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Development of a Geographical Information System for the monitoring of the health infrastructure in rural areas in Tanzania

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Abstract

Background: Setting up Geographical Information Systems (GIS) on the existing health infrastructure and ongoing and planned interventions in public health in Tanzania is still in its infancy. While there are several activities on gathering information and attempts of documentation there does not exist an overall systematic approach of generally capturing all health related facts and bringing them together into a unique information system yet. In order to strengthen the information system in the health sector in general, and to assist Ministry of Health and Social Welfare (MoHSW) in better receiving an overview of health related infrastructure and intervention data for management purpose, a first-pilot GIS was built up in the Mbeya Region in cooperation with Tanzanian German Programme to Support Health (TGPSH)/Gesellschaft für technische Zusammenarbeit (GTZ).
Methods: The Health-GIS contains information on all health facilities (HF) in the region and their infrastructure. Therefore, personal interviews were conducted in selected HF based on a comprehensive questionnaire. The spatial coordinates of the HF were taken with a Global Positioning System (GPS). In a relational database, the newly coded HF are linked to the gathered information pertaining to them and in a second step are analysed and visualised with help of GIS.
Results: First results show newly collected geometry and attribute data for a considerable number of HFs in Mbeya Region, which are then supplemented by information on the street network lately surveyed during the fieldtrip. With the help of a database management system (DBMS) all information are stored and maintained within one health database. By their spatial relation, data may be analysed and mapped with a Health-GIS. Because of the targeted cooperation with people and institutions from the local health sector, the way for integrating the Health-GIS into the health planning infrastructure is open. Also, the funding of an IT group comprised of members from national and international institutions is another step to gaining local acceptance for the system.
Conclusions: First steps have been taken to introduce the Health-GIS as a pilot project in the Mbeya Region. It has proved to be useful in order to collect the essential attributes of the HFs. Further development of the GIS will have to be taken into account simplicity of use. Hence this requires that the GIS needs to be integrated into the planning process.

Key words: public health, database management system, health management information system, GIS

Introduction

As postulated by the Millennium Declaration signed during the United Nations Millennium Summit in 2000, the improvement of health is a central challenge to be achieved by 2015. The eight Millennium Development Goals (MDG) [1] define essential targets concerning combating development and poverty as well as protection of the environment. Furthermore, three call for measures to improve the state of health of different sections of the population, especially those who are poor. This includes amongst others the enhancement of the gathering and preparation of health data in order to evaluate the achievement of the millennium goals.

Two of the MDGs are considered more closely for the United Republic of Tanzania. Goal 4 "Child Health" aims to "reduce by two-thirds, between 1990 and 2015, the mortality rate among children under five" [1:20]. Table 1 shows an estimated

Table 1. Under-5 mortality and maternal mortality ration in Tanzania.

Years	Under-5 mortality per 1000 live births	Maternal Mortality ratio (per 100 000 live births)
1980	175[a]	-
1990	161[a]	770[a]
1995	-	1100[a]
2000	141[a]	1500[a]
2004	126[a]	-
2006	118[b]	-

[a][29] [b][30]

trend of this indicator that assumes a noticeable decline of the child mortality in Tanzania, although, the goal is to reach an under-5 mortality of 55 per 1,000 live births [2]. The Millennium Development Goal 5 "Maternity Health" is to "reduce by three quarters, between 1990 and 2015, the maternal mortality ratio" [1:24], for which there has not been any positive trend in Tanzania since 1990 (see Table 1).

Because of the spatial and temporal relation of health and illness the geographic health service research may add important contributions to the achievement of the MDGs as well as to the supervision and compliance of health planning requirements.

Aims of Project

Better health is central to human happiness and well-being. Many factors influence health status and a country's ability to provide quality health services for its people. The mission of public health is to fulfil "society's interest in assuring conditions in which persons can be healthy" [3]. To carry out this mission the public health system relies on, amongst others, the information and communication systems used in collecting and disseminating data. In many developing countries the most basic information on health services is often incomplete. Therefore, World Health Organization (WHO) considers as a priority the strengthening of national health information systems in order to guide policymaking, program design, management, and service provision in the health sector.

In Tanzania, health connected sectors such as agriculture, education, roads and water have developed systems for gathering information and ensuring documentation. However, an overall systematic approach of generally capturing all health related facts and bringing them together into a unique information system does not exist yet. GIS technology provides opportunities for making better use of health related data by linking and integrating multiple data sets rapidly and accurately [4].

The overall aim of the project is to construct a Health-GIS to be applied in the field of health infrastructure in Tanzania, starting in the Mbeya Region as a pilot area. The GIS project in Mbeya Region intends to implement an instrument that supports monitoring and more effective planning of the health sector directly on its basis – in the districts and regions.

The main focus of the application would be the spatial analysis and the compilation of maps showing HF locations including infrastructure, service and resource availability. All HF will be interviewed on the basis of a questionnaire for which the results are stored in a Microsoft Access database. It is anticipated that a process of linking data resulting in data-sharing multisectoral partnership between health departments and other entities as well as the community for a better planning and management of resources will be undertaken. The analysis of the maps should guarantee a good overview of what already exists and therefore lead to better multisectoral coordination at all levels.

One of the main concerns of the project is that it will be sustainable and transferable to other regions in Tanzania. The possibility of achieving these goals also depends on external general conditions.

GIS for health infrastructure planning

Effective health planning is often difficult to realise in developing countries. Besides the constraints of a difficult economic framework, data is often lacking in order to initiate essential measures. Whereas reliable data are available in many countries, their access and their usability is still a challenge to be mastered in the developing world. Results of a first survey in Tanzania showed that a great variety of data does exist [5]. Though, applications for making this data usable for planning purposes are lacking. Because many data have a spatial relation, they might be used within a Geographical Information System (GIS).

At first, when spatially related data were analysed, it was done mainly by mapping health phenomena e.g. occurring illnesses. The visual interpretation has an exploratory analytic character [6,7]. The most cited example of exploratory data analysis is the map cholera outbreaks in London in 1849 conducted by Dr John Snow (1813-1858). This marked the beginning of modern epidemiology [8].

The building of computer-aided planning systems known as the "Health Management Information System" (HMIS) commenced in developing countries in the 80s. Because of the limited technical functionalities, the cartographic and analytical capabilities of these systems were very restricted [9]. Nowadays, new hardware and software offer all eligible functionalities to develop complex monitoring systems. New dimensions of spatially related analysis methods and quantitative and qualitative analysis of health data are opening [10:6]. In English speaking countries, implementation of health GIS is already state-of-the-art [11], as it is an appropriate tool to analyse the organisation of health systems [12,13]. Implementation of GIS in health services research derives from its standard functionalities which were adopted for the project in Tanzania [14:24].

- With help from geometric characteristics distance queries for example, about geographic accessibility and barriers to access of health facilities (HF), may be determined.
- In order to transform punctual data such as attributes of HF into line or area models, mathematical and geometric algorithms are used. Several functionalities are applicable such as buffering.
- Spatially related queries allow for connecting and the browsing of complex databases.
- Overlaying and overlapping of existing data may generate information of a new quality. This may be helpful for infrastructure planning by defining certain features such as: access to the street net, proximity to the target population, minimum distance of existing facilities etc.

Based on these functionalities, position of HF may be optimised. Other outcomes of these techniques are the mapping of potential health risks [15]. GIS is especially suited for the analysis of medical infrastructures related to socio-demographic characteristics of the population [7,16,17]. In developing countries, data quality and lacking geo-data infrastructure make use of GIS more difficult, however it is feasible to implement it into public health.

Investigation Area – Mbeya Region

The Tanzanian German Programme to Support Health (TGPSH)/Gesellschaft für technische Zusammenarbeit (GTZ) supported Mbeya Region as one of Tanzania‘s 21 administrative regions of Tanzania's mainland. The regional capital is Mbeya. Its neighbouring regions are, to the northwest Tabora Region, to the northeast Singida Region, to the East Iringa Region, to the South the countries Zambia and Malawi and to the West Rukwa Region (see Figure 1). Mbeya Region has a population of 2,070,046 people, the population density is 34 per km² [18]. The Mbeya Region is divided into 8 districts: Chunya, Mbozi, Ileje, Kyela, Rungwe, Mbeya Urban, Mbeya Rural, Mbarali (see Figure 1) which are in their part furthermore divided administratively into wards. In Mbeya Region 174 wards exist.

The health system in Tanzania assumes a pyramidal pattern referral system as recommended by health planners, which starts from dispensaries and health centres and develops to district hospitals, regional hospitals then to consultant hospitals [19]. The number of these different types of HF forms a kind of pyramid showing that dispensaries are the most common form of facility. In the Mbeya Region, 410 HF have been established of which 354 are dispensaries (including closed ones), 31 are health centres (HC), 9 are specialized clinics and 16 are hospitals [20].

The aim of the government is to realise that "Most of the population [...] live within 5 km from a health facility; however, there are still geographical inequalities in access to health services." [21:2]. A GIS can be used as a tool to pursue this aim, by supporting the planning of the health care infrastructure. "The national health system is based on decentralized services to local government authorities [...]." [21:4], involving a GIS for the Health Management Team should therefore be established at the regional level.

Methods

For building up of the Health-GIS, primary data from official statistics are utilised including geometry as well as attribute data. There are several sources available especially for the required geometry data. These are of different quality and have already been tested for their usability [5].

The available data relating to the HF to be integrated in the Health-GIS are not appropriate. Therefore, a proper survey will be conducted. Primary sources have many advantages concerning actuality of information and flexibility in database design. The own-data survey on HF including their geographical position was evaluated to be the most reliable source. Existing secondary statistics in Tanzania were evaluated as well.

The field survey of the HF' infrastructure and their geographic coordinates is based on a questionnaire. This questionnaire was worked out in collaboration with different national and international institutions mostly active in the health sector in Tanzania, under the auspices of the Ministry of Health and Social Welfare (MoHSW). They decided that this questionnaire

Figure 1. The investigation area of the project "Health-GIS in Mbeya Region", Tanzania (own illustration).

should be tested in the Mbeya Region within the Health-GIS project. The questionnaire is comprised of eight sections:

- Section 1: General characteristics
- Section 2: Services and General purpose equipment
- Section 3: General purpose equipment (only for Hospital)
- Section 4: Injection and sterilization equipment
- Section 5: Human recourses
- Section 6: Drugs and commodities
- Section 7: Lab tests
- Section 8: Buildings

With the help of this questionnaire every HF in the Mbeya Region will be individually interviewed. In the first data collection period (September 2008) a tandem system was used, each team consisted of one local student and one German participant. This aims to ensure support should language problems occur as well as provide for an intercultural exchange. The interviews in the dispensaries took about 35 minutes , while in the HC they took an hour and in the hospitals almost a day.

To map the HF the teams travelled to most of the HF by car and took coordinates with Handheld GPS (Global Positioning System). The focus during the mapping was the collection of coordinates for the main buildings. Furthermore, the roads should be recorded with the GPS's "track log" function while travelling by car. The teams also had the task of mapping the infrastructure in the districts, e. g. schools, industry, churches, bus stations or markets as well as bridges. While visiting the HF all teams took several pictures of the HF buildings, of the different water sources and sometimes of the special equipment. All of the picture numbers were recorded in the list together with the GPS coordinates and coded so that it is possible to create links between the pictures and the geographical points within the GIS.

The database may be expanded by linking it to existing datasets e.g. population data from CENSUS 2002 and geodata of administrative units, edited by National Bureau of Statistics (NBS) as well as locations of villages and their boundaries, surveyed by the Ministry of Lands and Human Settlements Development (MLHS).

To administer the collected data a relational data bank is to be developed using Microsoft Access. The data stored in this database will later be used for compilation of thematic maps and analysis for future health planning. This could be accomplished with GIS software (Esri ArcGIS). Together with members of the health sector it was decided to develop a coding system for the database in order to remove any ambiguity that may exist if only the facilities names were to be used.

Results

In market research, the external framework is looked at from four perspectives: political factors, economic factors, technical elements and socio-cultural parameters [22,23]. Because the project is based on close cooperation with the MoHSW, the political framework is perceived to be favourable. When it comes to economic preconditions, the project started with a low budget, as a pilot study, that keeps the expenditures in Mbeya Region contained. The economic balance will very much depend on to what point the introduced monitoring system will be implemented as a management system used by decision makers. The tool itself has enormous potential to support improved management of scarce resources in the health sector and it will depend on the degree to which the system is used as to whether the investments pay-off in the medium- or long-term. The technical elements including the coding system and the database as well as the socio-cultural parameters are explained in more detail below.

Coding System

In terms of GIS, HF will be stored in a relational database with their attributes as well as geometry. Therefore it is necessary to give every object a unique address in order to identify every object unambiguously. To meet the acceptance of the local authorities an IT group "*National Health Facilities database of Tanzania*" was set-up. This group consists of staff of MoHSW, NIMR (National Institute for Medical Research), TGPSH/GTZ, TFH Berlin (University of Applied Sciences Berlin) and NGOs. This IT group as well as the designated MoHSW official agreed on the use of MS Access. Furthermore the IT group also agreed that the TFH Berlin members would build up a database structure proposal for storing the data of the HF. The IT group decided that the database should fulfil following requirements:

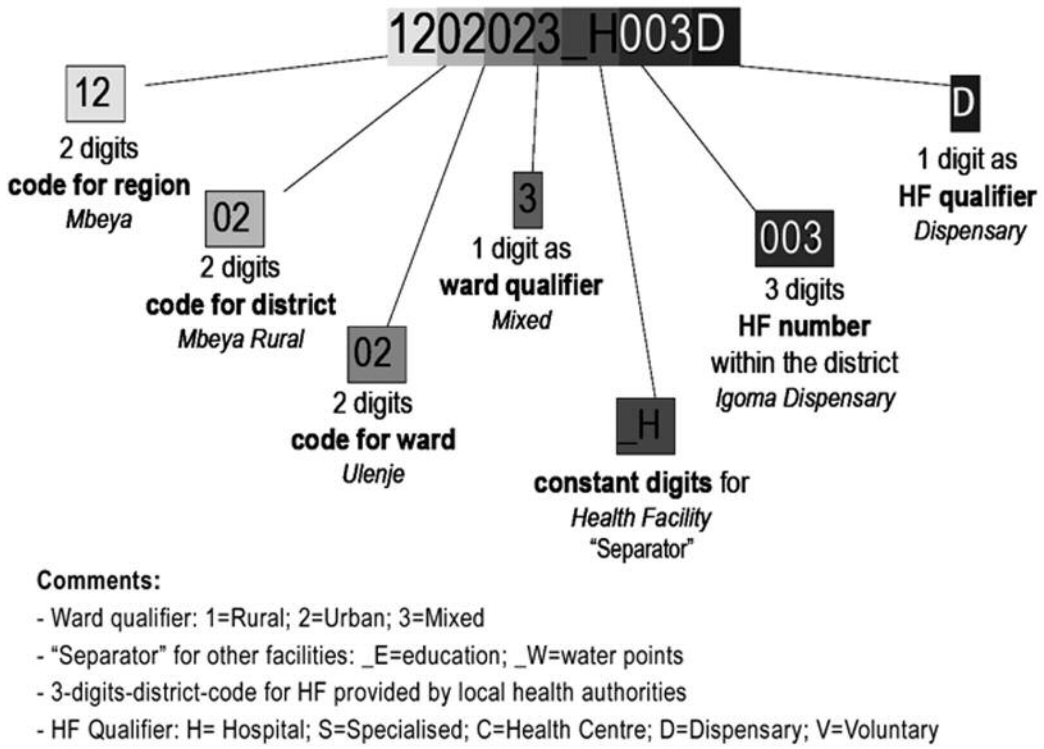
- the number of digits and the used data type for the address of every HF should be similar,
- the chance of misspelling should be as low as possible,
- the code should be divided into logical parts as demonstrated by internet URL-addresses or by identifying digital objects (Digital Object Identifier) [24-27],
- the code should be self explanatory to guarantee the proper assignment of new objects as well as to select the required ones from the database,
- the code should have a part which is related to the coding of the administrative units, in order to have an spatial component for linking and direct location as used in other coding systems like the UN/LOCODE [28],
- the code should allow for the direct linkage to other databases e.g. This point is very important for the linking of data with epidemiological data from MTUHA (Swahili: Mfumo wa Taarife za Uendeshaji wa Huduma za Afya), means Health Management Information System (HMIS).

These requirements are best achieved by an adapted coding system. To guarantee the suitability, the acceptance as well as the maintenance of the arising coding system it was crucial to involve the responsible persons of the government and other organisations in the development of the coding system. This was another duty of the IT group.

The code consists of 13 digits (see Figure 2). It is already unique for each HF by using the first 4 digits (region and district) and combining them with the 3 digits of the HF. The separator _H increases the recognition and identification as a HF when incorporating data of different kinds of facilities within the GIS, f. e. _E might be used for education facilities. The administrative part of the code (first 7 digits) allows a fast spatial reference as wells as a fast spatial selection down to the ward level.

Within a database management system (DBMS) different data may be linked by the unique code without using any geographic coordinate of the facility or any GIS spatial join functionality. The qualifier at the end improves the selection of HF by their types. If the status of a HF changes, so will the last digit. The code will also change if the boundaries of administrative units change. However, this problem may be solved technically. The code depends on a non-spatial numbering of the local health authorities. Thus it is very

Figure 2. The Coding System for the health facilities (own illustration).



important to stabilize this part of the code from the beginning.

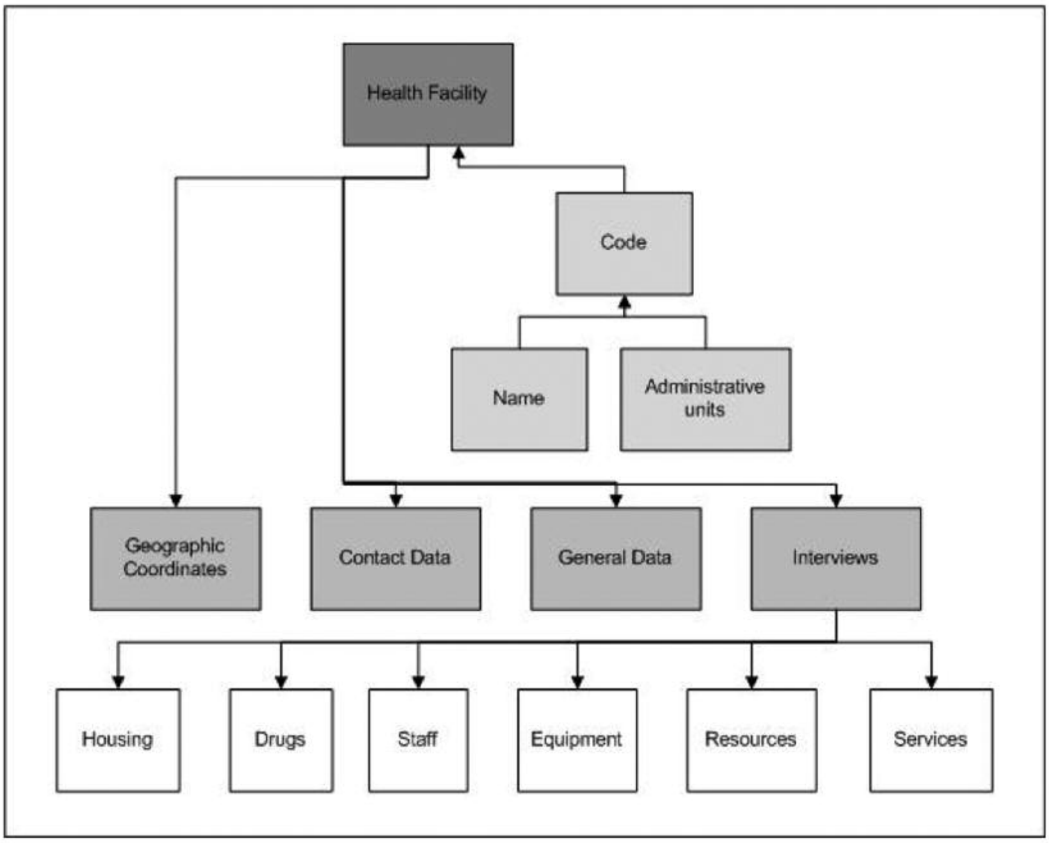
Design of database and GIS

The only suitable way of storing the data is a digital relational database. The outcoming Health-DB consists of 48 related tables (15 coded value domains, 33 data tables) and 53 forms. Based on different periods of changing actuality there is a three level hierarchy within the database structure (see Figure 3). On the upper level there are administrative data, for example, the code and name of regions, districts and wards. This allows for the linking of data surveyed within the administrative unit at a later point in time, and may be used for example for population data. On the second level the user finds information relating to geographic position, contact data, general data and the track of the undertaken interviews. Related to the interviews of the HF there is a third data level with all of the characteristics of the services provided, available resources, equipment, staff, drugs and housing, which may vary from interview to interview. A total of 53 different forms were created to facilitate this process and to reduce manual data entry.

There was an agreement within the IT group, as well as in the governmental institutions, to use mainly ArcGIS for analysing and visualizing the data of the HF as there are a lot of advanced analysing and visualising tools available. Figure 4 shows one of the first maps that depicts the newly covered HF and roads by GPS surveying in the Mbeya Region. Therefore it is to guarantee that the HF and all related features (roads, water, land use data, and boundaries) will be realisable within ArcGIS. Normally this will ensure that the most other GIS programs will be able to import the data in an easy way. The related data such as roads, water, and boundaries come from external sources and have mainly been provided as ArcGIS native shapefiles. Though MS Access is not able to store geometries, the point geometry of the HF can be generated out of the database by the stored coordinates. So by connecting the MS Access database with ArcGIS the attributes of the longitude and latitude combined with the HF code are used to create the point features of HF within ArcGIS. These simple ArcGIS features can be linked with the MS Access database by their code to analyse the connected data. This ensures a simple update of the data by forms within MS Access and an easy generation of actual HF point features within ArcGIS.

Because of the structure of the MS Access database and the special possibilities of feature classes within ArcGIS it will be possible to link other data with the HF point features as well as pictures of these break after.

Figure 3. The Basic Structure of the Health-Database (own illustration).



Socio-cultural aspects and sustainability

In order to obtain a sustainable monitoring system transferrable to other regions in Tanzania, it is important to maximize acceptance for the system. So in an early stage of the project, local decision makers, expert staff working in the IT sector, health care organisations as well as students and teachers of the local universities (Ardhi University, University of Dar es Salaam) were involved in building up the system.

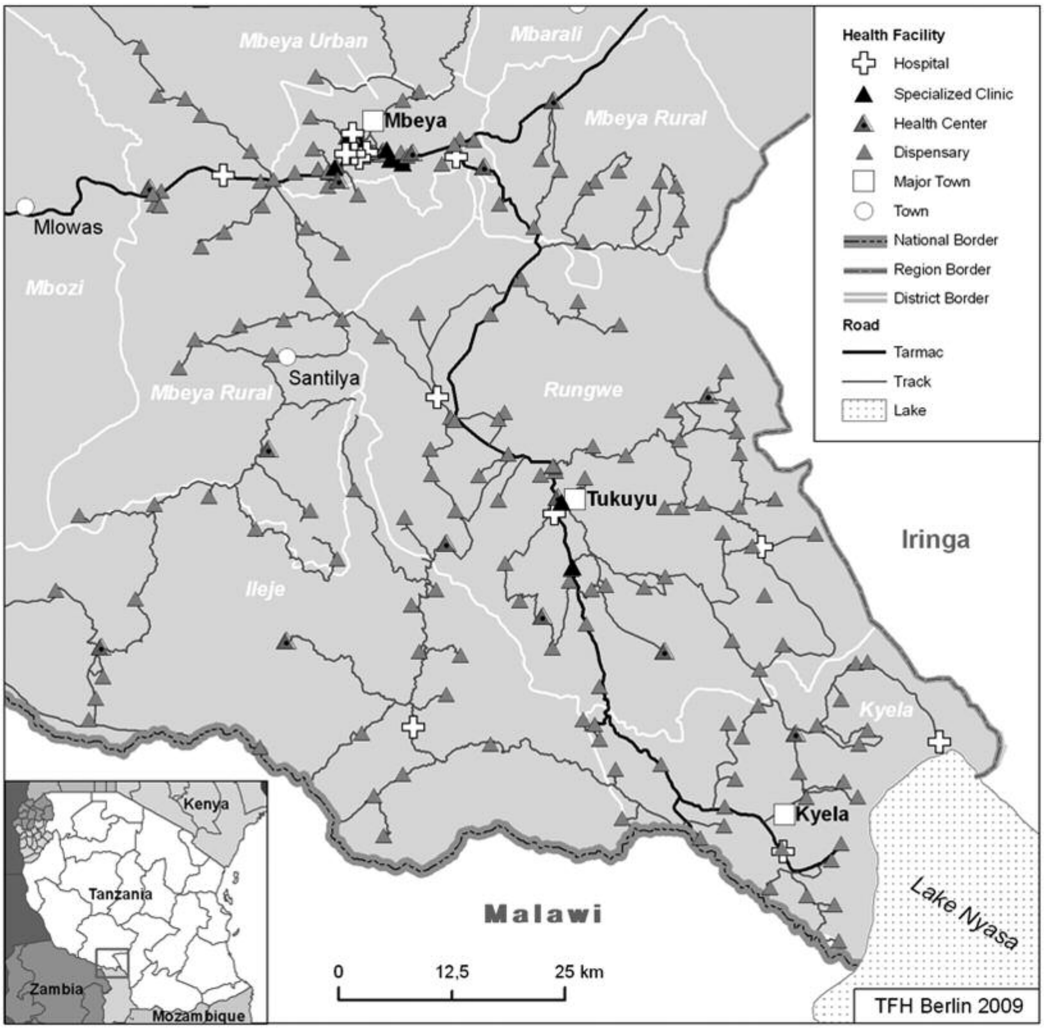
A multisectoral approach was chosen in order to ensure that the Health-GIS will not become an isolated approach but GIS is incorporated into a bigger framework. This is mainly important because the costly generated geometry data should be used in other domains as well due to the fact that there is no geodata infrastructure to be established consequently. At this time, several public and non-public data collections in different areas do exist but are not developed in a coordinated way. Therefore, the introduction of all relevant actors is to counteract this. Concentration of all available and valid geo data in one multisectoral GIS in the pilot region aims to ensure more transparency and to avoid extensive multiple investigations.

Parallel to the one in the health sector, another GIS is to be set up that compiles, stores and visualises data concerning water supply. Both systems use the same geometric basic data, and both sectors constitute administrative units of Mbeya city. The central GIS unit underlines the interdisciplinary character of a GI-System by sharing one office as well as soft and hardware. The extension of the GIS system, e.g. by incorporating education facilities, is possible at any time. Two GIS experts will be responsible for the compilation, support and usage of the system.

Conclusions

The projects' work status to date shows clearly that local institutions are willing to integrate Health-GIS as a planning instrument. This motivation explains the broad support of the projects as well as the consensus with regards to the content in case problems have to be resolved. The chosen approaches are no longer limited due to restrictions of hard and software. Up-to-date software allows for realisation of GIS applications by respecting regional and intercultural demands. But, this does not apply for proprietary and Open Source software similarly. To use free software for all steps of the project might turn out to be problematic because of several reasons: enormous

Figure 4. Map with newly covered health facilities and tracks (by coordinates) in a part of the Mbeya Region, Tanzania (own illustration).



development efforts, absence of documentation, lacking of skilled employees.

On the other hand, an essentially improved data basis is in itself promoting the project. During the last few years, many institutions became active and consequently have build up basic spatial data banks. At the same time, working with GIS became an inherent part at the county's universities. Though study courses are still concentrated on teaching theoretical basics, applied programs are increasing which also provide training on proprietary software. This allows for the use of local experts for GIS projects and substantially contributes to the acceptance of the local decision makers.

Despite the many preconditions that foster the use of GIS, setting up a comprehensive GIS system is still a complex challenge. Two parts have to be differentiated: the building-up of the database and the GIS on the one hand and the use of GIS in daily planning routines on the other. Whilst a certain complexity occurs in the development process, it should be avoided in other respects. In fact, the KISS principle may help to ensure acceptance from all actors and might become the ruling policy: as a development concept, "keep it small and simple".

First experiences in the pilot region of Mbeya indicate how to organise the following activities: Before the local facilities may use the Health-GIS, some problems have to be resolved. First, the data collection in Mbeya Region should be finished in the near future, so that the questionnaire can be adapted based on the experiences in the field. Furthermore, information material and appropriate technical conditions have to be set up in order to prepare an uncomplicated integration of GIS in the local institutions (see Table 2). So, measures are planned that allow for easy access to this complex instrument. A user-friendly documentation concerning the design and content of the database is already under way.

Table 2. Timetable of the project 2007-2009.

Timetable of the project "Health-GIS in Mbeya Region"

	2007		2008												2009											
Activities	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Project Finding Mission	■	■																								
Period of contract of project								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Kick off meeting											■															
Data collection and training											■									■						
improve Health-DB											■	■	■	■	■	■	■									
Input of Data into Health-DB																	■	■				■	■	■		
Development of Health-GIS																		■	■	■	■	■	■	■	■	■
Integration of health data (MTUHA, TOMSHA, SAM)																									■	
Report of field work												■	■	■							■	■				
Health-GIS Workshop																							■			
Documentation of DB and GIS																								■	■	■
Debriefing Session																							■			
Creation of health care indicators																								■	■	■
Results be visualized in thematic maps																										■
Final Report																										■

Also, the databank will be enhanced gradually so it may also be utilised by non-experts. Furthermore, it is necessary to conform to certain requirements of the project as well as the intercultural needs. This includes on the one hand the design of entry and output forms and on the other hand the compilation of different standard SQL-queries and reports effected by one mouse click.

Similar functionalities will be provided for the GIS. So the possibility to create standard layouts for thematic layers or whole templates for maps within ArcGIS will be used to establish constant styles for similar queries. Furthermore the Visual Basic for Applications (VBA) tool will be used for programming new routines and buttons for regularly repeated queries. All this should guarantee the maintenance and acceptance of this GI-System by non-experts. It is nevertheless necessary for both systems – database and GIS – to prepare a handbook for routine working and analysis procedures and to instruct a local GIS-expert who deals with more challenging tasks. In spite of numerous specifics adaption to the system it is still adjustable to technical developments e.g. Web-GIS and may be employed by users of multiple sectors.

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