The Development and Implementation of the Lake Rukwa Basin Integrated Project Environmental Information System (LRBIP-EIS) Database, Tanzania

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Key words: Environmental Information Systems (EIS), Software Development Methodology, Geographic Information System (GIS), Relational Database Management System (RDBMS), and Lake Rukwa Basin Integrated Project (LRBIP).

SUMMARY

The quest for sustenance inevitably forces mankind to exploit natural resources found within their environs. In many cases, the exploitation results in massive environmental degradation that disrupts the ecosystem and causes loss of bio-diversity. There is generally a lack of holistic information systems to monitor and provide quantitative information on the state of the affected environment. This is mainly due to the fragmented nature in which environmental information databases have been designed in the past. Decision-makers usually fail to collate information from the various sources in order to make informed decisions regarding to the exploitation and conservation of the environment. The need to provide decision-makers with quantitative environmental information forms the basis of this paper.

An integrated environmental information system (EIS) database was designed using an ecologically sensitive area in the Lake Rukwa Basin of Tanzania was used as a case study. The design was based on the Software Development Methodology. The database model consisted of three environmental sectors (Fisheries, Wildlife and Apiculture). The spatial and textual information requirements for each sector were identified through a detailed user needs assessment for each sector. The results were used to design separate data models for each sector because of the diversity of their requirements. The models were then merged using areas of common interest as bridges to create an integrated data model for the database application.

A fisheries application prototype has been developed to implement the proposed database design. The prototype has three major components. The Geographic Information System (GIS) handles the spatial data such as rivers, settlements, roads, and lakes. A relational database management system (RDBMS) was used to store and maintain the non-spatial data such as fisherman's personal details and fish catch data. Customized graphical user interfaces were designed to handle the data visualization. Using passwords to enhance the security of the prototype application restricted to the users' access to the GIS and RDBMS environments.

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1. BACKGROUND

The quest for sustenance inevitably forces mankind to exploit natural resources found within their environs. In many cases, the exploitation results in massive environmental degradation that disrupts the ecosystem and causes loss of bio-diversity. While it is highly unlikely, if not entirely unrealistic to assume, that environmental management models will provide for full sustainability, every effort must be made to minimise negative human impact on the environment. There is generally a lack of holistic information systems to monitor and provide quantitative information on the state of the affected environment. Decision-makers usually fail to collate information from the various sources in order to make informed decisions regarding to the exploitation and conservation of the environment.

Environmental information systems (EIS) provide a powerful management tool and a heuristic approach to the decision-making process and development planning at all levels of governance. Environmental information systems are concerned with the collection, analysis and representation of disparate data about the environment. The data comes in different formats and from a wide array of sources such as forestry and pastures, agriculture and fisheries, water resources, transportation and urban infrastructure, mining, wildlife, and satellite imagery (Kalensky *et al*, 1998). The environmental data is geo-referenced using geodetic control networks, aerial photogrammetry and remote sensing techniques to provide a platform for the integration of sectoral data.

Geographic Information Systems and their associated databases are the fundamental components of EIS because of their capability to combine spatially referenced information and other relevant data into computer-based integrated information systems, which can be utilised by decision-makers, planners, scientists and experts, to carry out spatial analyses, provide geo-statistical data and display and report the results. (Ruther, 2001). These integrated information systems provide environmental managers with quantitative data to minimise the guesswork associated with making decisions without reliable and up-to-date information in a form suitable for the task at hand (Humphries in Dahlberg *et al*, 1991).

2. CASE STUDY AREA

Lake Rukwa Basin is located in Mbeya region on the south-western part of Tanzania and is part of the Rift Valley with Lake Tanganyika on the northwest and Lake Malawi on the southwest. The area of Lake Rukwa, which strides the regions of Mbeya and Rukwa is isolated compared to the main economic development axis of Tanzania. According to Rüther (2001), the case study area covers approximately eighteen thousand (18 200 km^2) square kilometres and has a rich endowment of natural resources including both fauna and flora species (Figure 1). This area is classified as an area of low productive potential, except for some restricted zones that are suitable for corn, tobacco and cotton production (Davenport, 2000). The ecological balance of this region is under threat from increased human population demands on the natural resource base. As a result, the governments of Tanzania and Italy signed a bilateral agreement in 1991, to implement the Lake Rukwa Basin Integrated Project (LRBIP). The main objective is the sustainable utilisation of the natural resources for the benefit of the local communities living in the Lake Rukwa Basin and its environs, without extensively altering the ecological balance.

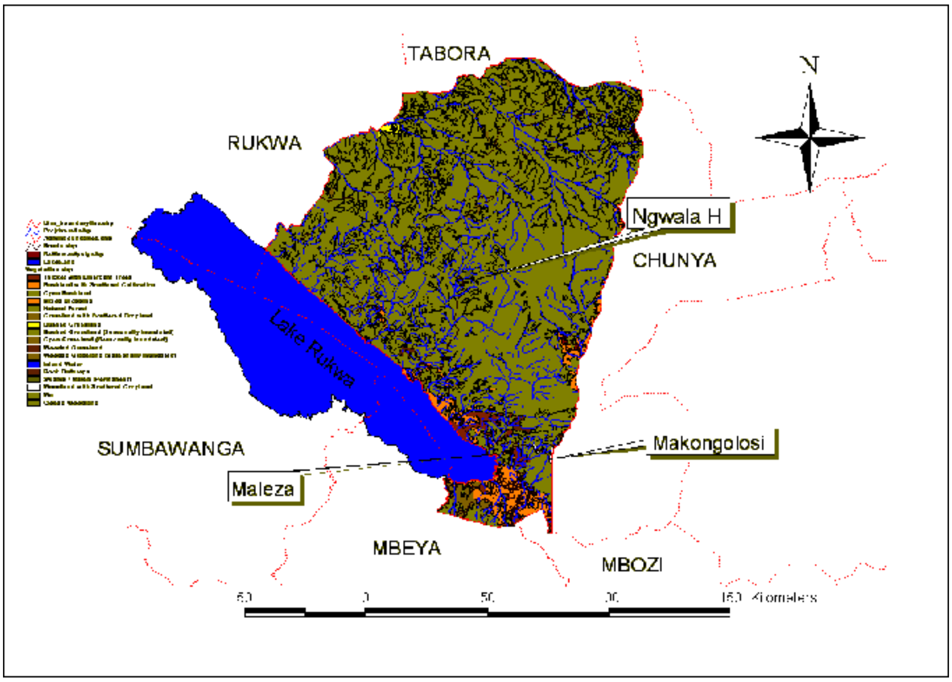


Figure 1: The Case Study Area

3. PROBLEM DEFINITION

The evolution of GIS applications in environmental management has traditionally followed the sectoral approach, focussing on particular areas such as fisheries, wildlife or forestry (MacDevette *et al*, 1995). These developments have tended to produce incompatible and inconsistent heterogeneous manual and digital databases that require extensive effort to identify, acquire, comprehend and integrate (Slagle in Michener *et al*, 1994) because of the diversity of environmental data. Tanzania is divided into regions that are made up of districts. Each district has environmental departments that work with the local communities and provide expert advice on the exploitation of natural resources. Efforts to provide appropriate environmental information at the different levels of government and private sector have led to the development of fragmented environmental information systems making it almost impossible to collate and use these systems in decision-making processes. In situations like these, Humphries (in Dahlberg et al, 1991) argues that integrated spatial information systems have become urgent requisites. This paper outlines an effort to develop an integrated environmental information system database for the Lake Rukwa Basin Integrated Project (LRBIP) that can provide decision-makers with quantitative environmental information.

4. LRBIP-EIS USER NEEDS ASSESSMENT

Six environmental sectors (fisheries, beekeeping, wildlife, forestry, agriculture and mining) were identified as the core of the Lake Rukwa Basin Integrated Project Environmental Information System (LRBIP-EIS) database. The decision was based on the environmental activities taking place in the case study area. A thorough user needs assessment was conducted to identify the information requirements of the database. A user needs collection guide (based on Wiggins *et al*, 1991) was developed to help identify the users' information requirements. Much of the information was gathered from literature reviews of the LRBIP documents as well as other database applications of a similar nature. For brevity, the spatial and non-spatial information requirements of only three of the identified sectors (fisheries, apiculture and wildlife) are detailed in this paper.

4.1 Fisheries

In Tanzania, the Fisheries Act of 1970 provides for the protection, conservation, development, regulation and control of fish, fish products and aquatic flora (Ssentongo *et al*, 2000) in the commercial fishing sector. The collection of data is fragmented in artisanal (small-scale) fisheries, which consist of large numbers of small and dispersed units operating on subsistence or semi-commercial level. According to Bianchini (2001), although, fishing is the main activity in the Lake Rukwa Basin the knowledge on the Rukwa ichthyofauna is still limited. According to Davenport (2000), there is no official inventory of fish species, distribution, population and harvesting quotas. Fish stocks are under considerable threats from overexploitation, including indiscriminate fishing practices such as the use of gill nets and poison to kill fish, habitat destruction through pollution and siltation of watercourses and lakes, lack of sound policy on the issuing of fishing permits, and shortage of manpower to enforce fishing regulations (Mukwada, 2000). Fish production information such as annual fish yields, yield per fish species, and the number of fisherman and canoes, fish sales and market distribution, is highly inconsistent in the case study area.

4.1.1 Fisheries Information Requirements

Fisheries spatial data requirements include fish species distribution on lakes and rivers (breeding and fishing grounds that could be captured using GPS), lake and river networks, and fisherman village distribution. The non-spatial component of the fisheries sector should provide attribute data on *(1)* the biological characteristics of the fish species found in the Lake Rukwa Basin. *(2)* the fish production figures in terms of catch by species, gear and area of capture as well as giving weekly, monthly and annual summary data. *(3)* the fish marketing data giving an indication of income generated and market distribution and *(4)* the fishing equipment such as vessels and gear used for catching fish on Lake Rukwa and the rivers.

4.2 Apiculture

The abundance of the 'miombo' type of vegetation in the Lake Rukwa region creates favourable conditions for beekeeping at a commercial scale. There are two types of bee species that are found in the Lake Rukwa Basin, the mellifera scutelata (very aggressive) in the plains and the mellifera monticola (less aggressive) in mountainous regions. Beekeepers use cylindrical beehives that are constructed from tree. Hassan *et al* (2001) points out that the shortage of large trees suitable for bark hive making is already evident in the region. Annual honey production and revenue figures are not readily available but it is estimated that 20 tons of honey and 5 tons of wax were harvested per annum over the last few years (CIC Report, undated). Lack of licensing procedures makes it difficult to keep track of the beekeepers that are permitted to trap bees and collect honey in the case study area. The beekeepers rely on traditional methods for the collection of honey, and in most cases use fire to inactivate the bees. Occasionally, these fires run out of control and spoil the environment (Hassan *et al*, 2001).

4.2.1 Apiculture Information Requirements

The spatial data requirements for the apiculture sector include *(1)* location of apiaries (beehive sites) and forest camps and road networks, *(2)* market locations and distribution of diseases affecting apiaries, and *(3)* land use/land cover data including forest cover and extent of fires. The beekeeping component should provide attribute data on *(i)* beekeepers and honey traders, *(ii)* honey and honey-related product harvests, *(iii)* climatic conditions (temperature, rainfall, blooming seasons).

The users require the system to provide for analyses such as comparing wildlife poaching activities relative to apiary site locations, comparing honey production relative to surrounding land use/land cover including forested areas, and providing time series of harvest and income generated for each beekeeper, village and district.

4.3 Wildlife

The prominent mammal fauna found in the miombo woodlands, grasslands around the lake, water basin and in the lake and neighbouring swamps include Kudu Major, the topi, the cane field antelope, elephant, hippopotami, and crocodiles. The bird fauna is also very diverse with at least 360 species, including among the most important ones, the robust parrot (CIC Report, undated). Wildlife activities are governed by the Wildlife Conservation Act of 1974, which prohibits subsistence hunting of game. As a result, the poaching of wild animals by the local population is rife. Legal hunting is carried out by Safari operators (catering mainly for the international clientele) and local hunters (predominantly expatriate residents and wealthy nationals) who can afford to purchase hunting licenses from central government (Davenport, 2000). There is no current inventory (hunting quotas, licensing, zones, seasons, species, seasonal routes etc) of hunted mammals and birds. Hunting quotas are not determined using quantitative data. There is speculation that the wildlife species in the region of Mbeya are diminishing drastically although there is no statistical evidence available on the processes of loss of any single species (CIC Report, undated). There is limited quantitative data on the impact of animals described as ‘vermin’ in some local reports. These animals (e.g. baboons, elephants and bush pigs) inflict crop damage (Mbassa *et al*, 2001) while hippopotami, crocodiles and lions cause loss of both human and domestic animal lives.

4.3.1 <u>Wildlife Information Requirements</u>

The spatial data requirements of the wildlife sector included *(1)* species distribution including seasonal migration routes *(2)* eco-tourism locations (game reserves and hunting grounds, animal viewing sites) *(3)* Spatial distribution of poaching activities *(4)* Administrative boundaries and Infrastructure (roads, transmission lines, telephone lines, health facilities). The attribute data of the wildlife sector included *(i)* Species composition and abundance, *(ii)* Hunting activities including licensing, quota determination and allocation, monitoring hunting harvests and overtakes, checking compliance by reconciling hunting licenses and animals harvested, *(iii)* Hunting clubs and Safari tour operators, *(iv)* Poaching activities giving vulnerable and threatened species, details of confiscated weapons and records on any criminal convictions, and *(v)* Quantitative data on vermin [specific areas trends with regards to human and livestock losses, damage to crops (Davenport, 2000)].

5. LRBIP-EIS SYSTEM DESIGN

The results of the user needs assessment were used to develop separate conceptual and logical data models for each sector. This was the best approach because of the huge differences in individual sector information requirements. An integrated global logical data model was created by identifying areas of overlapping interest between sectors.

5.1 LRBIP-EIS Conceptual Data Modelling

The conceptual data model is based on what the users and organisation’s perception of the relationships between the entities that make up the system. The conceptual data model is constructed from the enterprise rules derived from the user requirement specifications. The conceptual model represents the basic entities and their associated relationships using entity-relationship diagrams (ERD). The fisheries sector will be used to illustrate the principles involved in the conceptual data modelling for the LRBIP-EIS. Conceptual data model schemas were also developed for the apiculture and wildlife sectors.

Fisherman - Fish Species
A fisherman may catch many kinds of fish species
A fish species may be caught by many fisherman
Fisherman - Fishing Gear
A fisherman may own many fishing gears
A fishing gear must be owned by one fisherman
Fisherman - Fish trader
A fisherman may sell fish to many fish traders
A fish trader may buy fish from more than one fisherman
Fish species - River
A river may have one or many types of fish
A fish species may be found in many rivers
Fish species - Lake
A lake may support many types of fish
A fish species may be found in more than one lake
Fisherman - Village
A fisherman must reside in a village
A village (settlement) may have many fisherman
Fisherman - Wildlife species
A fisherman may poach many kinds of wildlife species
A wildlife species may be poached by more than one fisherman
A fisherman may be attacked by more than one type of wildlife species
A wildlife species may attack more than one fisherman
Fish species - Wildlife species
A fish species may be consumed by more than one wildlife species
A wildlife species may eat more than one type of fish species

Figure 2: Fisheries Enterprise Rules

The enterprise rules are represented in the entity-relationship diagram below.

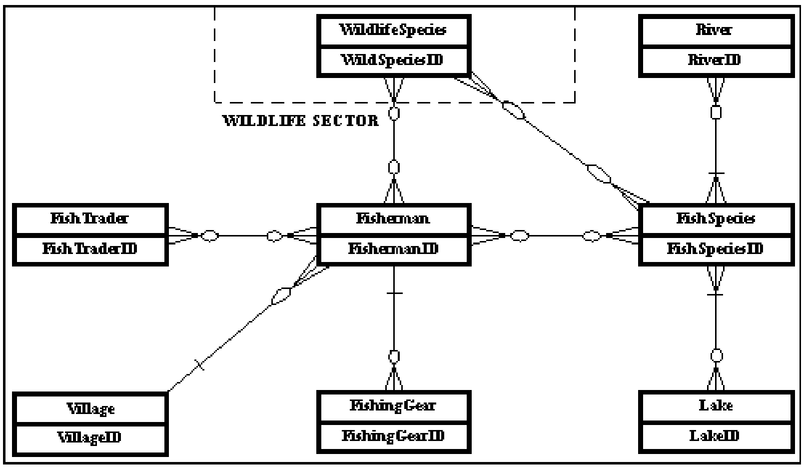


Figure 3: Fisheries Entity-Relationship Diagram

5.2 LRBIP-EIS Logical Data Modelling

The LRBIP-EIS database was based on the relational database model. A mapping process is applied the conceptual data model so that it can be implemented in the relational model. The mapping process involves the removal of that are not compatible with the relational model (such as many-to-many relationships) and the derivation of the relations (skeleton tables) for the database (Figure 4). Relations represent the entities, attributes and entity relationships that have been identified during the conceptual and logical database design. Attributes are defined by the type of information that is required to held about an entity or relationship.

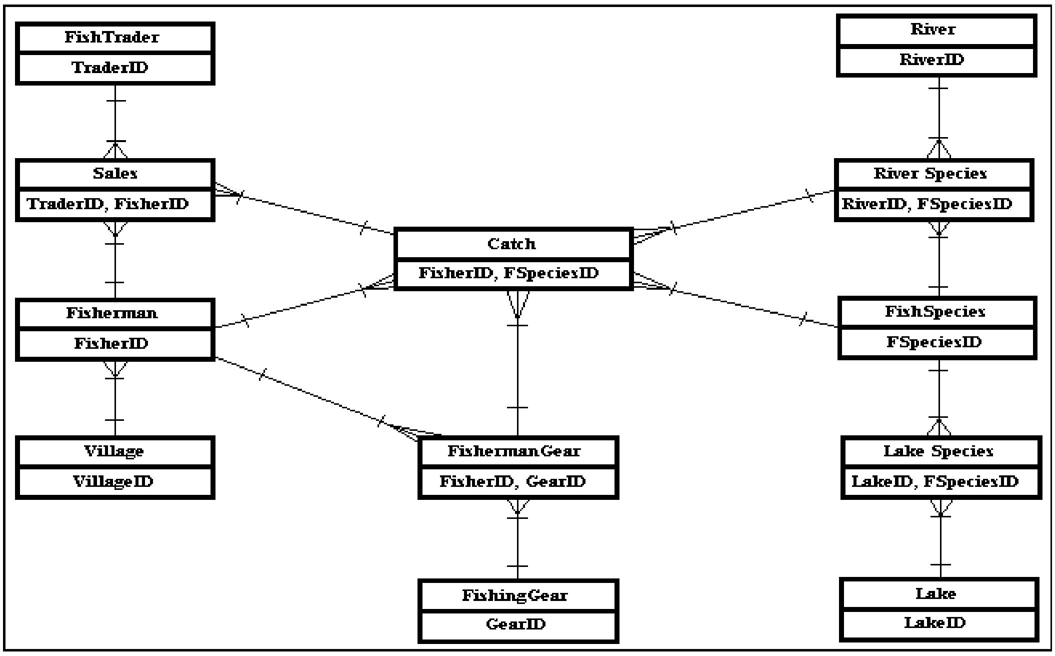


Figure 4: Fisheries Logical Data Model

The relations for entities and attributes are given by the name of the entity followed by its associated attributes in brackets. The relations show attributes that are associated with these tables including primary keys (underlined) and any posted (foreign keys) that are used to uniquely identify them e.g.

Fisherman (<u>FisherID</u>, FirstName, Surname, Gender, MaritalStatus, ..)
Rivers (<u>RiverID</u>, RiverName, Length)

The relations were validated for anomalies using the process of normalization. The logical data models are also checked for fan and chasm traps before they are used for the design of the physical database model. The global (integrated) logical data model was created by combining the individual sector logical data models using areas of common interest to bridge the models (Figure 5).

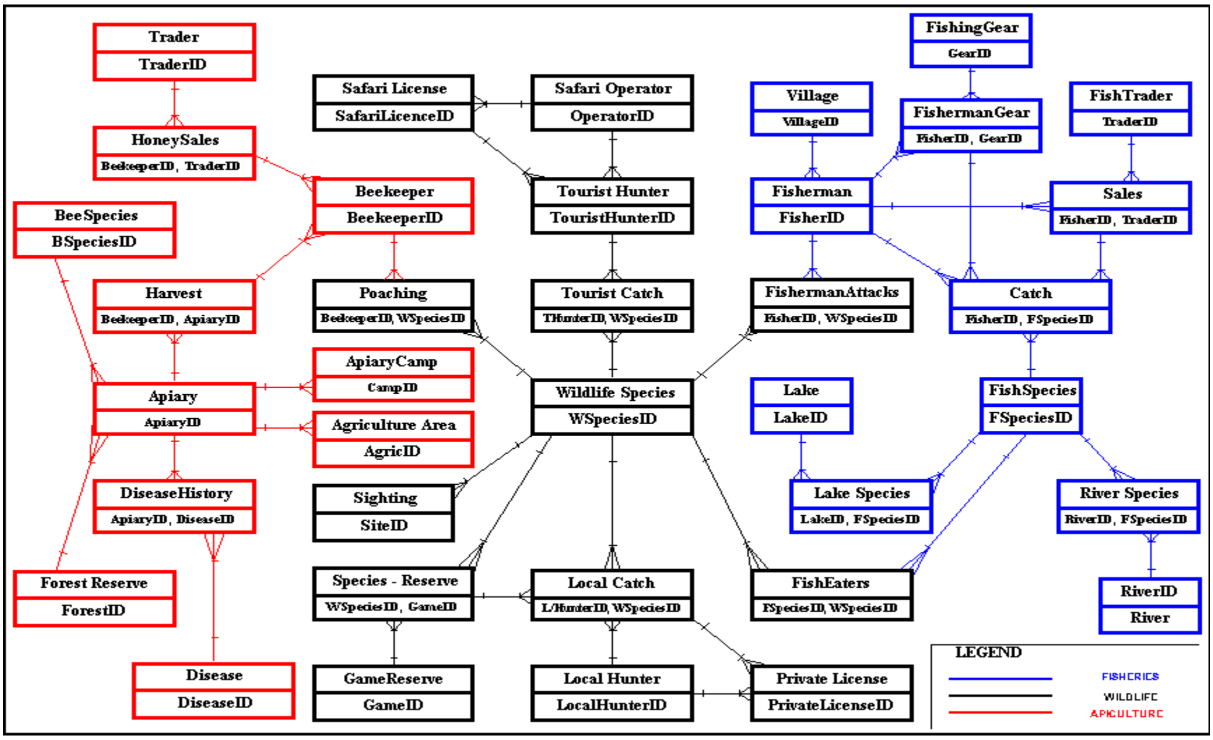


Figure 5: The Global Data Model

6. LRBIP-EIS DATABASE PROTOTYPING AND IMPLEMENTATION

The proposed LRBIP-EIS database has both spatial and non-spatial components and Figure 6 below shows the proposed scheme for the prototype database. A test database for the fisheries sector was developed on the basis of this scheme.

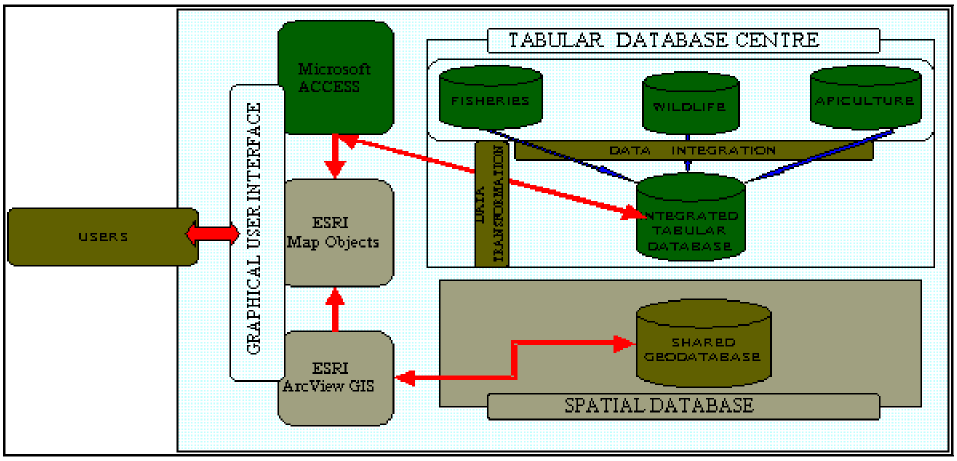


Figure 6: Proposed LRBIP-EIS prototype database scheme

6.1 Fisheries Test Database

A fisheries test database was created to provide limited data capture and viewing, data updating, and querying and reporting textual and spatial data functionalities. The entities (Figure 7) based on the fisheries logical data model, represent some of the entities that were populated with sample data for testing the prototype.

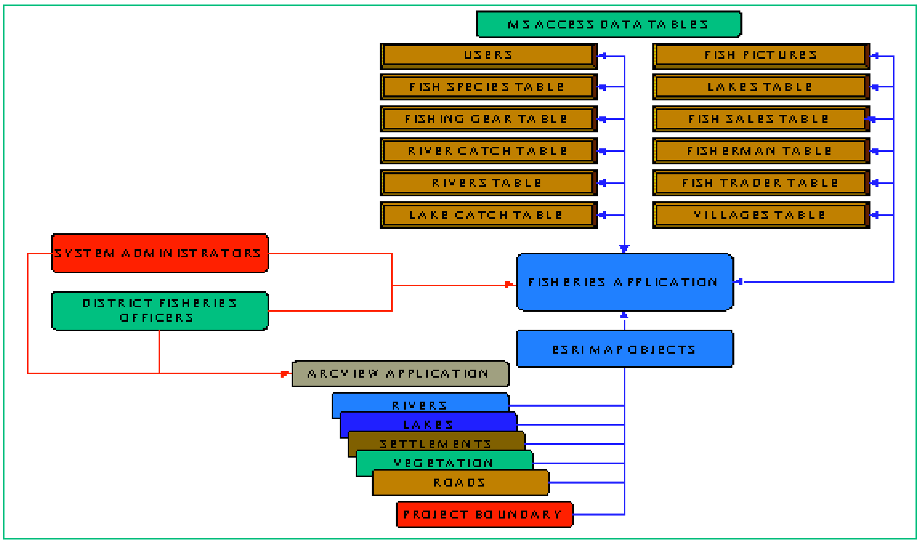


Figure 7: Fisheries test database

The test database is made up of the MS Access© database, the customised graphical user interfaces and the ArcView GIS© and MapObjects© spatial components.

6.1.1 MS Access© database

The Microsoft Access DBMS was used to provide the database engine for non-spatial data component of the system. The MS Access environment provides the platform for storing data and ensuring entity and referential integrity constraints are enforced. This is achieved by creating database tables from the skeleton tables and then defining the relationships between the entities. Figure 8 (overleaf) shows a portion of the relationships in the MS Access database.

6.1.2 Graphical User Interfaces

Graphical user interfaces (GUIs) were designed and developed using Microsoft's Visual Basic© (VB) environment that enables the user to capture, update and query the MS Access database. The users are registered and granted access privileges by the system administrators after verification with the relevant authorities. Users login into the system via a valid username and password. The system is designed to restrict users' access only to the sectors they are registered in. Data security is enhanced by limiting the number of the users who have rights to access and modify data held in the MS Access database and the ArcView GIS© components of the database application.

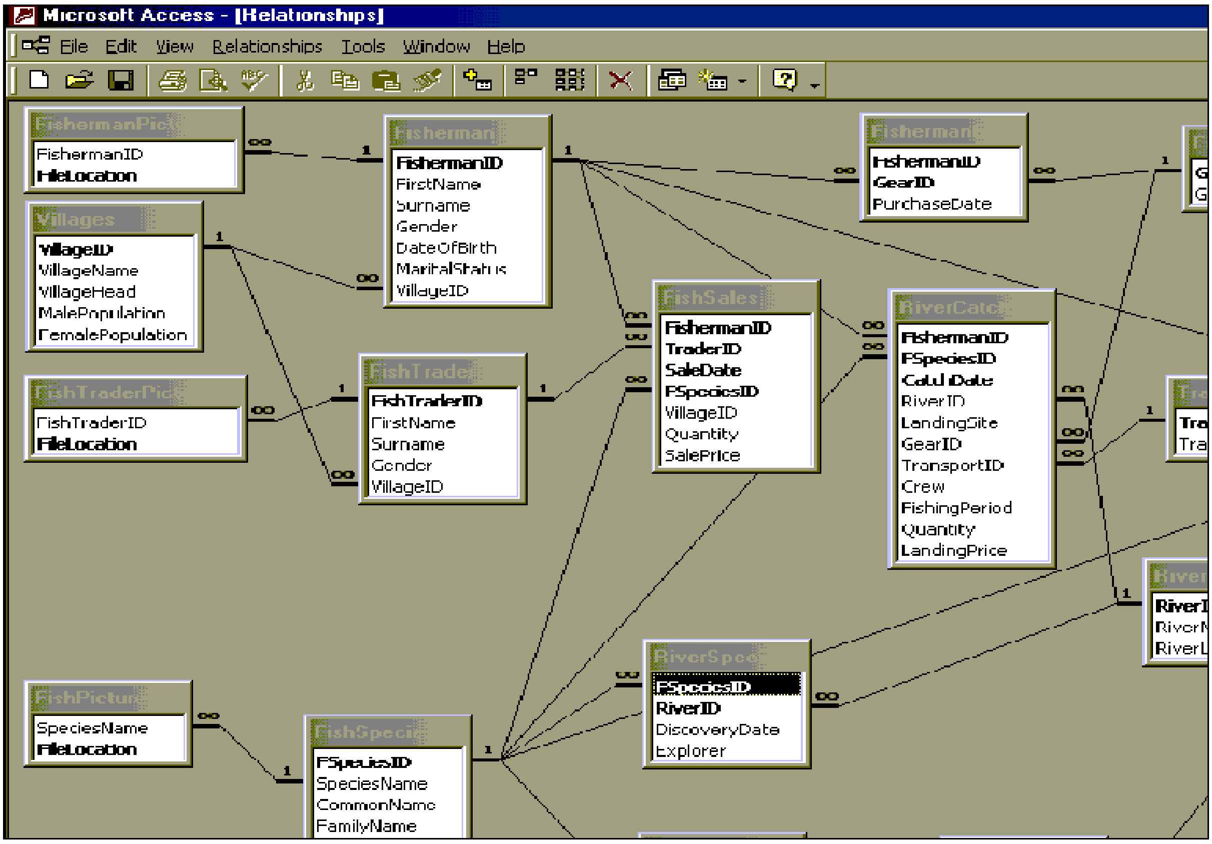


Figure 8: Microsoft Access© Entity Relationships

Pull-down menus and navigation buttons allow viewing of the database records. Data update (adding new record, deleting, editing or saving) is achieved by clicking the appropriate control. Data querying routines for finding, selecting and sorting records are provided on the user interface forms. The user chooses the appropriate query option and the results are displayed on the screen. Some *Find* and *Select* routines prompts the user to input values for the query parameters such as the select river query shown in Figure 9 below.

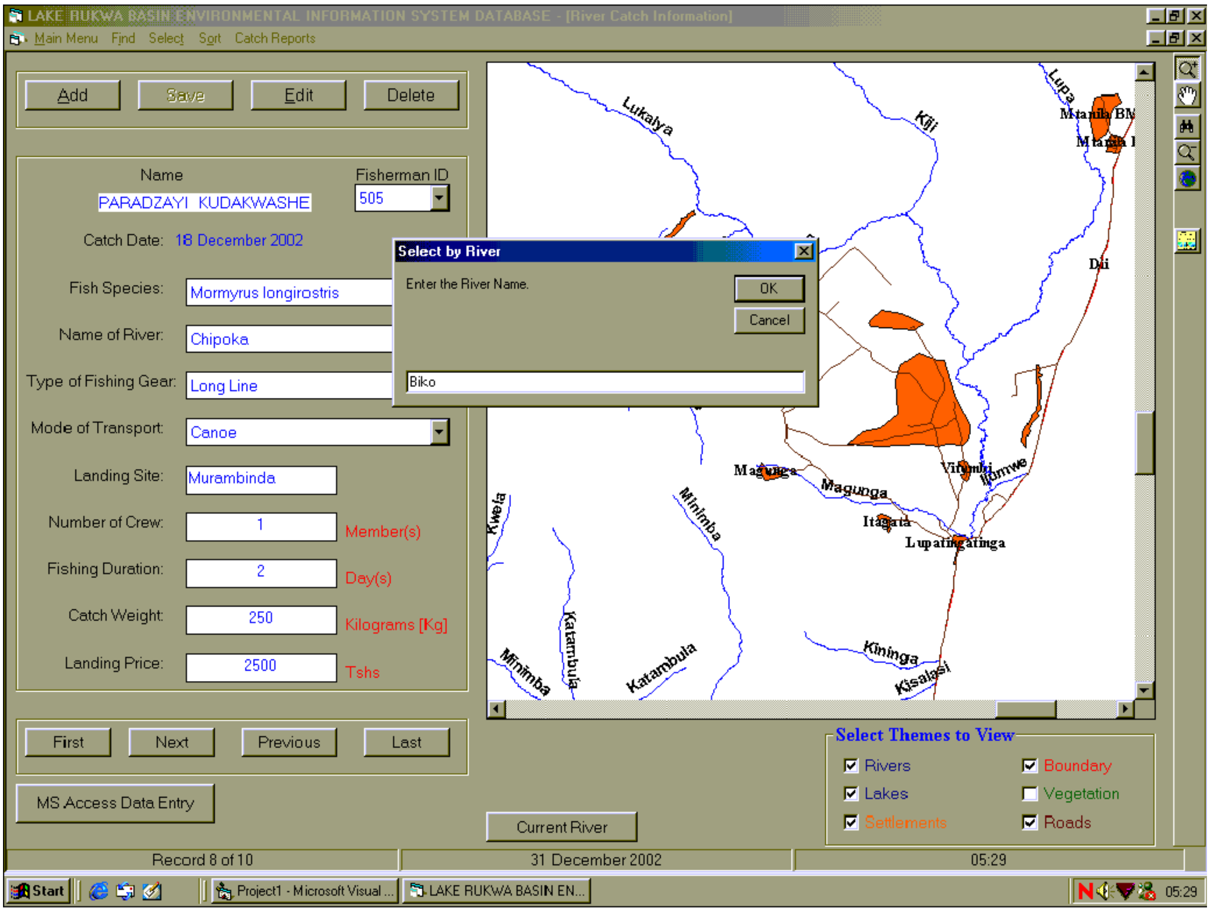
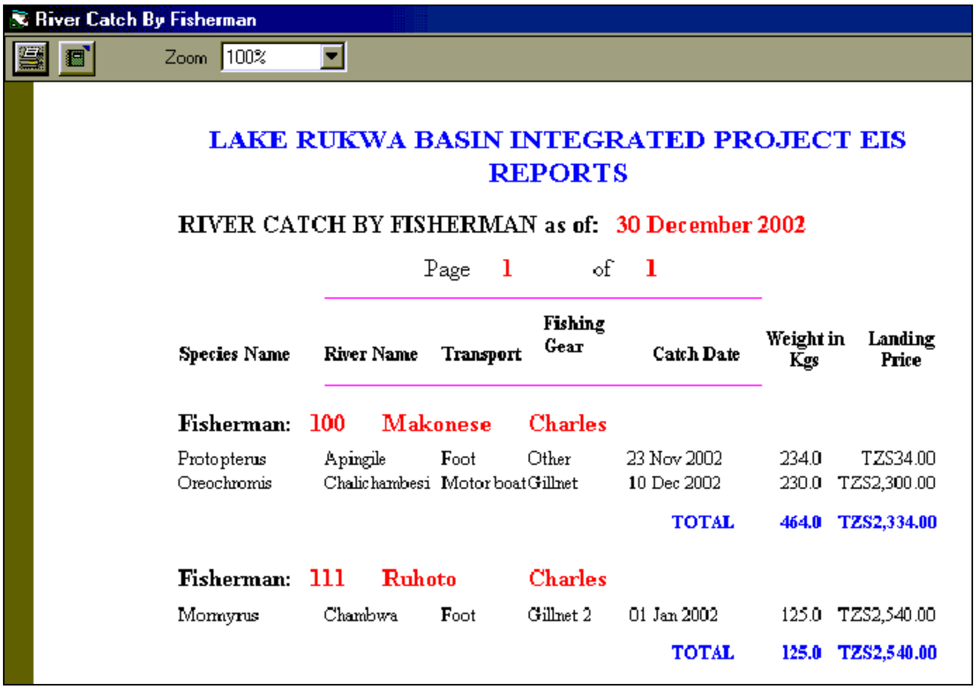


Figure 9: Select River Query

A number of reports (e.g. Figure 10) can be generated from the test database by using Structured Query Language to collect and group the appropriate report information. The Data Report Designer in the Visual Basic Data Environment was used to create report templates. The reports can be printed or exported in a variety of formats including one that is web-compatible.



River Catch By Fisherman

Zoom 100%

LAKE RUKWA BASIN INTEGRATED PROJECT EIS REPORTS

RIVER CATCH BY FISHERMAN as of: 30 December 2002

Page 1 of 1

Species Name	River Name	Transport	Fishing Gear	Catch Date	Weight in Kgs	Landing Price
Fisherman: 100	**Makonese**		**Charles**			
Protopterus	Apingile	Foot	Other	23 Nov 2002	234.0	TZS34.00
Oreochromis	Chalichambesi	Motor boat	Gillnet	10 Dec 2002	230.0	TZS2,300.00
				TOTAL	**464.0**	**TZS2,334.00**
Fisherman: 111	**Ruhoto**		**Charles**			
Mormyrus	Chambwa	Foot	Gillnet 2	01 Jan 2002	125.0	TZS2,540.00
				TOTAL	**125.0**	**TZS2,540.00**

Figure 10: River Catch By Fisherman Report

6.1.3 Spatial Component

Access to the ArcView GIS© package is restricted by means of access privileges that are granted to users as they register with the System Administrators. ESRI ArcView GIS© and MapObjects© packages were used to edit the spatial data, and to create only shapefiles for the spatial component of the system. The shapefile data is displayed in the customised graphical user interfaces via ESRI's MapObjects© package. This functionality links textual data and spatial data allowing textual and spatial queries to be related. For example, selecting a fisherman from a MS Access© table causes the fisherman's village to be highlighted in the mapping component (Figure 11).

The MapObjects© component has been programmed in the GUIs to give limited map viewing functionality. These include zooming, panning and spatial search options. A generalised display (with fewer themes) is shown when the user zooms to the full extent of the map display. This helps to reduce overcrowding in the display. Some themes can only be displayed when the user zooms in on the map display.

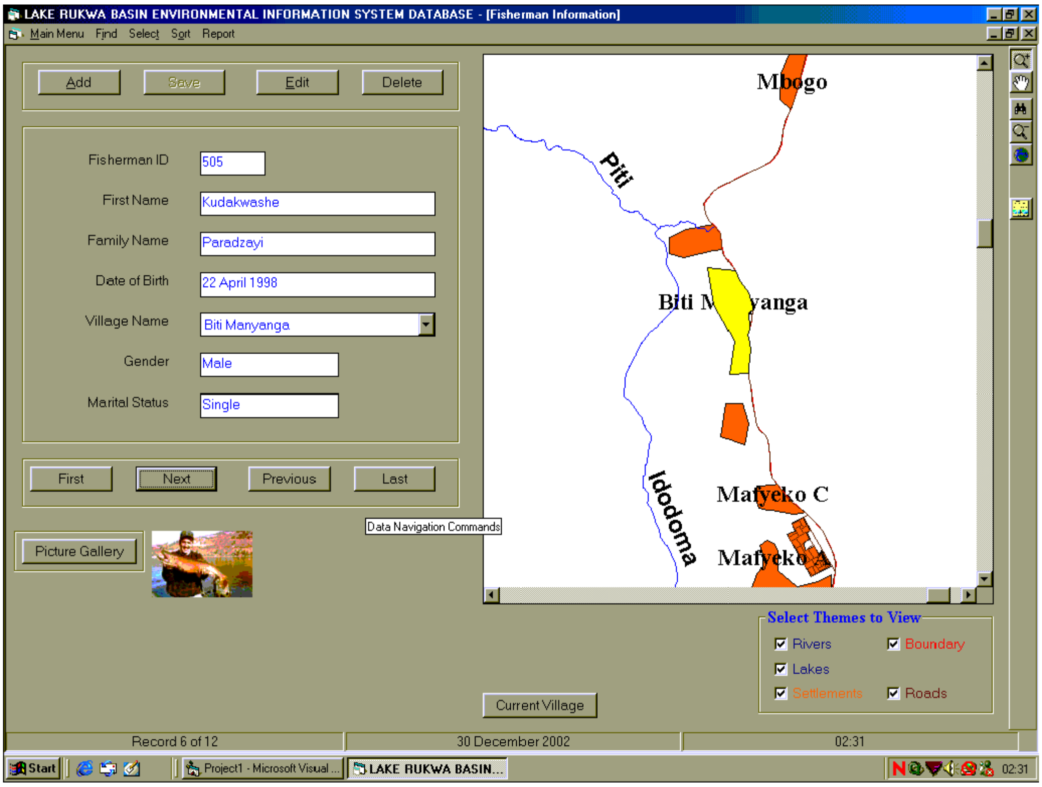


Figure 11: Fisherman Data Capture, Update and Query interface

7. CONCLUSIONS

The prototype has limited functionality with regard to some of the requirements outlined during the system design stage. Reports such as individual fisherman catch, fish trader sales, weekly, monthly or yearly summaries have not developed due to time constraints. The prototype should be developed further to cover the wildlife and apiculture sectors for evaluation by the users before the development of the final LRBIP-EIS database application. The research work involved the integration of skills from disciplines such as systems analysis, database design, computer programming and geographic information systems (GIS) in an attempt to develop an integrated environmental information system database. It is possible to achieve these efforts given enough time and enough financial resources to involve all the stakeholders in the Lake Rukwa Basin.

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BIOGRAPHICAL NOTES

Charles Paradzayi, is currently lecturing Surveying Computer Application and GIS modules at the Midlands State University. He graduated with a BSc (Surveying) Honours degree from the University of Zimbabwe in 1992. He taught at the Harare Polytechnic's department of Surveying from 1994 until 1998. From October 1998 until March 2000, he became a part-time lecturer in the Civil Engineering department of the University of Zimbabwe, taking the Surveying for Engineers module.

He then moved to the Midlands State University, where he assisted the introduction of the Surveying and Geomatics department. In 2001, he was awarded a Staff Development Fellowship to study for his MSc (Engineering) Geomatics degree with the University of Cape Town in South Africa. His Masters dissertation was on the development and implementation of a GIS-based environmental information system database for an ecologically sensitive area in the Lake Rukwa Basin of Tanzania.

Charles Paradzayi has research interest in developing GIS applications to solve environmental management problems. He is involved in the Zimbabwe Metadata initiative that is pushing for the adoption of metadata standards by the various stakeholders who use GIS data. He also has a passion for engineering surveying and he has worked on various civil engineering projects.

Professor Heinz Ruther, Professor for Geomatics at the University of Cape Town, graduated in 1969 with the Degree of Diplom –Ingenieur at the University of Bonn and obtained his Ph.D. in photogrammetry at the University of Cape Town in 1982. He is a Fellow of the University of Cape Town, a Fellow of the South African Academy of Engineers, a Member of the South African Academy of Science and an Honorary Member of ITESSA. He is a past Council member of ISPRS, present Chair of the Financial Commission of ISPRS and Vice President of the African Association for Remote Sensing of Environment. From 1990 to 2002 he was the Head of eth Geomatics department

Professor Ruther has worked on photogrammetric and surveying projects in Europe, Asia, the Middle East and especially Africa. He has extensive experience in the areas of digital photogrammetry, close range photogrammetry, precise engineering surveying and deformation analysis. He has supervised numerous MSc and PhD research projects and published more than 100 papers in scientific journals and at international conferences.

Professor Ruther's special interest lies in the area of digital photogrammetric 3D-modelling of architectural structures and the documentation of Heritage sites.

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