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Spatial data and applications for environmental studies in Africa

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Abstract

Environmental studies in Africa are hampered by *inter alia* lack of spatial and temporal data, computer resources and knowledge infrastructure. Only small-scale maps cover large regions. With the growth of geoinformatics, global and continental scale data are increasingly made available via the internet or compact discs by various organisations also for Africa. The global trend in adopting remote sensing for environmental studies is strong in traditionally data poor regions. Access to this data in Africa, however, is often illusive due to poor communications and meagre financial resources. Global datasets are seldom adjusted for continental needs, leading to semantic discrepancies and interoperability problems when merging datasets. Local knowledge is mostly disregarded. Further, studies employing global data in Africa are often esoteric, and seldom used for policy or management inside Africa. The future perspective of standardised, higher resolution spatial data is promising for Africa; acknowledging local knowledge and empowering the disadvantaged is a more severe barrier to overcome. It is concluded that internet access and education of the next generation is most important for disseminating geoinformatics to Africa and thus aiding a sustainable development.

Introduction

A decade ago Hastings and Clark (1991) identified poor softwares and user interfaces, lack of technical support and absence of sustained training as obstacles for the dissemination of Geographic Information Technology (GIT) in Africa. Yeh (1991) instead pointed at lack of data and shortcomings in institutional arrangements. Today, the hindrance of GIT in Africa is attributed disappointment after bolstered expectations, reinforcing top-down approaches (also regarding semantics), negligence of local knowledge and culture, absence of empowerment of disadvantaged groups and lack of data and standards (e.g. Pickles, 1995; Mather, 1997; Zietsman, 2000).

Before GIT (or geoinformatics) can become an operational tool for decision and policy making in Africa four significant data related problems must be overcome (cf. Miller, 1996): i) the need to develop both spatial baseline data and time-series databases; ii) adjusying semantic coherency for African environments for this data; iii) the need to create data sets merging physical/biological and socio-economic data; and; iv) the need to expand data (i.e. internet) access and computer capability on the continent.

In context of the four mentioned problems, the article presents some of the public GIT-related databases presently available for environmental studies in Africa, as well as some applications. Most of the data mentioned are available either via the internet or as Compact Discs (CD) from various organizations – as given in appendix 1. Some free softwares that can be used for retrieving, storing, manipulating and presenting the data are given in appendix 2, and some internet sites with learning materials for the data and software are given in appendix 3. The listed resources are by no means complete, several other databases, freewares and learning resources are available, both via the internet and on CD. The author's direct experience of Africa is restricted to South Africa, and neighbouring countries, and is hence not representative for the whole continent.

The aim of the article is to identify data problems and needs for improving spatial data accuracy, use and dissemination in Africa, and to direct researchers and students studying African geography to existing databases.

Databases for Environmental Studies

In this article spatial databases are divided into framework databases and field databases (Goodchild, 1996). Framework databases equal base maps holding mostly information on anthropogenic-derived features – e.g. political boundaries and infrastructure, but sometimes also physical themes like elevation contours and hydrography. These databases are typically object oriented and in vector format. Framework data can seldom be directly used for environmental studies. Environmental studies demand field data, usually in raster format, for example, soil, drainage, elevation, temperature, precipitation, wind etc. Semantic problems plague both framework and field datasets, with errors propagating and escalating in merged data sets (Burrough et al., 1996).

Framework databases

The most important framework database for Africa is the Digital Chart of the World (DCW). DCW is a 1:1 million scale thematic base map of the world developed by the Defence Mapping Agency (DMA) and compiled by Environmental Systems Research Institute, Inc. (ESRI). DCW is based on the DMA aeronautical Operational Navigation Chart series (DMA, 1992), which is the largest scale map with consistent global coverage. For large parts of Africa these base maps are the largest scale maps available, either due to lack of other data or larger scale maps being classified. The aeronautical maps as such are useful for interpreting some of the information in DCW, as well as for some additional features, e.g. geomorphologic patterns. Themes in DCW include political boundaries, populated places, roads/railroads and other infrastructure, hypsometry, hydrographical data, and rudimentary land coverage. For remote areas the information in DCW is surprisingly detailed – dirt roads in Botswana are included, whereas some high ways in South

Based on the DCW ESRI has assembled a more easily accessible World Base Map Database with global coverage. In addition ESRI has also developed a more field oriented World Thematic Database. ESRI has also georeferenced and disseminated the Newsweek Demographic Database. For Africa this is the most easy, and sometimes only, socio-economic data readily available (except for population data – see below).

Field databases

Elevation. For Africa the elevation data in DCW (contour lines and spot elevation data) are together with generalized 3-arcsecond digital terrain elevation data the primary source for the global 30-arcsecond (approximately 1 km) GTOPO30 elevation database released by the United States Geological Survey (USGS) in 1996 (Gesch et al., 1999). The data in GTOPO30 have been hydrographically corrected and resampled to a 1 km grid using Lambert Azimuthal Equal Area projection, to create the HYDRO1k database. From the hydrologically corrected HYDRO1k Digital Elevation Model (DEM) seven derivative themes have been extracted: flow directions, flow accumulations, slope, aspect, compounded wetness indices, stream-lines and basin areas.

Population. The Center of International Earth Science Information Network (CIESIN) hosted by University of California has compiled gridded global population data. The data has an original resolution of 5 arc-minutes (approximately 10 km), but in Africa the data mostly represent averages for larger regions. Still for developing countries in Africa this is often the best population data available. United Nations (UN) African population figures for selected countries covering the second half of the 20th century is available from Central African Regional Program for the Environment (CARPE) (see appendix 1) and on the Miombo CD (see below).

Digital Soil Map of the World. The UN Food and Agricultural Organisation (FAO) has produced a Digital Soil Map of the World (DSMW) in 1: 5 million scale. Soil classes are given as polygons, with derived characteristics attributed. The soil map is only available as a CD.

Land use/cover. A global land cover database at 1 km resolution has been created by USGS (Loveland and Belward, 1998). Land cover was classified from NOAA-AVHRR scenes obtained over the period April 1992 through March 1993. The database is projected to two projections: Lamberts Azimuthal equal area and Interrupted Goode Homolosine. The data have been classified into monthly average NDVI images and several thematic map products, for e.g. land atmospheric interaction models used by global circulation modellers. The thematic maps are:

Global Ecosystems (Olson, 1994a, 1994b)
IGBP Land Cover Classification (Belward, 1996)
USGS Land Use/Cover System (Anderson et al., 1976)
Simple Biosphere Model (Sellers et al., 1986)
Simple Biosphere 2 Model (Sellers et al., 1996)
Biosphere-Atmosphere Transfer Scheme (Dickinson et al., 1986)

The themes of these datasets were originally dictated by needs in global modelling, primarily of the climate system. Even if the classification was continentally adjusted, the classes poorly reflect semantics used in Africa, that in itself is not always well established.

The original NOAA-AVHRR scenes that were used for the land use/cover classification are all freely available as 10-day composites, including for extended periods during 1995 and 1996 (totalling 93 scenes) from USGS. The NOAA-AVHRR scenes are accompanied by classification of Normalised Difference Vegetation Indices (NDVI) and technical (metadata) information on the acquisitions and manipulation (Eidenshink and Faundeen, 1994). Additional, raw, NOAA-AVHRR data are available via the NOAA Satellite Active Archive on the internet, or from USGS at cost of reproduction.

Updated time series of climate and vegetation. For the African continent USAID, as part of the Famine Early Warning System (FEWS), continuously provide 10-day composites of NDVI derived from NOAA-AVHRR in 7.6 km resolution covering the whole African continent. The data set goes back to 1981 and is archived and disseminated by the USGS and can be retrieved from the African Data Dissemination Service (ADDS).

Thermal Meteosat images together with 760 ground precipitation stations are used for estimating precipitation over Africa as part of USAID FEWS. Processing is based on 30-minute image intervals for cloud top temperature combined with the ground data and derived fields of humidity, winds and DEM (Herman et al., 1997). The data extends from 1995 and are archived and disseminated by USGS (i.e. the ADDS webpage) as 10-day composites of 0.1 degrees resolution.

More coarse resolution databases over climate as well as scenarios of climate conditions under various assumptions of human impacts on the climate are available from the climate research unit (CRU), University of East Anglia in the United Kingdom, either directly via the internet, or from the Intergovernmental Panel of Climate Change (IPCC) as a CD.

Other satellite image sources. Remotely sensed (RS) data are increasingly important for creating and updating both physical/biological and socio-economic databases (e.g. Liverman et al., 1998). Access to RS data is constantly improving both due to lowered prices, declassification of historical high resolution data, a new generation of multi-sensor satellites being put in orbit, improved computing power and better software user interfaces. For national to continental studies NOAA-AVHRR data and their derivatives are the most easily accessible. Other data of similar resolution that can be easily accessed include the European Space Agency (ESA) ERS-2 satellite and its ATSR 7-band sensor (which can be downloaded from the internet in near real time), and the SeaWiFS 6-band sensor.

The Earth Observing System (EOS) mission by NASA has recently begun operating the TERRA satellite and its five sensors, covering a spatial resolution range from 0.015 to 20 km. Together with Landsat 7, this is leading to a new era in portraying the Earths surface from satellites. Southern Africa is further the main evaluation site for the TERRA satellite (Swap and Annegarn, 2000).

High resolution mapping of elevation and e.g. water surfaces has improved with the growing availability of radar data. The Shuttle Radar Topography Mission completed its data acquisition earlier during 2000, and from the data a global DEM in 30 m resolution will be created within two years.

Data access

A major problem for GIT development in Africa is access to internet and e-mail. The transfer rate is not seldom 1000 times less than that common elsewhere; combined with less reliable electricity and telephone services this often prevents files larger than a few megabytes (MB) to be downloaded. As download is often interrupted, software for tracking data download is essential. Further, the fraction of the population with telephone connection is very low (fig. 1). Hence the above-mentioned data often need to be disseminated via other channels. Much of it is available on various CDs – the most comprehensive being the Miombo CD. This CD includes the mentioned 1992/93 NOAA-AVHRR images, and the derived land cover and vegetation classifications, time series data of precipitation and temperature, elevation data and some spatial framework data.

Databases covering precipitation and temperature timeseries have been assembled within the framework of the Southern African Development Community (SADC) and its Regional Remote Sensing Unit (RRSU) in Harare (van der Harten and Masamvu, 2000). RRSU co-operate with FEWS and much of the data found on the ADDS homepage can also be accessed via the RRSU on CD. The RRSU CD also includes climate data and interpolated historical climate surfaces.

Another database is the Global-GRASS CD series (Lozar, 1996). It predates most other databases and partly overlaps the NOAA-AVHRR derived vegetation and land characteristics data – but in addition contains more datasets intended for climate change changes. Climate data and scenarios over climate change are, as mentioned, also available via a CD from the IPCC. However, even if data and CDs are distributed at a cost recovery base only – already this far exceeds the economical capacity of many African countries (Fig. 1)

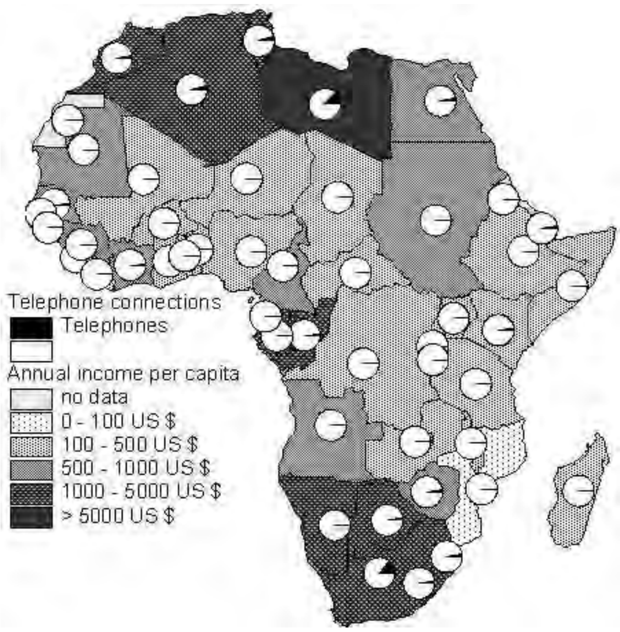

Figure 1. Telephone connections and income per capita in Africa – data from Newsweek 1994 (see app. 1)

Data accuracy and merging

Most global and regional databases are not quality labelled, neither regarding positional error nor attribute accuracy. As stated above the road coverage in DCW is very different in different regions, potentially leading to large problems in interpretations and applications. The per capita income distribution in Fig. 1 reflects the situation 1994, but no metadata is available.

The NOAA-AVHRR scenes and derived products (i.e. land use/cover) are georeferenced but the error can be up to 3 pixels (or 3 km). But is generally within 2 pixels as discovered by the author when building an animation for the Okavango Delta, Botswana (cf. Gumbricht et al, 2000). This error obviously has propagated to the derived land cover classification that is not correct in the resolution it is distributed (1 km).

The semantics for the derived land use/cover maps are further not coherent with that used in different parts on the African continent. That, however, is also due to a poorly developed unanimous semantic over natural geography on the continent. As emphasised by Pundt and Bernhardt (2000) semantic inconsistencies lead to information loss, and prevents sound conclusions.

The authors experience is that the accuracy of GTOPO30 and HYDRO1k over Africa do not allow application to smaller elements than 10 x 10 pixels (cf. Gumbricht, 1997; Gumbricht et al, 2000). A new, improved version of GTOPO30 (GLOBE) is however in the pipeline.

Merging data is necessary for most environmental studies. Most satellite images must be georeferenced to framework data before they can be used for environmental studies. And in most cases only small scale framework is available. Field data sets are further continuously varying over time and space at different scales. A satellite image is already an aggregation of the land surface over the pixel size. Field data, including socio-economic data are further often up- or downscaled, or aggregated. The quality difference between datasets of the same origin but presented at different scales is seldom reflected in the metadata. Knowing the timing of acquisition, grain size and scaling of field data is extremely important when analysing, interpreting and applying such data. For most of the global datasets available this is seldom a problem. However, most local users are ignorant of the problem and secondary datasets derived from those sources often lack metadata.

Applications

One of the more successful studies in merging socio-economic data with biological/physical is a study of the spread of ancient cultures in Africa. There is a strong relation between soils and paleoclimate on one hand and the spread of agricultural societies and cultural artefacts on the other (Sinclair, personal comm.)

More recent studies relating climate and vegetation include Anyamba and Eastman (1996) who used the 7.6 km NDVI signal derived from NOAA-AVHRR (see above) to estimate interannual vegetation variability and how it relates to the El Nino/Southern Oscillation

(ENSO). They applied Principal Component Analyses (PCA) to 4 years of monthly data – and found significant ENSO effects on vegetation dynamics in different parts of Africa.

Tyson and co-workers, among others, have repeatedly shown that process oriented models can be used in predicting and forecasting effects of global climate change and ENSO over southern Africa (e.g. Joubert and Tyson 1996). That such information is both needed and useful for planning and management of the food and water situation in Africa is evident (e.g. Stewart et al, 1996). Except for the international workshop report by Stewart et al (1996) one of the few examples of using such scenarios for spatially resolved studies on the continent is by Schulze (2000) – focusing on modelling hydrological responses to land use and climate change in South Africa and enclosed countries.

Strömquist et al (1999) framed synoptic imagery from Landsat TM with geological, geomorphological and historical information to analyse and predict environmental change in different landscapes in Tanzania. To improve dissemination they applied a freeware, and a portable computer that allowed image analyses on the spot. The interpretations of images and landscape developments were done in conjunction with local experts.

Mertens and Lambin (1997) used Landsat Multi Spectral Scanner (MSS) data from 1973 and 1986 to evaluate deforestation in southern Cameron. Maps in the scale 1:200 000 where used as framework datasets, and they also had access to socio-economic data with a resolution of approximately 7500 km^2. These data were, however, not used in the study.

Ringrose et al (1997) used one Landsat Thematic Mapper (TM) scene, field data, aerial photographs and maps in the scale 1:250 000 to evaluate land management/fenceline effects on vegetation in Botswana. From their synoptic snap shot image they concluded that vegetation was more degraded in a nature reserve and a controlled hunting area compared to a common grazing area. This contradicts the results found by Gumbricht et al (2000) using NOAA-AVHRR time series data in 1 km resolution over the same region.

The author has used HYDRO1k and DCW data for modelling the water resources at a potential hydropower station in Ruhudji River in Tanzania (Gumbricht, 1997). And Gumbricht et al (2000) analysed the Okavango Delta Botswana using DCW as framework data and NOAA-AVHRR scenes for estimating vegetation status and inundated areas over a three-year cycle. Applying remotely sensed data for parameterisation of water cycle and climate models is today a standard procedure also in Africa. Other common uses of remotely sensed data in Africa are for fire detection (Mnanike, 2000), for tracking urbanisation and for census surveying (Sultan et al, 2000).

Learning application

The author introduced merging of DCW framework data with various field data for studying the importance of water resources in Southern Africa. Only obvious conclusions linking availability of surface resources to population density (historical and present) could be drawn – nevertheless the students found it useful (Gumbricht, unpublished teaching material, Uppsala University - see appendix 3).

The FEWS data available at ADDS (see appendix 1) are comprehensive and still each 10-day composite image of climate and vegetation is small enough to allow direct download with a transfer rate of 1 KB/second. The data are also accompanied by freeware for storing, manipulating and presenting the data. The author has used this freeware (WinDisp – appendix 2) to interprete raw NOAA-AVHRR images and combine them with DCW framework data in a teaching environment. For Swedish undergraduate students in a military academy it took less than two hours to create a useful map.

University of Texas have developed a set of tutorials for water cycle studies in Africa using HYDRO1k as a starting point (appendix 3).

Several of the freewares listed in appendix 2 are accompanied by learning material, even if not directly using African data the examples can often be translated to the African databases given in appendix 1.

Discussion

Different environmental problems demand spatial and temporal data at different scales. For Africa most spatial databases available are applicable only for regional to global scale problems, with a temporal resolution of at least months and spatial scales spanning from several kilometres to the whole continent. Application to local problems is hindered by lack of data and standards, and by accuracy problems, especially when merging databases. The semantics of the globally available datasets do not necessarily correspond to the needs in Africa.

A typical GIT based study in Africa focuses on resource inventory. Is done by applying remotely sensed data of relative high resolution, combining it with map (framework) data of coarser resolution and (more rarely) socio-economic data (and then of even coarser resolution). Usually spearheaded by researchers from outside Africa (Republic of South Africa excluded), sometimes associated with an African university, but normally under the auspices of a non-African university. More recently there has been more studies presented by African universities and national agencies (e.g. Sultan et al., 1999; Mnanike, 2000). This development needs to be encouraged, also for establishing a more coherent and representative semantics for African environments.

The most common type of study is related to regional land cover changes and parameterisations of primarily general circulation models or regional hydrological models. The data most commonly used are NOAA-AVHRR and Landsat TM and MSS. Several studies also use derived land cover classification products from NOAA-AVHRR for regional studies, e.g. of vector borne diseases (e.g. Epstein, 1998). Very few studies manage to combine framework and field data, and even less succeed in combining physical/biological data with socio-economic data. Despite this there is convincing evidence that socio-economic factors are important for many environmental problems; famine in Africa is suggestively more dependent on infrastructure and socio-economic status than on climate conditions (Hutchinson, 1998).

Criticizing the typical application of spatial data in environmental studies in Africa Strömquist et al (1999) suggested an extended base line approach. They made the thought provoking analogy between applying a single remotely sensed image and interpreting a motion movie by looking at only one picture frame. They emphasised that the landscape must be interpreting in its spatiotemporal setting.

Conclusion

Physical/biological databases applicable for studying regional to global environmental problems over Africa have been developed by various international agencies over the last decade, however to the author's knowledge no equivalent development has taken place when it comes to local environmental problems or socio-economic databases. And despite large efforts in disseminating the existing data it is largely ignored within Africa. It is concluded that this ignorance is related to: i) lack of hard- and software platforms; ii) lack of communication, particularly internet access; iii) unawareness of the existence of the datasets; iv) the disparity of projections and reference systems used, and; v) semantic inadequacies in the datasets. In summary the data related problems puts very large demands on the user.

Merging of physical/biological and socio-economic databases is developing both with the aid of new software and of databases with higher and more coherent spatial resolutions – however the African continent have only seen very little of this development. Still socio-economic data is mostly restricted to national levels. Hence, for Africa there is a large risk in merging existing (better) field datasets with (poorer) socio-economic framework data – sound conclusions can seldom be drawn.

Africa encompasses a high variety of geographic regions and ecosystems, and there is a lack of coherent semantics for this on the continent. Local communities have precise semantics for natural facets of the landscapes, but the national agencies for mapping etc., do not always acknowledge this. In a sense the semantics is there and it can be argued that the evolved semantics is sustainable and cannot be improved (sensu Wittgenstein). Thus, it must be concluded that ignorance from national and international agencies are responsible for the semantic problems. More efforts must go into capturing the existing knowledge and translate it into a semantic coherent pattern. The tendency of fitting natural environments into semantics rather than the other way around need to be reversed.

Expansion of data access and electronic capability has been slower in Africa than elsewhere during the last decade. The lack of data, and computer knowledge restricted to a very small minority are still major obstacles for the growth of GIT in Africa. The hitherto concept of international agencies and researchers in using GIT as a top-down "quick fix", and teaching GIT from a technical view point has not led to GIT becoming an integrated part of environmental policy and management in Africa.

Framework datasets, baseline datasets and time-series data must be developed and maintained at a level and cost that allow also developing countries access and use. Echoing the suggestion of Goodchild (1996) there is a need for expanding national data disseminations policies to an international level. A concerted effort by national aid agencies and international organisations for assembling, processing, storing, analysing, error tagging and disseminate spatial data is urgently needed.

The most positive development is the increasing accessibility of GIT related hardware, software and remotely sensed data of different resolution. With an internet connection anyone with sufficient computer skills and a basic knowledge in GIS can download data and software from the internet for analysing environmental conditions in Africa. The obstacle to come over for disseminating these resources to Africa is education of the next generation. The main focus of the international community should hence be towards educating the African youth.

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Appendix 1 Selected free or low cost databases with African coverage

ADDS - African Data Dissemination Service
http://edcintl.cr.usgs.gov/adds/

ATSR near real time satellite data
http://192.111.33.173/ATSRNRT/

NOAA-AVHRR, selected dates 1992-1996
edcwww.cr.usgs.gov/landdaac/1KM/comp10d.html

CARPE (Central African Program for the Environment)
carpe.gecp.virgina.edu/partners/gsfc-umd/UMD/index.html

CIESIN global gridded population
www.ciesin.org

Digital Chart of the World
www.maproom.psu.edu/dcw/

Earth Observation System data gateway
Edcimswww.cr.usgs.gov/pub/imswelcome

ESRI World Base map & World Thematic Map
www.esri.com/data/online/index.com

FAO Digital Soil Map of the World (CD)
Must be ordered from FAO, UNESCO, or USGS

Global land cover
edcwww.cr.usgs.gov/landaac/glcc/glcc.html

GTOPO30 (global DEM in 1 km resolution)
edcwww.cr.usgs.gov/laddaac/gtopo30/gtopo30.html

HYDRO1k (hydrologically corrected global DEM)
http://edcwww.cr.usgs.gov/landdaac/gtopo30/hydro/ index.html

IPCC/CRU Climate change scenarios
www.cru.uea.ac.uk/cru/data/

Miombo CD
miombi.gecp.virgina.edu/

Newsweek demographic database
www.esri.com/data/online/index.com

NOAA Satellite Active Archive
www.saa.noaa.gov

SeaWiFS satellite data
seawifs.gsfc.nasa.gov/seawifs.html

SADC climate data (also as CD)
www.zimbabwe.net/sadc-fanr/intro.htm

Shuttle Radar Topography Mission
www.jpl.nasa.goc/srtm

The Tropical Rain Forest Information Center
www.bsrsi.msu.edu/trfic

USGS Global Land Information System
edcwww.cr.usgs.gov/webglis

Appendix 2 Selected GIS and RS freeware

ArcExplorer
www.esri.com/software/arcexplorer/index.html

ERViewer (viewer for many image formats)
www.ermapper.com

Mapmaker basic
www.mapmaker.com

GRASS (GIS and image analysis for UNIX or Linux)
www.baylor.edu/~grass/

Microdem
www.usna.edu/users/oceano/pguth/website/microdem.htm

WinDisp (simple image analysis software)
http://ag.arizona.edu/~epfirman/windisp3.html

Appendix 3 Selected GIT pedagogical material available from the internet

Uppsala University (full text demands password, please contact the author)

www.geoinformatik.geo.uu.se/exercises/exercises.html

University of Texas - Water Balance of Africa applying HYDRO1k

www.ce.utexas.edu/prof/maidment/gishydro/africa.htm

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