomed to show more clearly the district of interest. The irrigation/drainage database text file for that district was then loaded into ArcView. The relative accuracy of the GPS for each scheme was checked for integrity, based on known indicators, such as nearness to towns, rivers and roads, and any corrections cross-checked with the maps. The other thematic layers were then loaded onto the map, which was then printed. A sample GIS irrigation thematic layer for a district is shown in appendix 1 (Embu district), as well as the sample data used (appendix 2). Out of a total of 69 districts in Kenya, 57 have been mapped in this way. However, GPS and baseline data from 11 districts had not been received at the time of writing this paper. The 57 district files (table 1) were combined to create one file containing data on smallholder irrigation and drainage in Kenya. This file is too large to be appended in this paper and, therefore, its contents have been summarized and presented in table 2.

Data Analysis and Presentation in GIS

Due to the changes in district boundaries from the time (1994) when the smallholder irrigation and drainage data were compiled, there were overlaps in the data presented in districts that had been split up to create new districts. Thus, a cleaning exercise was done to weed out schemes appearing in duplicate across the districts. This was achieved by sorting the data in the spreadsheet by scheme name, then deleting those that appeared twice. Care was taken to avoid losing important details attached to each scheme. These are the data that were used to create the map of irrigation and drainage schemes in Kenya (figure 1).

Table 1. List of districts in the GIS database of smallholder irrigation and drainage in Kenya.

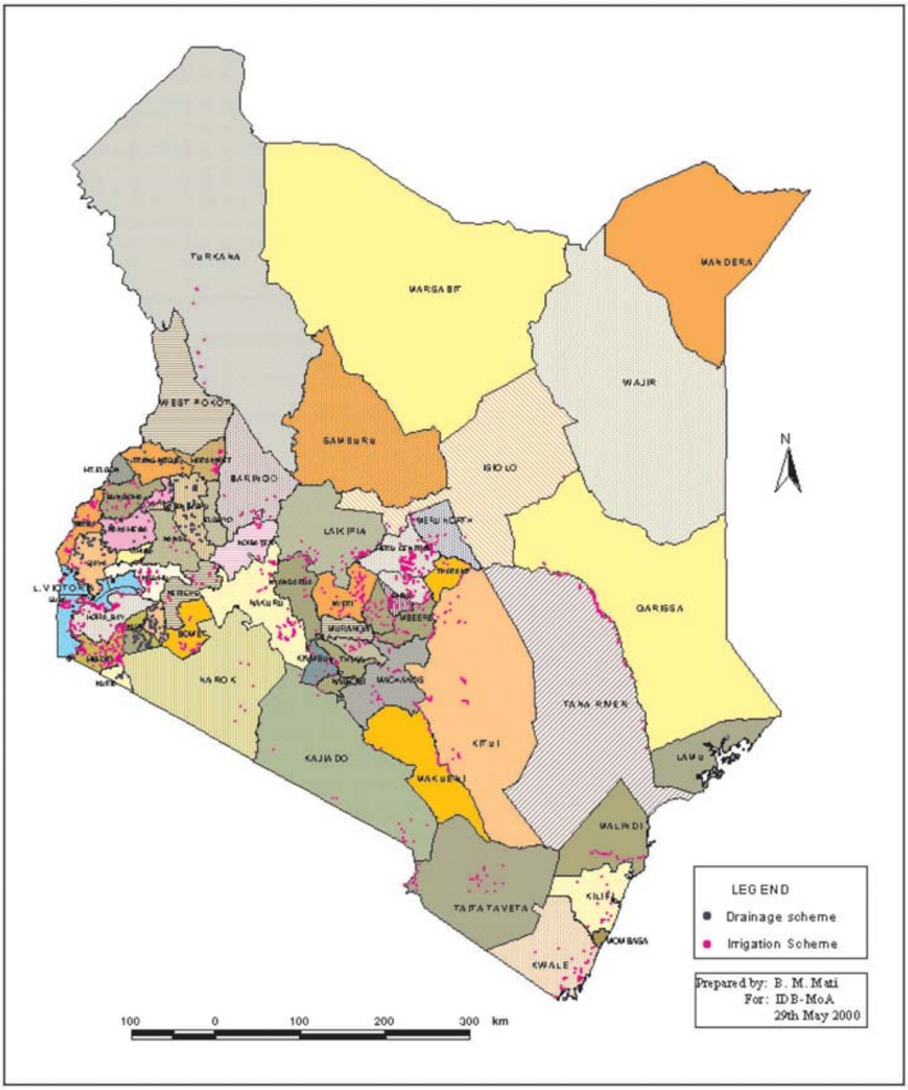
Province	Districts in Irrigation and Drainage GIS Database	Districts Not in GIS Database
Central	Kiambu, Kirinyaga, Maragua, Muranga, Nyeri, Nyandarua, Thika	
Coast	Kwale, Kilifi, Malindi, Taita, Taveta	Tana river, Lamu, Mombasa
Eastern	Embu, Isiolo, Kitui, Mbeere, Meru Central, Meru North, Meru South, Mwingi, Machakos, Tharaka	Makueni, Marsabit
Northeastern	Garissa	Mandera, Wajir
Nyanza	Bondo, Gucha, Homa Bay, Kisii, Kisumu, Kuria, Migori, Nyamira, Nyando, Rachuonyo, Siaya, Suba	
Rift Valley	Baringo, Bomet, Kajiado, Kericho, Koibatek, Laikipia, Marakwet, Nakuru, Nandi, Narok, Samburu, Transmara, Trans-Nzoia, Turkana, Uasin-Gishu	Keiyo, West Pokot
Western	Bungoma, Busia, Butere-Mumias, Kakamega, Lugari, Mt. Elgon, Teso	Vihiga
Nairobi		Nairobi

Table 2. Summary of irrigation and drainage data in the GIS.

Item	Irrigation and Drainage	Irrigation	Drainage	Percentage of Total
No. of irrigation/drainage schemes	2,210	1,860	350	
Potental irrigable/drainable area (ha)	32,8001	243,060	84,941	
Actual area under irrigation/drainage (ha)	56,603	40,265	16,338	
Potential area (%)	17.3	16.6	19.2	
Total no. of farmers	196,864	160,109	36,755	
Water demand (m^3/s)		0.01–86.8		
Water supply (m^3/s)		0.01–750		
No. of schemes providing data on crops	1,776			80.3
Schemes growing field crops	1,055			59.4
Schemes growing local horticulture	1,222			68.8
Schemes growing export horticulture	261			14.7
Schemes growing Asian vegetables	97			5.5
Schemes in the GIS database	1,656			74.9

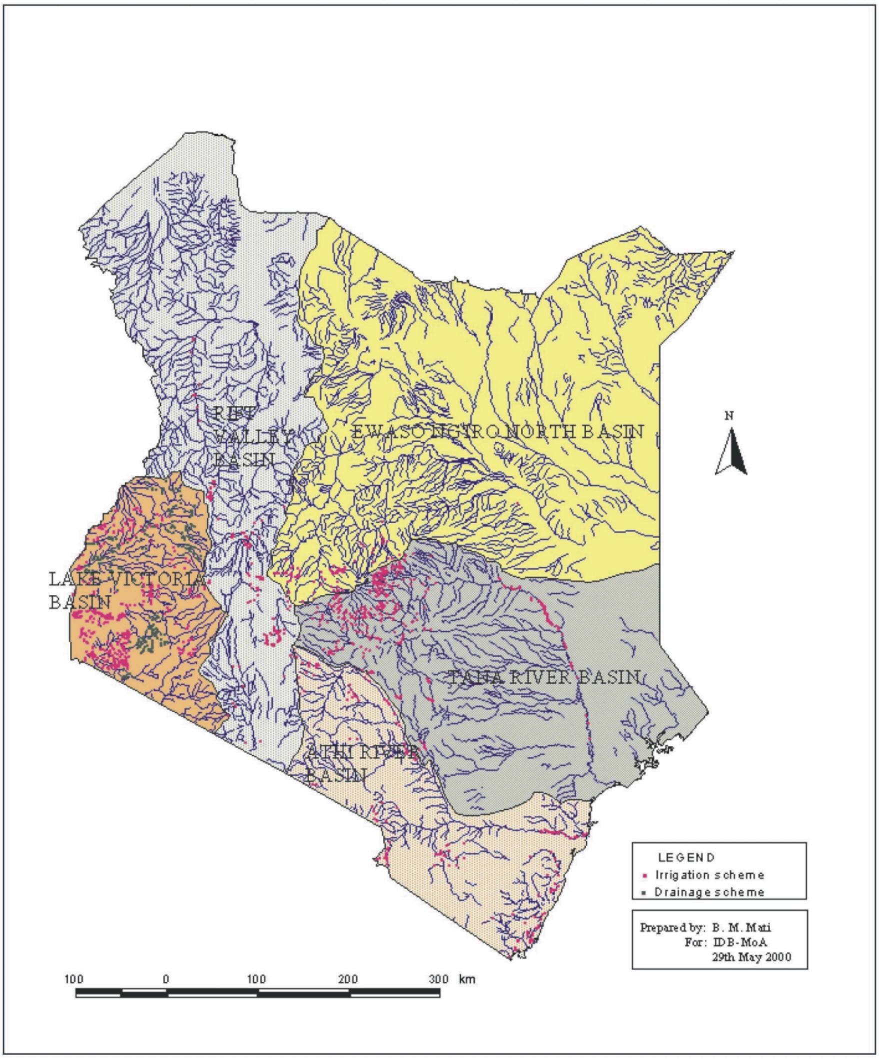
Source: District Profiles database, current study.

Figure 1. Location of smallholder irrigation and drainage schemes in Kenya.



The baseline data clearly indicated that some schemes were drainage schemes or some districts had only drainage schemes. These were put together in one file showing the drainage schemes of Kenya (figure 1). By overlaying the coverage of the major rivers in Kenya, it was possible to show the distribution of the irrigation and drainage schemes in relation to the major rivers as well as the five main drainage basins of Kenya (figure 2).

Figure 2. Location of irrigation and drainage schemes with respect to rivers in Kenya.



Available GIS Data on SID in Kenya

Districts in the Database

This paper presents a report on the first comprehensive GIS database on SID schemes in Kenya, which has been prepared using cost-effective methods. It provides the basic variables associated with agricultural production such as area, number of farmers, crops grown, water availability and, most importantly, the geographical location of each scheme. At the time of writing this paper, 57 districts were depicted in the database (table 1), while 11 districts had not yet submitted their data. Such are some of the gaps in this database, which still need to be addressed. As the districts that had not submitted their data in time do not have significant irrigation activities, the current database gives a fair representation of the national perspective.

Distribution of SID Schemes in Kenya

The location of each SID in Kenya is presented in figure 1. It shows the spatial distribution of the schemes in terms of the administrative districts. These data show that most of the irrigation schemes are concentrated in the following districts: Nyeri, Meru Central, Meru South, Garissa, Nakuru, Homa Bay, Migori, Kisumu, Busia, Bungoma, Taita Taveta and Kwale. Drainage schemes are concentrated in western Kenya in Kisii, Nyamira, Uasin Gishu, Trans Nzoia and Bondo. A common feature of these districts is that they are in the wet agro-climatic zones of Kenya, enjoying a relatively high density of streams (figure 2), proximity to market centers and high population densities. These are the same areas where rain-fed agriculture is also best-suited (Jaetzold and Schmidt 1983). It is ironic that in the dry areas of Kenya, where irrigation is most necessary, very few schemes are found, with the exception of the Garissa district (probably because the Tana river passes through it). From the inventory of existing smallholder irrigation activities, it was noted that most smallholder schemes are presently operated by farmers' own initiative, with little assistance from the IDB or other government agencies.

SID in Kenya: A GIS Overview

Attempts have been made in the past to assess Kenya's irrigation potential. Two authoritative reports are the 1980 National Water Master Plan (Herdjk et al. 1990), compiled by the Ministry of Water Development and the "Study on Options and Investment Priorities" conducted on behalf of the Government of Kenya and the World Bank in 1987. Herdjk et al. (1990) proposed that a policy framework should include a mechanism for updating data on available water resources and competing uses, as well as disseminating such information to planning and implementing agencies. An irrigation policy could also help define how different water sources relate to different types of irrigation. For instance, in the ASALs, a strategy might call for conjunctive use of groundwater and surface water resources to attain local food security. On the other hand, in the medium- and high-potential areas, supplementary irrigation based on surface flows could be perceived as instrumental in increasing productivity of high-value crops. Herdjk et al. (1990) recommended that a study should be done with the aim of defining the type, extent and geographical distribution of services that irrigation enterprises need, and which of these services could be rendered by the Irrigation and Drainage Branch (IDB), or by the private sector.

Trends in SID Development in Kenya

Table 2 shows a summary of SID development, as depicted in the GIS database. An analysis of these data takes into account the fact that only 57 districts are represented. It shows that there has been more irrigation development than drainage. From the comments of the current status, it was found that the most common methods of irrigation were furrow, sprinkler and bucket (watering can). Irrigation by bucket-kits has been spreading especially in central and eastern Kenya, where there are many streams.

Table 2 shows that there are 2,210 hectares of documented SID schemes in Kenya, covering an area of 56,603 hectares, constituting only 17.3 percent of the total potential. This area produces the bulk of the local horticultural crops consumed in Kenya, as well as some of the export horticultural crops. About 196,864 farmers are involved in irrigation and drainage, but 81 percent of them are involved in irrigation only. Figure 2 shows that the Tana river basin has the highest concentration of irrigation schemes. The biggest constraints to irrigation development are inadequate water, low technological inputs (e.g., using watering cans is inefficient), poor infrastructure and marketing. It should be noted that only 80 percent of the database had indicated the types of crops grown. From these data, it emerged that field crops and local horticulture are the major products from smallholder irrigation.

The development of drainage has tended to lag behind that of irrigation. Perhaps this has more to do with the topography and the presence of wetlands. From figure 2, it is apparent that most of the drainage schemes are in the Lake Victoria basin. Drainage occupies 16,338 hectares constituting only 19.2 percent of the total potential, as obtained from the current study. This calls for more investigations into the possibilities of reclaiming land through drainage in the areas where it would not lead to adverse environmental effects.

River Basin as a Unit of Interest

The river basin has become increasingly accepted as a unit for water resources management. The rationale stems from the concept of a river as an organic entity, so that interference with or modification of any part of it will be felt elsewhere in the system (Biswas 1990a). In most cases, river basins have been used for the collection of data on the quantity and quality of water, or for setting up large hydroelectric power-generation projects. In Kenya, eight river basins are recognized for purposes of irrigation and drainage (Republic of Kenya 1990). These are the Tana, Athi, Ewaso Ng'iro north, Ewaso Ng'iro south, Kerio and Turkwel, Lake Victoria, Lake Naivasha and Lake Baringo. Table 3 shows the areas under irrigation and drainage in 1990 compared to their potentials. For the larger basins (Tana, Athi, Ewaso Ng'iro, Lake Victoria and Kerio), the government has set up large state corporations for their management since they have several projects.

Although SID is implemented by the IDB, other players in the irrigation sector are important in getting the general trends of irrigation development in Kenya. These include the Ministries of Agriculture and Water Development, the NIB, three Regional Authorities (Tana and Athi Development Authority, Lake Basin Authority and Kerio Valley Development Authority), District Development Committees (DDC), NGOs, FOs, the private sector, donor agencies and other agencies, e.g., the Horticultural Crops Development Authority (Herdijk et al. 1990). Although the current GIS database targets only smallholder farmers, it is necessary in the future to develop a more comprehensive database of all irrigation and drainage activities in Kenya, at all scales. Therefore, these agencies should be included as partners in such an endeavor. To conduct basin-wide studies on water availability and use, a complete inventory of water users should be compiled, including seasonal demands. Also, as water becomes scarcer in Kenya, trade-offs have to be made between various uses. Irrigation users will need to provide data on their requirements, including diversions, crop water usage, water losses, etc.

Table 3. Irrigation and drainage in the major basins of Kenya.

Basin	Irrigation		Drainage		
	Actual (ha)	Potential (ha)	Actual (ha)	Potential (ha)	Percentage Developed (%)
Tana	18,841	91,000	0	0	20.7
Athi	15,898	49,500	0	-	32.1
Ewaso Ng'iro north	1,236	15,700	0	-	7.9
Ewaso Ng'iro south	172	-	0	-	-
Kerio and Turkwel	4,702	31,000	140	-	15.6
Lake Victoria	3,606	57,000	801	-	7.7
Lake Naivasha	3,577	-	0	-	-
Lake Baringo	971	-	0	-	-
Basin totals	49,003	244,200	941	-	20.5
Basin totals were distributed as follows:					
Commercial, large scale	22,743	-	-	-	46.4
Central managed by basin authorities	10,325	-	-	-	21.1
Smallholder irrigation	15,935	-	-	-	32.5
Smallholder drainage	-	-	941	-	-

The Case for Setting up GIS Databases

GIS in Monitoring and Evaluation of Irrigation Projects

In most developing countries, the development of irrigation and drainage has suffered from lack of regular monitoring and evaluation. Rarely have the results of proper monitoring and evaluation been used to improve the management of irrigation projects to ensure that the benefits accrue within the planned time horizon. Monitoring may be defined (Biswas 1990b) as "continuous or periodic surveillance over the implementation of irrigated activities, including their various components, to ensure that work schedules, input deliveries, targeted outputs and other required actions are progressing according to plan." As the primary purpose of monitoring is to achieve efficient and effective project performance, GIS should be made an integral part of the management information system, and thus should be a regular internal activity.

On the other hand, evaluation determines systematically and objectively, the impact, effectiveness and relevance of project activities in terms of their objectives. Therefore, evaluation can be an ongoing activity, fitting easily within a GIS, or it can be done on a periodic basis. Ongoing evaluation with a GIS can be used to determine whether changes are necessary for O&M of the project to ensure satisfactory performance, while periodic evaluation is carried out after longer time intervals, say every 5 years. Periodic evaluation deals with the achievement of socioeconomic objectives, and may not show any discernible change over a shorter period of time. Such evaluation studies have been made in Kenya, with special reference to smallholder irrigation (Republic of Kenya 1990, 1995, 1999).

Most irrigation schemes have undergone some form of evaluation and monitoring. For instance, many irrigation schemes monitor flow rates in the main irrigation canals, but they may not have data on corresponding watercourses. Often, losses occurring in distribution are unknown. In some cases, crop yields are monitored, but even these may not be monitored on a regular basis or with acceptable margins of error. In addition, activities such as types and amounts of chemical inputs, changes in the chemical composition of soil, labor, transport and marketing costs, and even socioeconomic impacts are rarely monitored. If this type of information is available in a GIS format, evaluation and monitoring can be made easier, timely and cost-effectively.

Regular and reliable evaluation of irrigated agricultural projects is not an easy task under even the best of conditions. There are methodological problems that need to be resolved in order to find a cost-effective and reliable approach that can be used within the resources and expertise available (Biswas 1990b). There are also institutional barriers that make the exercise complicated since the demands of national institutions may contradict those of the community. The use of GIS in evaluation and monitoring of irrigation projects makes it easier to:

- determine the extent of achievements of the goals of the project
- identify limitations within the project
- help understand the management of the various interlinked processes and aid in decision making

- verify the relevant project assumptions
- permit transferability of technology to other areas
- plan later phases of the project much better
- contribute to the modification of the organizational behavior on the basis of the relative successes or failures based on reliable experience.
- provide facts and baseline data, which can be used to defend certain actions and also for lobbying for financial support
- provide national policy makers with objective information, which can be used for planning for other areas in the country

GIS in Watershed Management and Basin-Level Studies

Watershed management, in its broadest sense, is the attempt to ensure that hydrological, soil and biotic regimes, on the basis of which water development projects (e.g., irrigation) have been planned, can be maintained or even enhanced (Biswas 1990c). It is well known that changing land use patterns affects soil and water regimes of any watershed. These changes, if properly managed, could be beneficial. However, unplanned and ad hoc land use changes, as has happened in much of Kenya, have detrimental effects. Individual activities that affect land use practices are generally small and incremental. However, when all the individual activities over an entire watershed are considered, their overall aggregated impacts could be substantial, and these can be shown much better with GIS.

Watershed management has become an important consideration for sustainable water development projects. However, this is not a simple task. It requires simultaneous achievement of many tasks, among which are afforestation, strict control of land use practices, and more emphasis on small-scale structures, such as check dams for better conservation of soil and water. Land use practices are generally very sensitive issues in most countries, at least politically. Thus, success depends on strong policies and willingness of all the stakeholders to observe them. Depending on size, it is difficult to ensure proper implementation of specified land use practices on large watersheds. As watersheds normally cover large spatial extents, GIS becomes a powerful tool for showing trends of the various changes that take place. This can be done through the creation of awareness and setting up of implementation plans, and system evaluation and acquisition (Konecny 1992). It should be noted that, in some cases, it may take years before the benefits of GIS can be effectively realized.

Maintaining and Updating the GIS Database

A GIS is a dynamic database that should reflect changes occurring in the area of interest. In addition, a GIS must earn its keep. The current GIS database at IDB is envisaged to be dynamic as it still requires a lot of improvement. For instance, it is necessary to complete the data on districts missing from it. In addition, it is important that GPS units are bought and sent to officials in the field so that they can accurately locate even minor farm-based schemes. Current GPS units in the market are accurate to 2-m resolution, so it is possible to get detailed data, which are useful for planning.

The master database at IDB should be disseminated to the field, starting with district-based GIS databases. It will facilitate easier accessibility of data for planning, as GIS is a powerful tool for lobbying, able to show trends in development, and easier to access. A good GIS can also be used to convince District Water Allocation Boards, on the trends in river flow, impacts of excessive abstraction, and for planning water allocation in the district. It can also be used at community level in water users' groups to help them allocate water better.

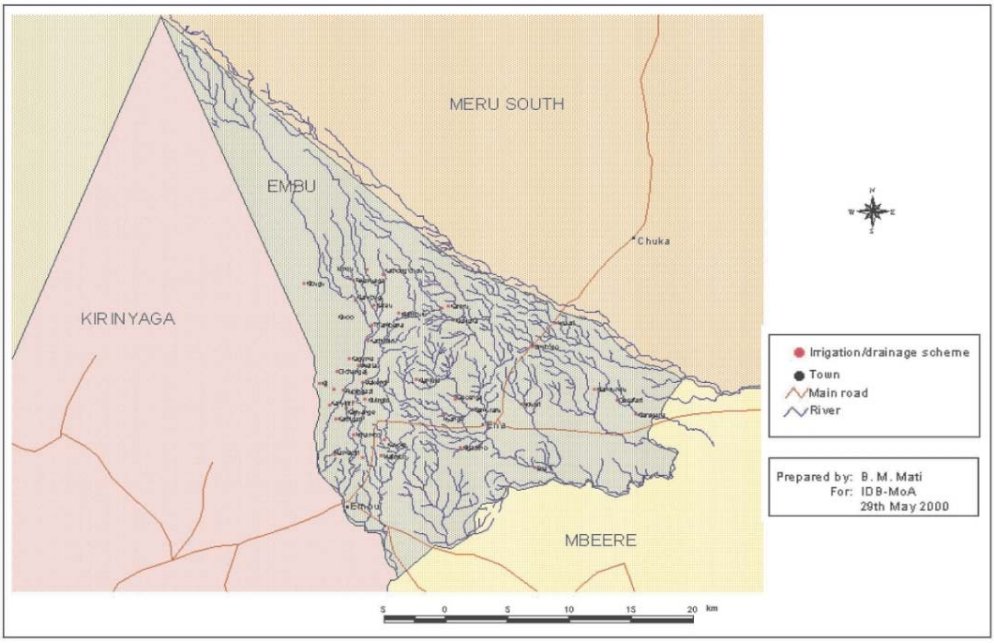
There are cost implications associated with any GIS database. These include the cost of data collection and entry, digitizing maps and dissemination. These costs can be met by introducing some cost-sharing element in data dissemination. For instance, a department wishing to access the GIS database for information should be charged a fee. There are many people who would be interested in such a database including researchers, project managers, donors and the farmers themselves.

Conclusions

The need for a GIS database of irrigation and drainage in Kenya was expressed over 10 years ago. However, in the intervening years, much of the GIS work at IDB has been ad hoc, project-based work, usually limited to the preparation of hard-copy maps of specific project areas of interest. Until now, all the data on irrigation and drainage could only be obtained from volumes of records and files, which are bulky, difficult to access and are few in number. The GIS database prepared in this project can contribute to improved planning and management of irrigation and drainage in Kenya. As an output of the GIS database exercise, it is now possible to easily extract scheme-, district- and national-level information. The current database obtained that the highest concentration of smallholder irrigation schemes are in the Tana river basin, while drainage schemes are concentrated in the Lake Victoria basin. Also, availability of water, roads and market centers appears to affect the development of irrigation. It was found that only 17.3 percent of the irrigation and drainage potential has been tapped in Kenya, benefiting nearly 200,000 farmers. The poor performance of this sector needs to be examined.

The advantages of a GIS database over conventional methods have been presented. The use of workshops to assist in preparing the current database was based on available resources and time. The database obtained is accurate within reasonable limits, but much work is needed to improve it. More needs to be done to make the GIS functional and self-sustaining. Among these activities are the need to train the staff at IDB in GIS, as well as the District Irrigation Engineers. Next is to equip them with modern GIS hardware and software, to enable them to update the data accurately. Also needed is publicity to make known the existence of the database, and to get clientele for it. It is also necessary to sensitize prospective users so that they can be aware of what they are missing. GIS is a powerful tool for planning, management and troubleshooting of problems, including maintenance requirements. But this cannot happen without continuous data collection from the field. Such data can come from several sources, including engineers, farmers, market surveys, etc. Proper planning and management of water resources, and irrigation and drainage that result from efficient data management should, in the end, benefit smallholder farmers.

Appendix 1. Smallholder irrigation schemes in the Embu district.



Appendix 2. Smallholder irrigation data for the Embu district.

Scheme Name	Easting	Northing	Potential Irrigable Area (ha)	Actual Irrigated Area (ha)	Area Irrigated (%)	Water Demand (m^3/s)	Water Supply (m^3/s)	No. of Farmers	Water Source	Crops Grown
Kiandundu	347,300	9,950,400	40	0	0	0.04		30	Gachungu	
Kianjuki	332,900	9,951,200	30	0	0	0.03	0	25	Kapingazi	
Kiaragana	350,600	9,948,300	80	0	0	0.08		40	Karurumo	
Kibugu/Nguviu	323,800	9,959,300	320	0	0		0	1,000	Rupingazi	
Kierisha	335,900	9,956,200	14	0	0	0.014	0.036	25	Kaena	
Kigaritho	336,500	9,945,500	15	1	7			20	Kamuraru	Kales, tomato, F. bean, chili
Kii	325,100	9,950,900	20	0	0	0.02	0.059	0	Kii	
Kithanje	326,200	9,950,400							Gichangai	
Kivingiri	328,700	9,949,600	18	10	56	0.018	0.02	18	Kapingazi	F. bean, tomato
Kivoo	328,700	9,956,900	13	1	8	0.013		3	Nyanjara	F. bean, tomato
Majimbo	330,100	9,944,800	30	1	3	0.03	0.08	80	Kapingazi	Tomato, F. bean
Makengi	328,600	9,951,000	40	0	0	0.04	0	50	Kapingazi	
Mukongoro			10	0	0	0.01	0.107	25		
Mwiria	328,200	9,952,400	30	0	0	0.03	0.118	0	Rupingazi/Nyanjara	
Ndaari	344,100	9,956,000	20	0	0	0.02	0.036	23	Gitwa	
Nduuri	341,400	9,949,200	15	1	7			25	Gachichiro	Kales, tomato
Nthambo/Njukiri	327,800	9,946,600	80	0	0	0.50	0	160	Kapingazi	
Nyange	335,100	9,948,300	30	10	33			25	Kamuraru	Chili, kales, F. bean
Riamaciri	326,300	9,944,900	10	5	50	0.01		35	Rupingazi	F. bean, maize
Rianjeru			100	15	15	0.10	0.368	40		Tomato, onion
Rupingazi	327,000	9,950,300	40	15	38	0.04		250	Rupingazi	
Rwanyaga/Gekago	327,800	9,959,600	32	0	0	0.03		17	Nyanjara	
Thambana	329,300	9,955,800	80	0	0	0.08	0.025	300	Thambana	

Note: The column on current status has been omitted due to lack of space.

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