2 Geospatial Information for Natural Resources Management - EthioGIS: Supporting NSDI in Ethiopia

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2.1 Introduction

Socio-economic and geo-ecological conditions in Ethiopia have a pronounced effect on agriculture, the nation‘s most important production sector. Most food production is at the subsistence level. Because it needs a comparatively large cultivation area for food production, the country is heavily dependent on the interaction between landscape, vegetation, soil and climate. If agriculture is to be intensified in order to fight hunger and malnutrition, decisive measures will have to be taken to change agricultural policy. The Geospatial Information System Ethiopia, known by its working title 'EthioGIS', developed at the Centre for Development and Environment (CDE), University of Bern brings into focus all relevant spatial data such as terrain, soil, land cover and use, climate, drainage, infrastructure, population and agriculture in a Geographic Information System (GIS) as a basis for decision making and planning of national resource management strategies.

The potential EthioGIS project output, in its final release, will consist of map models based on actual population pressure and different management scenarios, a framework for watershed-based analysis, and finally thematic and interactive mapping for publications on the web, on DVDs and on paper. As a function of the individual modules developed to gain access to the EthioGIS database, the target scale ranges between 1:100k-1:500k for interactive mapping (desktop maps in A4 and A3 paper format) with either DVD or the web as a source, non-authorised topographic large format paper maps at 1:250k (30 map sheets), 1:500k (8 map sheets) and, finally, three thematic overview maps 1:1 Mio (optional 1 map sheet 1:2 Mio.).

The Centre for Development and Environment is a department of the Institute of Geography at the University of Bern. The Centre's mission is to contribute to sustainable development in countries of the North, South, and East, through research partnerships, education and training, development of concepts and tools, sensitisation, and policy advice. CDE has a strong focus on management of natural resources, integrated regional development, and interventions that mitigate syndromes of global change. Within these contexts, applications of geographic information technologies GIT play a vital role and touch upon many aspects in development strategies.

2.2 Background

The beginning of Ethiopia's national geospatial data compilation at CDE dates back to the early 1990s when spatial data modeling concepts in the Soil Conservation Research Project (SCRP) demanded a regional extrapolation base for knowledge obtained from six research sites in the Ethiopian Highlands.

Alarmed by the seriousness of land degradation in Ethiopia and encouraged by efforts undertaken by the Ethiopian government to conserve soils and water for agricultural purposes, scientists and development specialists created the SCRP in 1981. Their aim was to contribute to the technical, ecological, economic and social improvement of governmental efforts. The SCRP was carried out with the support of the Swiss Agency for Development and Cooperation (SDC) in a series of programme phases that lasted from 1981 to 1998. Since 1998, regional SCRP offices have continued their own research at the original SCRP sites and research in the framework of EthioGIS has been supported by SDC's Eastern and Southern Africa Partnership Programme (ESAPP).

Apart from a huge database covering natural resources, agricultural use and socio-economic conditions in six research stations, SCRP has produced a number of outputs: Over 45 research reports, regular process reports, immediate recommendations at least once every year, as well as training manuals, training courses, school books, maps, GIS analyses and training. And, with the compilation of digital terrain models as well as land use and soil maps for local watersheds, extrapolations of the results to wider areas have been made. These outputs can be obtained from the Natural Resources Development and Regulatory Department in Addis Abeba or from the Bureaux of Agriculture in the Oromia, Amhara, and Southern Peoples' Region, as well as from CDE at the University of Berne.

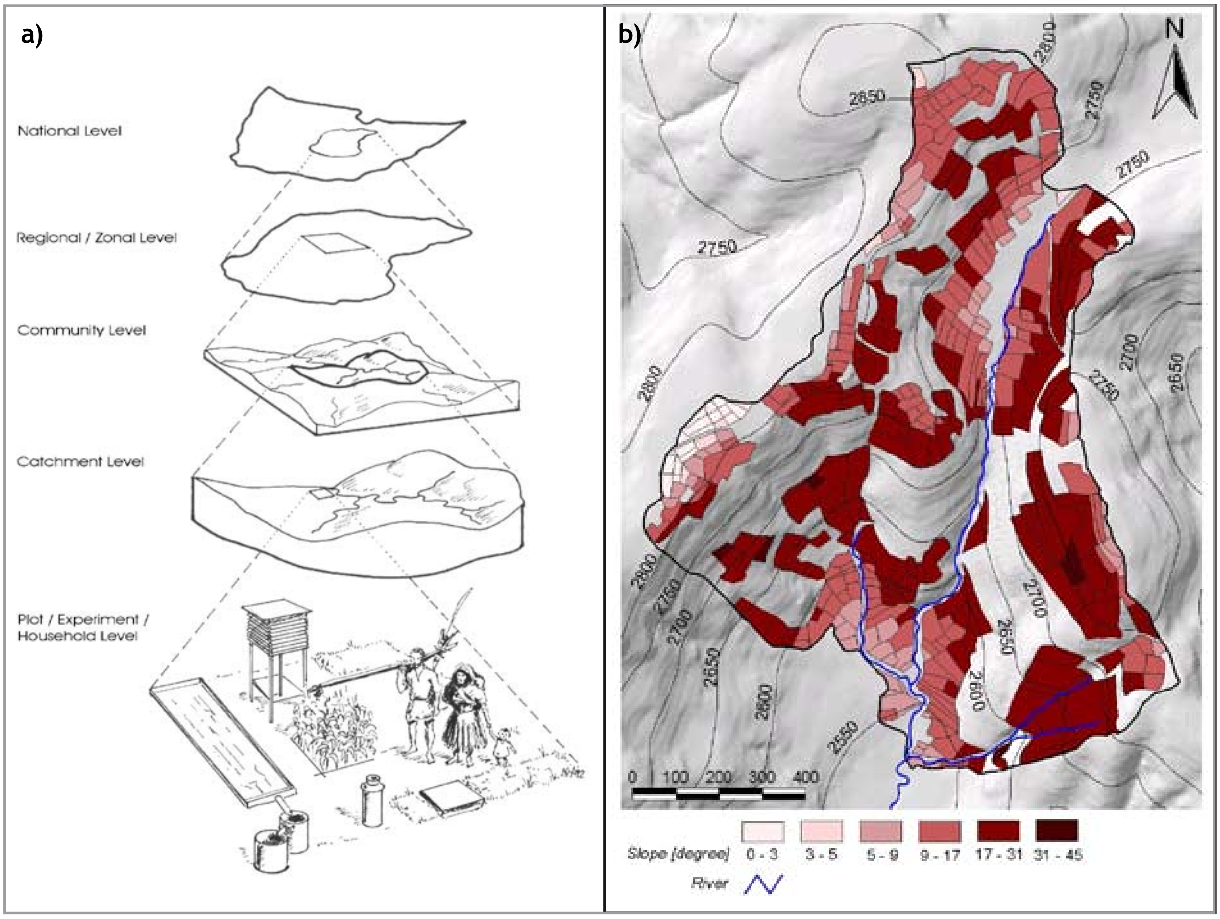

Figure 2.1: *a) Up-scaling within SCRP's research levels (Herweg & Hurni, 1993; b) Spatial distribution of slope classes within research catchment*

With the founding base of SCRP's geoinformation system for each of the six research catchments, the need to link research results to local or regional units (watershed or administration units) was the driving force for creating a national spatial data framework to support conservation strategies on a smaller scale. In an early evaluation of GIS and Environmental Information System (EIS) in Ethiopia, consulted by Joy Hecht (1992) for the UN Sudano-Sahelian Office, only a few spatial information systems were operational within the Ethiopian Government. One of the main actors was the Ministry of Mines and Energy with its Woody Biomass Inventory and Strategic Planning Project WBISPP project. Other key players apart from the UN agencies were found in watershed planning and forestry, the Land Use Planning and Regulatory Department (LUPRD), the Ethiopian Valleys Development Studies Authority (EVDSA), the Ethiopian Mapping Authority (EMA), the Central Statistical Authority (CSA) and the National Meteorological Authority (NMA).

In the early 1990s none of the authorities was in a position to provide national digital data sets at a working scale of 1:500k. Based on Landsat 5 imagery (total 55 scenes) provided by the UN through the Digital Exchange Platform of the Horn of Africa (DEPHA), and vector scans derived from the three map sheets 'Ethiopia Agroecological Belts 1:1 Mio', a first national digital terrain model was developed in 1991 with ESRI's Software ArcInfo (Environmental Systems Research Institute). In the late 1990s the national geospatial product was developed in its first release to a comprehensive national geographic reference system and distributed among all Ethiopian ministries. At the invitation of the Natural Resources Management and Regulatory Department (NRMRD) in September 1999, methods, a spatial information base, and the potential of geographic information systems were presented in a data transfer workshop to 30 participants from the Ministry of Agriculture, the Ministry of Water Resources, EMA, NMA, the Ethiopian Agricultural Research Organisation (EARO) and to regional authorities from Oromia, Bahir Dar, and Amhara National Regional State.

Data Transfer workshop at Natural Resources Management and Regulatory Department (NRMRD), September 1999. (Photo by Juerg Krauer)

At that time NARIC, the Natural Resources Information Centre of the MoA, was dedicated to making environmental information more readily and systematically accessible. Besides acquiring and disseminating integrated, spatially-referenced environmental data, NARIC has provided decision-support services to agronomists and environmentalists, governmental organizations, and NGOs. Due to the lack of free available spatially referenced data, the standard layers of EthioGIS became a widely used source for a national, spatially referenced information base.

2.3 Geographic Information Science (GIS)

In natural resource management, geographic information technologies - a set of specialized information and communication tools such as GIS, Global Positioning Systems (GPS), Earth Observation (EO) and web-applications - are mainly used for monitoring and analysis of spatial information. Geographic Information Systems can be defined either by their components, their functional requirements or by their mathematical definitions (see Figure 2.2). In a more generic sense, GIS is a tool that allows users to create interactive queries, analyses spatial information, edits data, and presents the result of all these operations in maps, models or statistics.

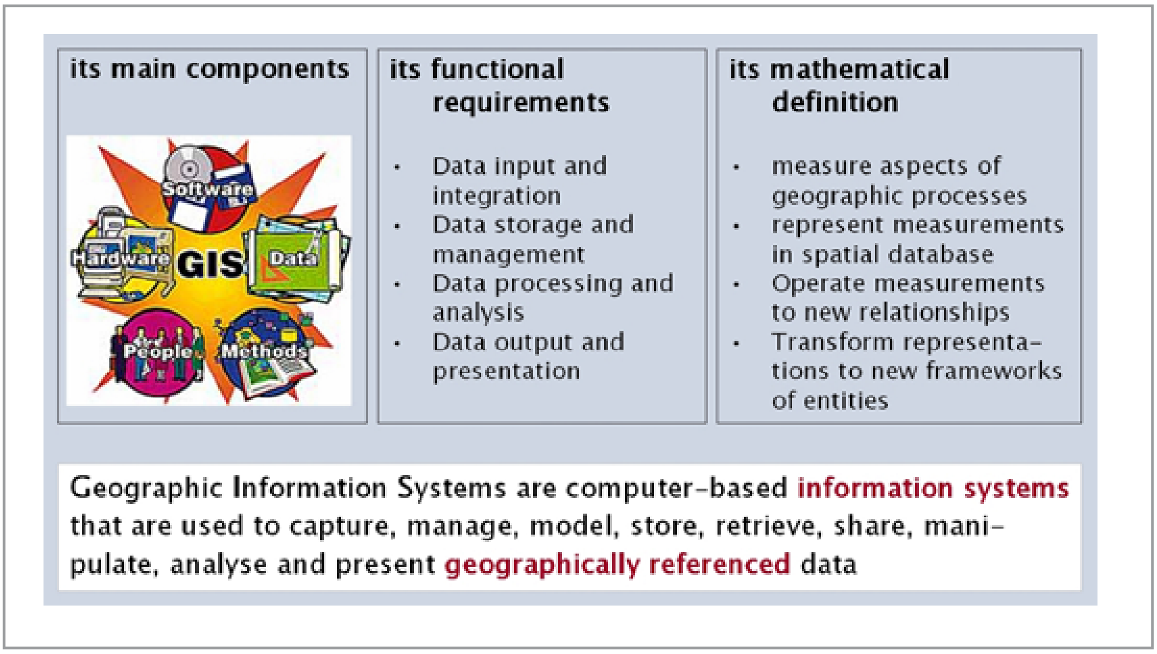

Figure 2.2: *Terms and definitions of Geographic Information Systems (GIS)*

The five elements in any GIS - the geographic media the spatial data are transferred from, the geospatial datasets, the processes and workflows used to compile the data, the models use to derive the parameters, and finally the data documentations - are listed below (Figure 2.3).

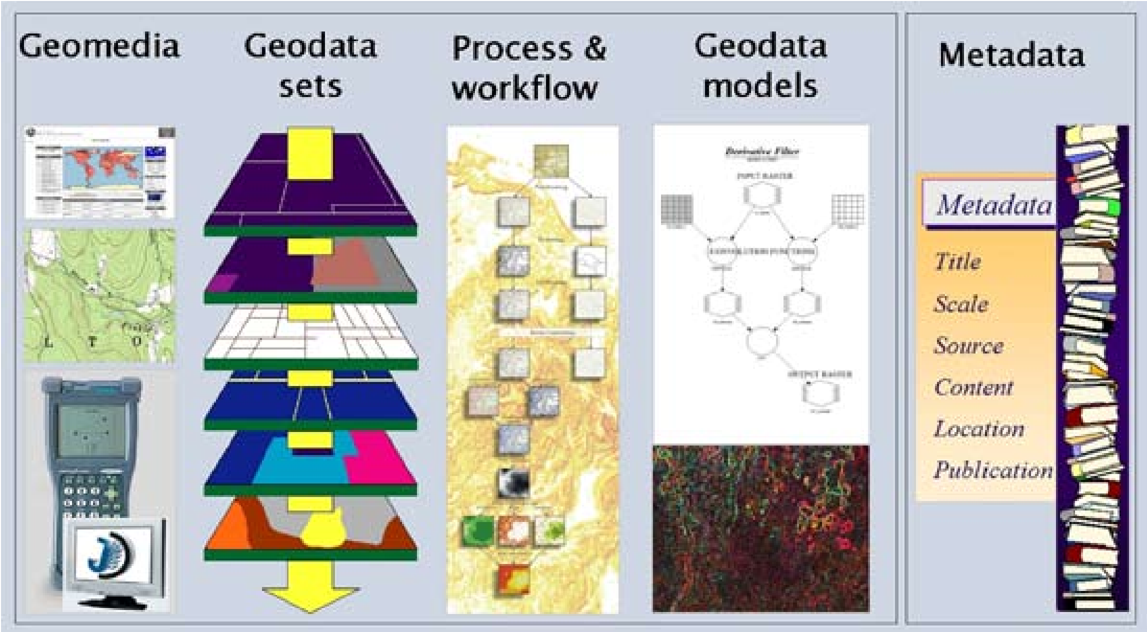

Figure 2.3: *The five elements of geographic information*

Geographic information science is the science underlying geographic concepts, applications and systems. Its main hallmarks are spatial analysis, geostatistics, place-based research, extrapolations, data integration, and decision support. The capability to visualize and present spatial information is an important feature for communication, dissemination and knowledge sharing among the NRM community.

Geoinformation science with a focus on NRM has emerged as an exciting multi-disciplinary research field, spanning such areas as environmental, economic and social geography, cartography, earth observation, image processing and communication technologies!

Areas where GIS-applications are used in natural resources management:

- **Impact on natural resources:** inventories, assessment of degradation and desertification
- **Land resources:** agricult. production and agro-forestry
- **Mitigation conflicts:** security, demining, peace building
- **Crises management:** rehabilitation, reconstruction, infrastructure planning
- **Urban environments:** population dynamics, migrations into cities
- **Watershed management:** irrigation, water resources use

The goal of any GIS application is to obtain a thorough basis of information for answering questions in decision making!

2.4 Geospatial Information for Natural Resources Management in Ethiopia

With the first release of EthioGIS in 1999, an initial step towards a national concept of spatial data infrastructure typical of the management of natural resources was initiated. The data compilation in the first release covered the most important national spatial data on a single CD-ROM, namely:

- Boundaries for three levels of administrative units (national, regional, *Weredas*)
- Monthly and annual average rainfall distribution (incl. rainfall erosivity model and rainfall and wind pattern regions)
- Towns and villages (with names and population figures)
- Infrastructure (railways, all weather roads, dirt roads, tracks)
- Topography (digital terrain model with slope, aspect, and elevation)
- Hydrography (streams, main rivers, perennial rivers, seasonal rivers, lakes and swamps)

The focus in release 1 was on principal geospatial layers for the scientific community in the field of natural resources management (i.e population density based on 1994 census data, see Figure 2.4). Metadata and procedures in data compilation were kept quite simple and dissemination was restricted to interested ministries of the Ethiopian Government.

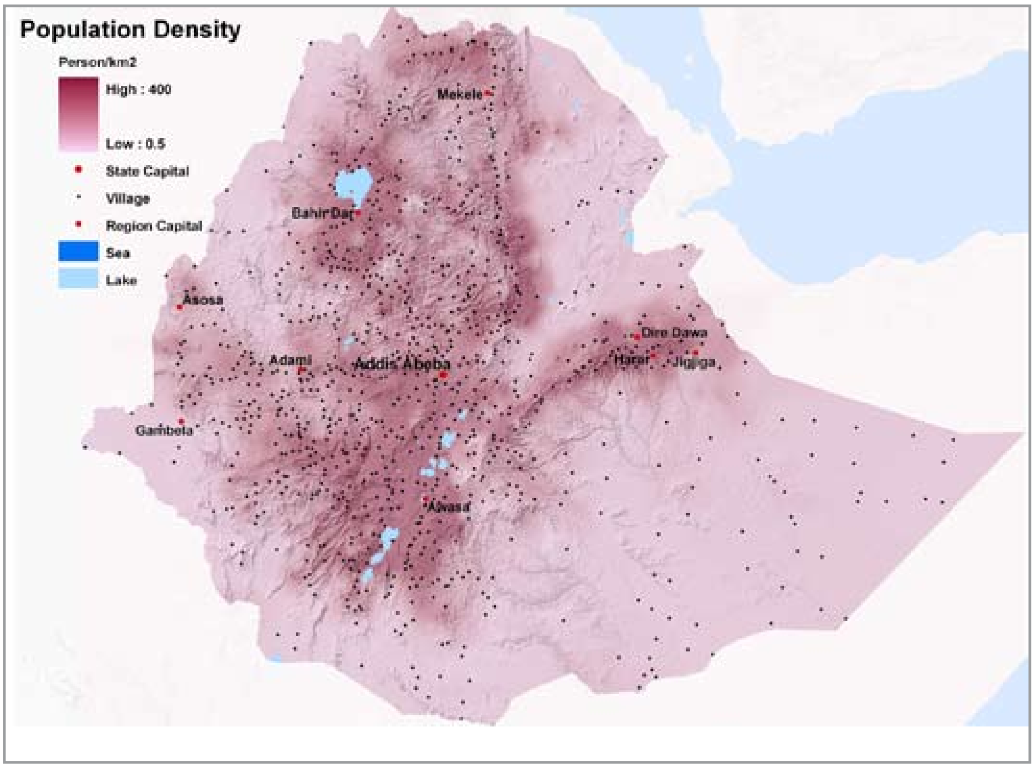

Figure 2.4: *Ethiopia: Population Density 1994 (EthioGIS, 1999)*

From 2000 onwards informatics and the use of geospatial data within the ministries has increasingly been used so that for the next release all related documents, metadata descriptions and geodata standards have to be enhanced and the contributing community has to be extended. But not only does the particular field of the geospatial information, - the Infoware – have to be updated; the other three dimensions of Geographic Information Systems also need to have a careful upgrade within the framework of release II of EthioGIS.

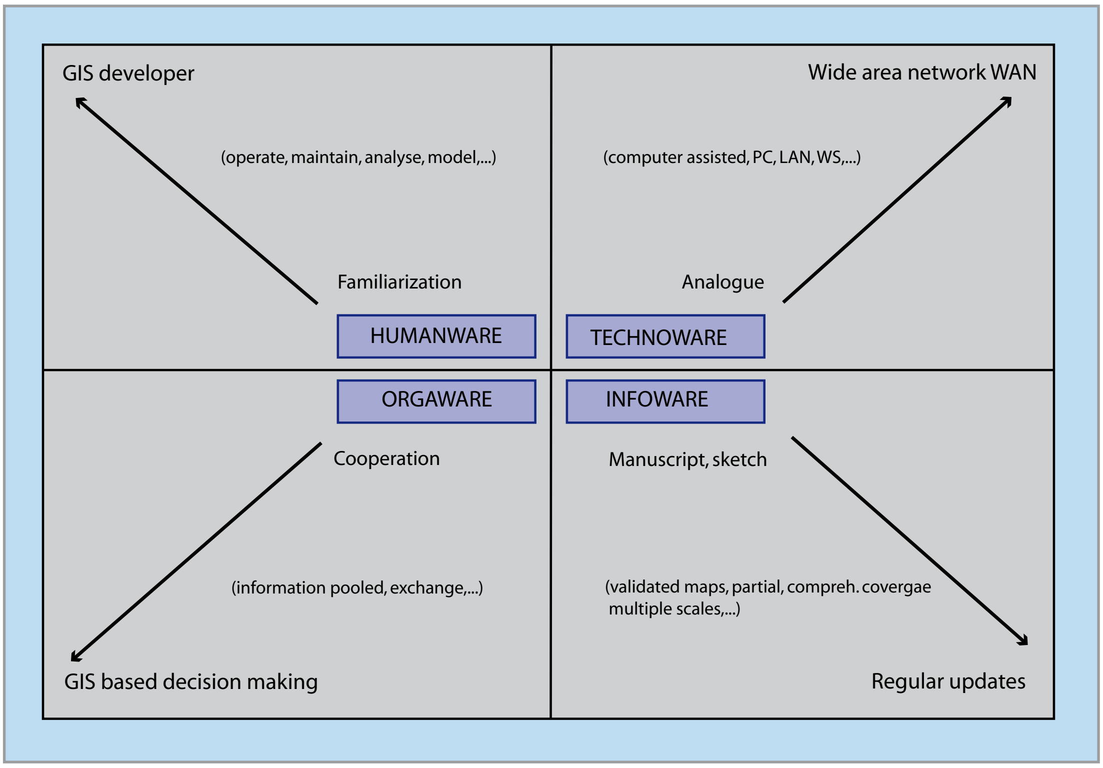

Figure 2.5: *The 4 dimensions of GIS in Ethiopia's Natural Resources Management*

While the technology or technoware is given by the soft- and hardware components of a geographic information system, and the degree of intra- and inter-institutional cooperation is determined by the set-up of the organizational workflows, the humanware is the most important dimension with a view to successful implementation of a GIS enterprise within the government of Ethiopia. Figure 2.5 illustrates that the provision of geospatial information needs to be accompanied by serious development of governmental structures and the building of enough capacity in the management of geospatial information. Since geographic information is widely used as a reference layer for any kind of location-based information, the need for spatially literate and trained staff is extremely high throughout all departments. A well-trained GIS analyst is in a position to create data processing workflows and to prepare geospatial statistics and knowledge, as a sound basis for monitoring, understanding and decision support within the government.

With respect to the wider prospective use of geospatial information within the government of Ethiopia, and with the great amount of feedback in recent years, release II of EthioGIS will give special attention

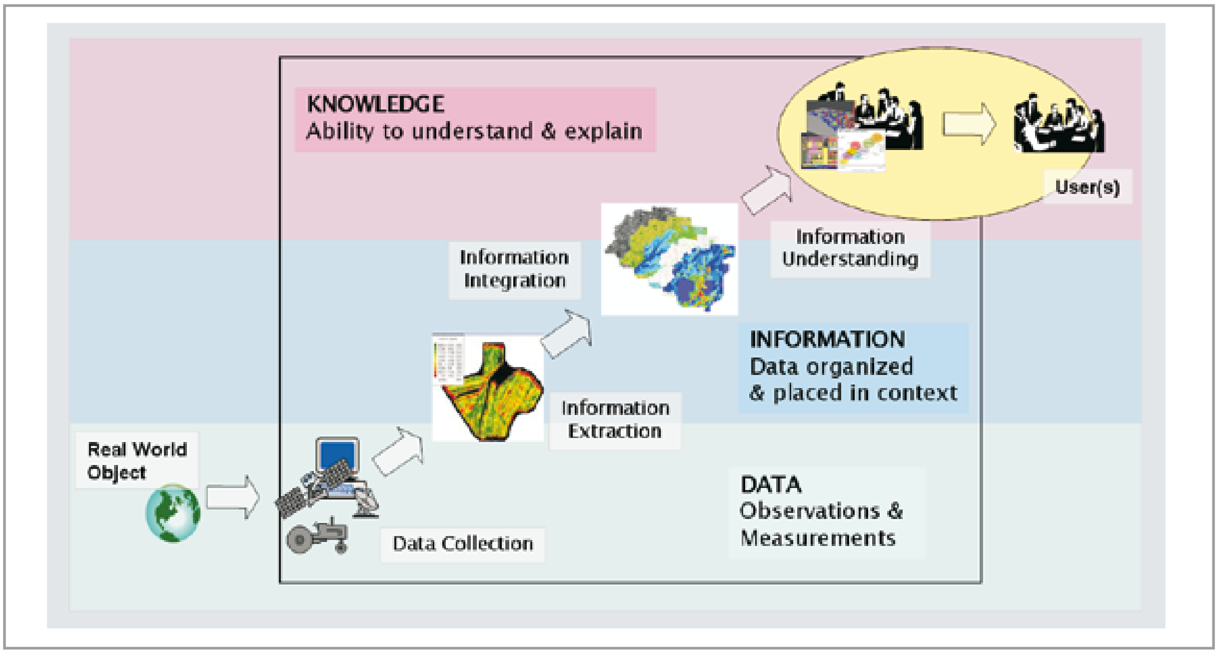

Figure 2.6: *Spatial information chain for decision support*

to the following two dimensions:

- Humanware: Handover and data dissemination will be conducted by a thorough introduction into geodata and modeling concepts for the national databank
- Infoware: All layers of release I will be improved (settlements, topography, hydrography, etc.), updated (i.e. administration, settlements, etc.) and upgraded (i.e. topology, hydrology, soil resources, land cover and land use types, etc.). Many more layers will be added to the standard layers of release I, namely nationwide and multi-temporal earth observation layers (i.e. radar rainfall, temperature, albedo, NDVI, etc.) and derivates from SRTM (Shuttle Radar Topography Mission) (i.e. watersheds, stream lines, flow accumulation, etc.). Meta-data and a detailed description of the source of information will also be part of the new release.

2.5 Developments of tools and geospatial data for Release II

In the framework of the 'EthioGIS' research project, a series of tools and models have been developed: In a first step, templates for large format map services have been programmed covering three map series between 1:1 Mio. and 1:250k. In a second step the script language program of ArcGIS (MXD) was enhanced by a module for the production of field maps with a variable geographic centre location (X/Y-coordinates in UTM) and a specified range of map scales, Any topic or theme can be chosen as principal map content; depending on their use, map features can be selected or deselected.

With a third module watershed-based interactive desktop mapping and reporting (pdf) was developed based on ESRI's ArcServer technology (see figure 2.7). This tool was requested by institutions working in the field of watershed planning, and makes it possible to provide spatial statistics in report form for any selected poor point on a stream. The state-of-the-art application also has some disadvantages: The costs for the software to run the application interactively are extremely high and internet connectivity (bandwidth) is still very poor in Ethiopia. For release II, a stand-alone version is planned and, to reduce the costs, open source software will be explored to cover the needs of desktop mapping and analysis based on interactive watershed delineation.

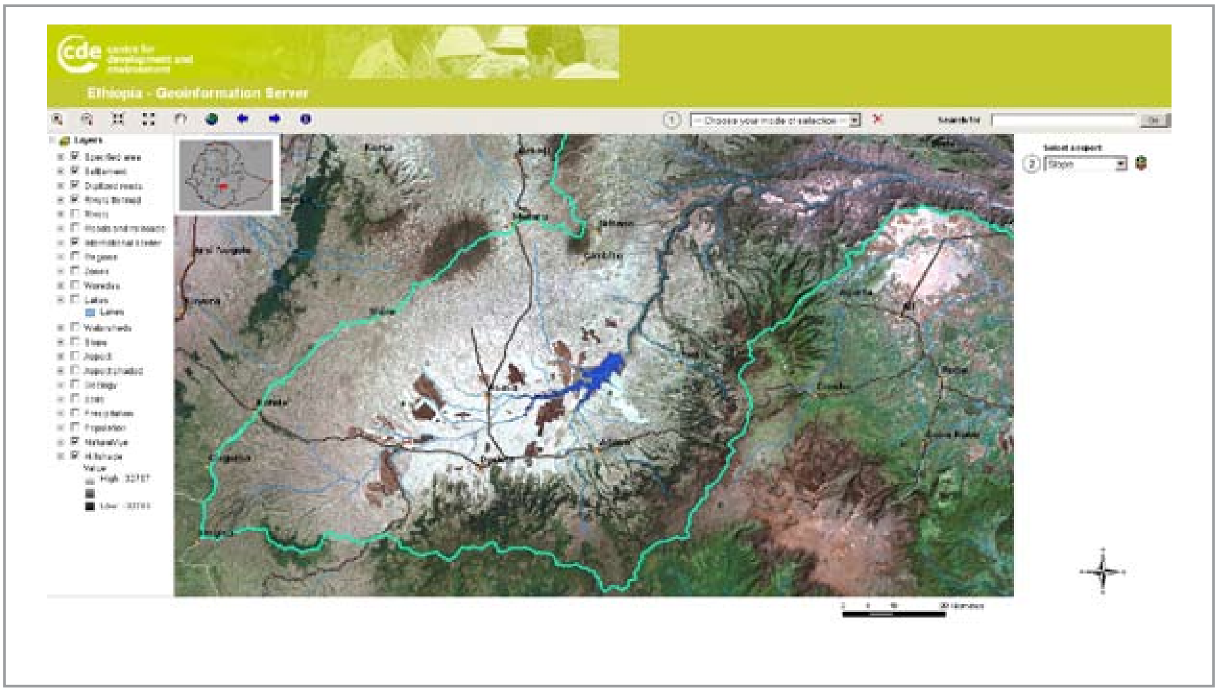

Figure 2.7: *Web-mapping and watershed planning based on interactive watershed delineation (Hösli, 2006).*

Based on the nation-wide 90 m digital terrain model (SRTM), watersheds of almost any size (< 10 km2) and corresponding geostatistics on any theme of EthioGIS can be calculated, presented as reports, and visualized with ESRI's ArcGIS software.

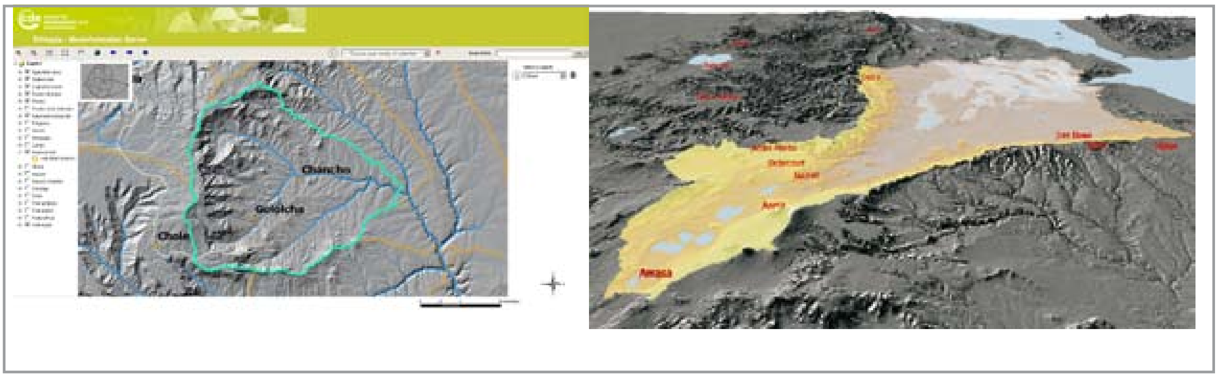

Figure 2.8: *Watershed boundaries as a result of interactive location of river outflow and 3D visualization in ESRI's ArcScene (Hösli, 2006)*

One of the most advanced developments within EthioGIS II is the Digital Drainage Model Ethiopia (DDM). Based on the principle of vector/raster modeling (surface flow direction for each pixel) a hydrological information system for water resources management was developed. In a first step a drainage direction matrix with a mesh of flow directions was created. The flow direction of each pixel was determined by the steepest descent direction among the neighboring 8 directions provided by the digital elevation model (DEM). Followed this rule, together with the accumulated amount of pixels, river lines were created in a hierarchical downstream order. Except for sinks, concave or completely flat areas, the drainage model derived from the DEM bore up against the satellite imagery (see Figure 2.9).

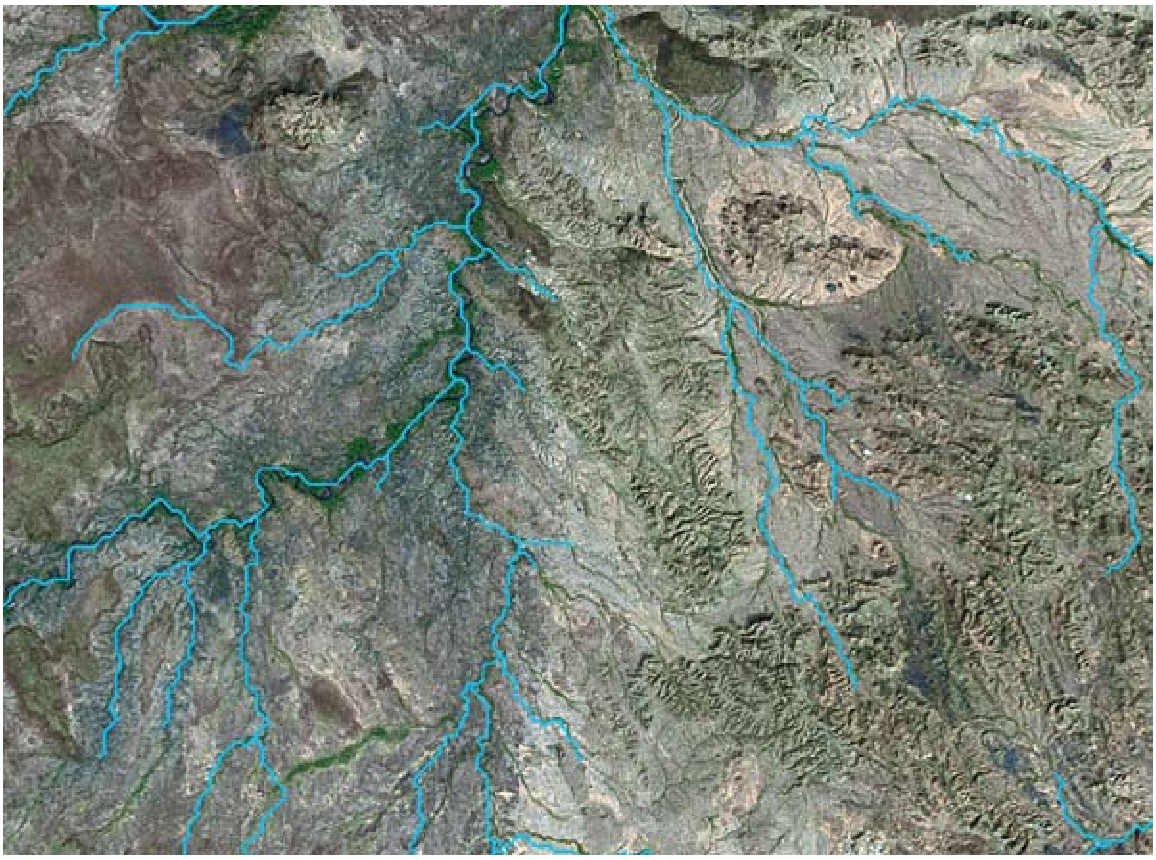

Figure 2.9: *Visual drainage model validation on top of EarthSat 15m psm imageries.*

Finally, release II will incorporate a series of multi-temporal imagery and models derived from Terra MODIS (Moderate Resolution Imaging Spectroradiometer), launched in December 1999 and Envisat MERIS (Medium-spectral Resolution Imaging Spectrometer), launched in March 2002. Terra and Envisat satellites view the entire Earth's surface every 1 to 2 days, acquiring data in 36, respectively 15 spectral bands. The range of the georeferenced themes covers radar rainfall estimations, various vegetation indices, surface reflectance, land surface temperature, and atmospheric water vapor. The image resolution of the multi-temporal data varies between 4 km and 250 m.

As a common geospatial reference for all imagery products and drainage derivates (stream lines, stream order, flow accumulation, watershed boundaries, etc.), the corrected and calibrated digital elevation model compiled from the Space Shuttle Radar Topography Mission (SRTM) data is used. As a sample, one of the products derived from the SRTM DEM is shown in Figure 2.10. Albedo or reflectivity is defined as the ratio of upwelling to downwelling radiative flux at the surface. The figure below presents the albedo over Ethiopia at local solar noon. The figure shows a marked difference between the reflections in areas of highest vegetation (bright, i.e. Bale area) and lowest vegetation cover in large river valleys and the lowland (dark, i.e. Danakil area).

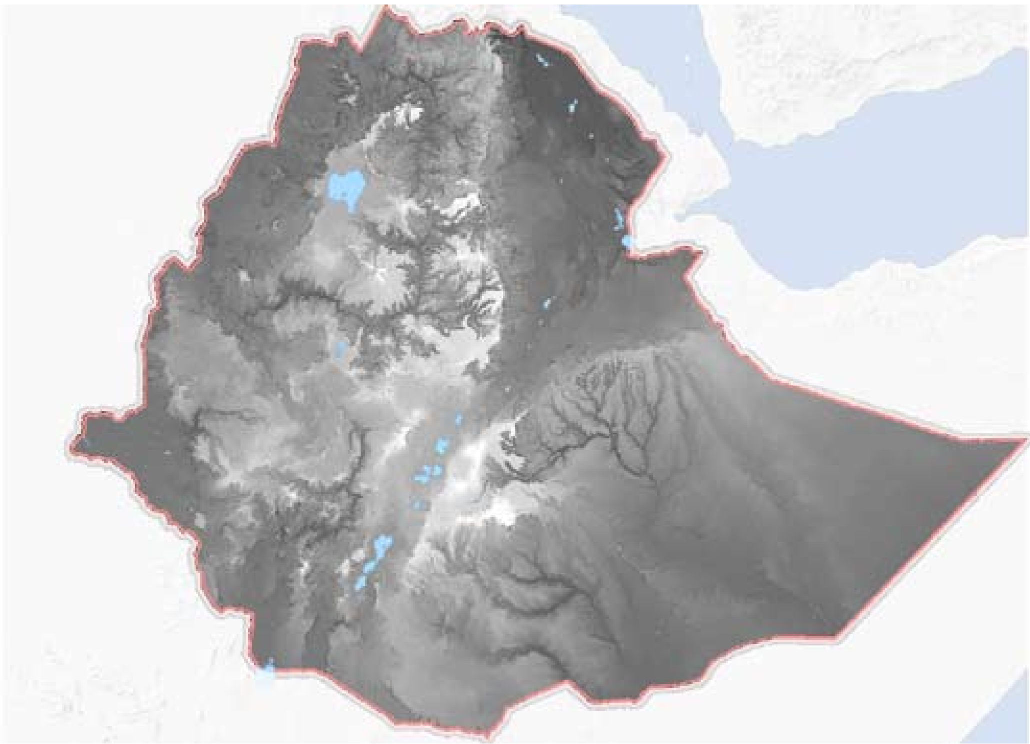

Figure 2.10: *16-day average reflectivity (Hergarten, 2007)*

2.6 EthioGIS a substantial contribution to the National Spatial Data Infrastructure (NSDI) in Ethiopia

National Spatial Data Infrastructure constitutes a set of policies, technologies and standards that interconnect a community of spatial information users, and related support activities for production, dissemination and management of geographic information.

The goal of the national initiative is to reduce duplication of effort among agencies and institutions, to improve quality and reduce costs related to all kinds of geographic information, to make them more accessible to the community, to increase the benefits of using available data, and to establish key partnerships with authorities, academia, the regions, the international community, and the private sector in Ethiopia.

Right from the project start, EthioGIS' contribution to a national geodata infrastructure was meant to avoid redundant efforts in digitizing of spatial data with a focus in natural resources management, to share resources, to consolidate information, and to disseminate all related products to interested local institutions.

In the early 1990s, standards in geoinformation projects were not quite common. Due to the general lack of information at that time, the EthioGIS project mainly followed the principles and formats provided by software resellers. With the first release, standards provided by the 'Digital Platform Horn of Africa' (DEPHA) and by UNITAR were applied. Meta-data were provided to both organisations in 1995 for cataloguing. Dissemination of EthioGIS release I was secured by presentations at Africa GIS in 1995, in Abidjan and 2000 in Nairobi.

In view of the forthcoming release II data format, standards and reference systems will be adapted to the latest developments in the filed of spatial data infrastructure. The dissemination will be arranged with leading institutions in Ethiopia and local specifications will be adapted beforehand. As far as possible, common NSDI efforts and standards used in Ethiopia will be applied. As long as local adaptations are missing, standards communicated by the Economic Commission for Africa (ECA) the Global Spatial Data infrastructure Association (GSDI) and EIS-Africa, with the collaboration of the International Institute for Geoinformation Science and Earth Observation (ITC), will be used. Together with the dissemination of the data, assistance will be provided to integrate the datasets into local GIS and to improve the management of their geospatial data resources in a way that effectively supports decision-making by the requesting institutions and governmental agencies.

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