THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

AUGUST 2002

DOWN TO EARTH
GEOGRAPHIC INFORMATION FOR SUSTAINABLE DEVELOPMENT IN AFRICA

Enhanced vegetation index map from MODIS satellite imagery (composite from Feb 21-Apr 21, 2002), courtesy NASA

Ten years after world leaders adopted Agenda 21 as the world's action plan for sustainable development at a 1992 U.N. convention in Rio de Janeiro, the 2002 World Summit on Sustainable Development in Johannesburg, South Africa sets the stage for leaders to assess progress and goals. The 38 action items of Agenda 21 are aimed at integrating environmental and developmental goals into a common sustainable development framework. While progress has been made, it has been slower than anticipated, and, by some measures, environmental degradation and poverty at a global scale are worsening.

Geographic data and tools are central to addressing Agenda 21 action items, because they can be used to understand and integrate social, economic, and environmental perspectives, and they can address relationships among places at local, regional, national, and global scales. The geographic information are used in early warning systems for natural disasters, human and livestock health, crop production and yields, and for monitoring soil erosion, rainfall, and biodiversity. There is a need to collect and use data at all scales to track trends in Earth's ecosystems to support decision-making in land use planning, water resource management, transportation planning, human health management, and other sectors (see Table 1).

The National Academies report, *Down to Earth: Geographic Information for Sustainable Development in Africa,* examines the geographic foundation for natural resource management and development issues in Africa. Based on experiences in African countries, the report examines how current and future sources and applications of geographic data could provide reliable support to decision-makers, emphasizing the potential of new technologies such as satellite remote-sensing systems and geographic information systems (GIS) that have revolutionized data collection and analysis over the last decade. Although African countries are the geographic focus of the report, the material in the report has broader applicability.

Issue	Geographic Data and Information Needs
Land classification and land-use planning	• Elevation data • Land use/Land cover • Soil data • Climatic data
Infrastructure and urban management	• Population distribution and demographic characteristics • Location of existing services: waste disposal, water, and power installations • Urban transportation networks
Transportation planning	• Elevation data • Geophysical data • Statistics of trips between population and employment centers
Water resource management/ conservation	• Location of water bodies and courses with flow and condition data • Location of water users • Meteorological data on precipitation • Geophysical data on rock formations • Water consumption statistics
Human health management	• Demographic data • Location /capacity of existing facilities • Distribution of disease vectors • Distribution of water for remedial action • Distribution, flow and chemical characteristics of water courses

Table 1. Examples of types of geographic information required for selected issues.

Progress To Date: Lessons Learned

There are a growing number of geographic data applications and users in Africa, including several organizations with continent-wide activities (see Box 1, next page) and numerous regional projects focused on specific issues. However, as stated in Agenda 21, "the gap in the availability, quality, coherence, standardization and accessibility of data between the developed and the developing world has been increasing, seriously impairing the capacities of countries to make informed decisions concerning environment and development."

Four critical needs lie at the heart of efforts to expand the use of geographic information. They are: 1) creating the infrastructures to support use of geographic datasets; 2) ensuring availability and accessibility of geographic data used for many applications, 3) developing decision-support systems that effectively use geographic data, and 4) expanding geospatial capacity at individual, organizational, and societal levels.

The report identifies five overarching lessons learned from case studies in Africa that provide direction for using geographic data and information:

Box 1
Five organizations with continent-wide activities involving geographic information

The Famine Early Warning System Network
Initiated in 1980 by the U.S. Agency for International Development (USAID), FEWS NET empowers Africans to find solutions to food insecurity problems by using satellite imagery to provide an estimate of the amount and vigor of vegetation across Africa. Seventeen African countries participate in the FEWS NET.

Economic Commission for Africa (ECA)
Promotes the use of geographic information in Africa. ECA supports regional training centers, provides advisory services, develops inventories and databases, and organizes conferences and meetings.

Food and Agriculture Organization (FAO)
In 1995, the FAO initiated the Africover project in response to national requests for assistance in obtaining reliable, geographically referenced information on natural resources for use in early warning systems, forest and rangeland monitoring, catchment management, and biodiversity or climate-change studies.

Environment Information Systems-Africa
Founded in 1999 with goals similar to ECA, EIS-Africa is a network of public- and private-sector institutions and experts that promotes “access to and use of environmental information in the sustainable development process.”

Collaborative Research Support Programs
Created by USAID and the Board for International Food and Agriculture Development in 1975,CRSPs promote agricultural research within Africa and elsewhere.

Lesson Learned 1: Needs-driven as opposed to prescriptive approaches with provision of information in usable forms are most likely to result in effective application of geographic information.

The quality of local involvement in natural resource decision support may be more important than the level of technical sophistication. For example, in Namibia, communities are experimenting with the use of paper maps generated from a GIS to manage natural resources at a community level. Programs of this type tend to foster feelings of ownership by rural people, promote sharing of data and tools, and generate trust and a common vision among organizational partners.

Lesson Learned 2: Geographic information and technologies are central to the transition from traditional environmental management to sustainable development that brings people to the fore, rightfully integrating environment and development.

A narrow focus on either economic development or environmental management can obscure the connections between environmental change and social, political, and economic activities, artificially separating environment from development. Sustainable development links people, their needs, and the impacts of their behavior over time, including patterns of population growth and consumption, cultural patterns, and political activities, to the environment and the economy. Data on human population distribution are fundamentally important to decision-makers to address Agenda 21 issues.

Lesson Learned 3: In this century many environmental problems will occur at the intersection of sectors. Geographic information technologies can assist people in tackling this integration challenge.

There is growing recognition by decision-makers in Africa that problems at the intersection of agriculture and environmental management, climate change, and land-cover change, with their attendant social and economic consequences, will be at the forefront in the new century. Technological advances fostering the integration of satellite imagery with other data, such as socioeconomic or health data, in GIS are opening new ways to synthesize complex and diverse geographic datasets and creating new opportunities for collaboration among natural and social scientists and decision-makers at all levels.

Lesson Learned 4: Good governance promotes geospatial capacity and vice versa. Access to integrated geographic information allows civil society to hold government accountable; and government creates policies that determine public access to information and public participation in the decision process.

Human and organizational capacity to apply geographic information and technology to Agenda 21 issues cannot grow or be maintained unless rooted in a wider societal context that values the contributions of science and technology, upholds principles of openness and sharing of information, and provides incentives for change and adaptation. Good governance promotes relationships among individuals, organizations and the larger society, thereby contributing to the development of geospatial capacity.

Lesson Learned 5: There are several barriers to the use of geographic data to address Agenda 21 issues. Despite the many organizations already using geographic data to solve regional issues, several barriers remain to more effective use of geographic information in Africa:

- Technical limitations such as inadequate telecommunications infrastructure, limited bandwidth, and low Internet connectivity.
- Administrative challenges including lack of efficient protocols for requesting government data and lack of common data standards to promote sharing.
- Inability to afford needed data and lack of hard currency and foreign exchange in many countries.
- Educational and organizational limitation on access to data and technology including a poorly trained workforce and limited private-sector demand to spur the development of tools and information.
- Ineffective transfer of technology to the local level where many decisions are made that impact sustainable development.

Box 2
Telecommunications in Africa

Low penetration of phone lines, personal computers and Internet connectivity impedes sharing of geographic data.

Of the roughly 800 million Africans:

- 1 person in 13 has a television (62 million)
- 1 in 40 has a fixed telephone line (20 million)
- 1 in 35 has a wireless telephone line (24 million)
- 1 in 130 has a personal computer (6 million)
- 1 in 160 uses the Internet (5 million)

Source: Jensen (2002)

The Infrastructure Challenge

There is no universally accepted framework for geographic data management in Africa. Decision-making on Agenda 21 issues requires access to data from multiple sources, including international ones. Many countries employ spatial data infrastructures (SDIs) as frameworks for managing geographic information. An SDI is defined as an umbrella of policies, standards, and procedures under which organizations and technologies interact to foster more efficient use, management, and production of geographic data. African countries are at various stages in building SDIs.

SDIs require efficient telecommunications infrastructures. Although telecommunications infrastructures are improving in Africa as in much of the developing world, they often are inadequate to support efficient SDIs (see Box 2). Access to geographic data through the Internet is limited, and high connection cost and low bandwidth restrict data sharing.

***Recommendation*:** Because of the potential benefits, developing countries should consider using a standardized SDI that is compatible with the emerging Global Spatial Data Infrastructure (GSDI). Data derived from international development programs (for example, those of USAID) should conform to the standards recommended by the GSDI. In this way, data collected by these programs are rendered more useful.

***Recommendation*:** The U.S. government (e.g., USAID and NOAA) should continue to assist African countries in improving telecommunications infrastructure so that large computer files containing geographic data can be readily distributed within national and global spatial data infrastructures.

Collection and Maintenance of Geographic Information and Data

For geographic information to be useful for long-term sustainable development and natural resource management, data sources need to be dependable into the foreseeable future, particularly for types of data used in more than one application (see Table 2). Without some way to assure data continuity, investments by development organizations in training and capacity building will be less useful than they could be and will make it more difficult for African governments to invest in their own capacity infrastructure.

Famine Mitigation	Monitoring deforestation and/or biodiversity
Political boundaries to facilitate movement of resources or people	**Political boundaries** to address politically sensitive border issues
Population distribution and demographic characteristics to identify people at greatest risk	**Population distribution** to predict future impact by humans on the ecosystem
Land cover type and condition to predict yield and/or pest habitat distribution	**Land cover/land use** to document historical change and predict future habitat change
Transportation infrastructure to deliver food, relocate people	**Transportation infrastructure** to identify access to ecosystem
Precipitation/soil moisture (recent and predicted) affect food production	**Precipitation/soil moisture** (recent and predicted) affect habitat growth
Elevation, slope, aspect affect food production and access to resources	**Elevation, slope, aspect** affect habitat

Table 2. The overlap in data needed to address famine, deforestation, and biodiversity demonstrates the need for certain fundamental geographic data types.

Box 3
Data Provided to Africa by the United States

The United States provides valuable foundation and thematic geographic data that can be used for a wide variety of applications in Africa. These data include

- free access to the 24-satellite Global Positioning System;
- global 30 × 30 m orthorectified Landsat Thematic imagery through NASA programs;
- imagery of many African countries from CORONA data and space shuttle photography;
- global digital elevation model information at (90 × 90 m spatial resolution) from NASA's Shuttle Radar Topography Mission radar data;
- hydrologic information derived from GTOPO30 elevation data;
- land cover derived from Landsat, Terra MODIS, and AVHRR imagery;
- remote-sensing-derived vegetation indexes, including the type used in FEWS NET;
- tropical rainfall measurement from the Tropical Rainfall Measuring Mission;
- soil moisture measurements from the Defense Meteorological Satellite Program (DMSP);
- estimation of human population distribution using LandScan 2000 and Gridded Population of the World datasets;
- fire monitoring using DMSP nighttime city lights and Terra MODIS imagery.

The report reviewed the sources, adequacy, and current applications of many of the most important SDI framework and thematic datasets necessary for addressing Agenda 21 issues: geodetic control and simple wayfinding, ortho-imagery, elevation data, cadastral data, population distribution, land use/land cover, vegetation amount and condition, rainfall distribution, and others. The United States currently provides a range of geographic data (see Box 3), and the report identifies ways the U.S. could build on existing activities to better meet African needs.

Geodetic Control and Simple Way Finding: Global Positioning Systems

Global Positioning System (GPS) information is broadcast worldwide to virtually anyone in any country, and is of great importance to the practical collection and use of fundamental geographic location data for Agenda 21-related initiatives. Relatively inexpensive, GPS can be used worldwide in many applications (see Box 4).

Recommendation**:** The utility of GPS information should not be reduced by reintroducing selective availability, and its continuity should be guaranteed. The U.S. Department of Defense should continue to allow free access to Global Positioning System data.

Land Use/Land Cover Information: National Polar Orbiting Environmental Satellite System, Landsat, and Terra/Aqua Sensor Systems

The pace, magnitude and scale of human alterations of Earth's land surface are unprecedented in human history. Consequently, land-cover and land-use data are central to such Agenda 21 issues as combating deforestation, managing sustainable development, protecting water resources, and are also used in early warning systems such as FEWS NET. There are relatively low-cost sources of coarse and medium spatial resolution land-cover information for Africa from a variety of sources documented in the report, including NOAA's AVHRR sensor, NASA's Landsat Enhanced Thematic Mapper, and Terra MODIS sensor, which can be used routinely to inventory the distribution, amount, and condition of vegetation and water resources on a global basis.

Box 4
GPS Helps Resolve Border Dispute

In 2000, the Tanzanian and Ugandan governments used GPS to resolve their border dispute that began in 1978. The Ugandan government gave up its territorial claim to a strip of land on the common border with Tanzania after GPS measurements proved that the pillars demarcating the two countries were 300 m inside Tanzania. Other GPS applications include locating villages and dwellings in censuses, and tracking movements of wildlife.

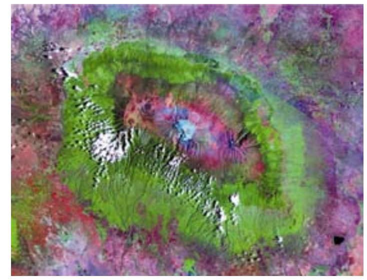
Source: People's Daily (2000)

Recommendation**:** Until at least 2018, NASA, NOAA, and the U.S. Department of Defense (DOD) should carry out their plan for the National Polar Operational Environmental Satellite System to ensure that it supplies relatively coarse spatial and high temporal frequency observations (such as the AVHRR follow-on) that are necessary for the multitude of land and meteorological applications in Africa and elsewhere.

Recommendation**:** NASA and the U.S. Geological Survey (USGS) should take measures to ensure that the Landsat data continuity mission(s) provides long-term continuous data, perhaps through making the Landsat program an operational system for land observations, to support sustainable development and natural resource management in Africa and elsewhere. NASA should also ensure that sensors on its Terra and Aqua satellites (e.g., MODIS, ASTER, AMSR-E) continue to provide data for meteorological and land observation applications.

Land Use Information: Very High Spatial Resolution Remotely Sensed Data

Many Agenda 21 issues concentrate on urban and suburban areas. Addressing sustainability issues relating to land use (including ownership) and infrastructure requires very high spatial resolution (≤ 1 × 1 m resolution) remote-sensing data (see Table 3). High-resolution data are costly whether obtained from satellites or airborne sensors.



A GeoCover-Ortho image of Mount Kilimanjaro derived from Landsat Thematic Mapper data (courtesy of Earth Satellite Corporation). Each color or shade is unique and depends on the vegetation type, health, and growth stage. Bright greens are dense vegetation. Purples and pinks are sparse to no vegetation.

Recommendation**:** USAID should consider purchasing very high spatial resolution images (i.e., < 1 × 1 m) on a regular basis (at 5 to 10 year intervals) for selected urban/suburban areas in Africa and donating them to African organizations to ensure continuity of the data source and change detection capability. The imagery might include airborne analog or digital photography or satellite-derived high-resolution imagery. The areas surveyed could be requested by African organizations on the basis of importance of the problem and technical and organizational capacity to use the data. One model for this concept is the U.S. Science Data Buy.

Human Population Distribution Information

Governments need national population data and the international community needs global population data to understand the impacts of population on the environment and, conversely, to better understand the impact of the natural environment on the well-being, vulnerability, and livelihoods of populations. The challenge lies in linking population and other socio-economic data with information on the environment in a common, geographically referenced format. Despite this need, datasets on population distribution from many African censuses are incomplete often owing to high costs and insufficient funds. Progress toward Agenda 21 goals is impeded by the lack of complete, reliable data on human population distribution.

Recommendation**:** USAID and the U.S. Bureau of the Census should provide financial and technical support to national census offices and bureaus in Africa to help them complete censuses, geographically reference the data, and make the data available to decision-makers in a spatially disaggregated format.

SRTM-derived digital elevation model of Mount Kilimanjaro observed from an oblique vantage point looking W-NW (courtesy NASA).

Elevation Data

Elevation (topographic) data have many uses but are often inaccurate, of limited extent or nonexistent, owing to inaccessibility of Earth's mountain ranges, deserts, and forests. To address these challenges, the United States has joined with a number of countries and organizations to produce two digital elevation datasets: the GTOPO30 dataset that covers 80% of the globe, and the Shuttle Radar Topography Mission (SRTM) dataset.

The GTOPO30 dataset is of limited value in Africa for monitoring ecosystems, urban and rural infrastructures, and hydrology because of its coarse spatial resolution (1.1 × 1.1 km). Fortunately, elevation data derived from NASA's Shuttle Radar Topography Mission in 2000 may be more suitable for many applications because all data (a) were collected during a single 11-day mission using standardized technology, (b) will have accurate geodetic control, and (c) will be homogeneous across each continent.

Recommendation**:** NASA should produce digital elevation data from the Shuttle Radar Topography Mission (SRTM) at the highest possible spatial resolution (e.g., 30 × 30 m) for all areas. The data should be made available without restriction and at affordable cost. Serious consideration should be given by the USGS to modeling the Shuttle Radar Topography Mission-derived 30 × 30 m digital elevation data to produce the most accurate, affordable hydrologic network database with global coverage.

Data being collected	Temporal Resolution	Spatial Resolution
Disaster Emergency Response		
Pre-emergency imagery	1 - 5 years	1 - 5 m
Post-emergency imagery	12 hr - 2 days	0.25 - 2 m
Damaged housing stock	1 - 2 days	0.25 - 1 m
Damaged transportation	1 - 2 days	0.25 - 1 m
Damaged utilities, services	1 - 2 days	0.25 - 1 m
Socioeconomic Characteristics		
Local population estimation	5 - 7 years	0.25 - 5 m
Regional and national population estimation	5 - 15 years	5 - 20 m
Quality of life indicators	5 - 10 years	0.25 - 30 m
Building and Property Infrastructure		
Building perimeter, area, height and cadastral information (property lines)	1 – 5 years	0.25 – 0.5 m

Table 3. Examples of both the temporal resolution (frequency) and spatial resolution (size of pixels) of remotely sensed data required for selected applications.

Legacy Data

The earliest baseline against which future change can be compared often comes from historical legacy data (e.g., paper maps, and information in monographs, other documents, and verbal histories). Legacy data are valuable because they extend the time scales for detecting change, contain place names, and help bridge local knowledge to modern technology. In many instances legacy data can be digitized, placed in a GIS, and analyzed in conjunction with more recent geographic data, such as satellite remote-sensing data.

***Recommendation*:** To complement existing efforts to preserve and enhance the use of valuable legacy data, U.S. government agencies (e.g., USAID and USGS) should assist African countries and organizations to identify, integrate, and maintain existing sources of information (legacy data). They should also provide African countries with copies of such legacy data as reports, maps, statistics, aerial and satellite photographs, and other relevant data and materials currently held outside those countries.

Cadastral Data

Owning land provides individuals with economic assets that can be traded in land markets, used as collateral to raise credit or as security for various forms of economic improvements. Because individual land ownership is nonexistent in large parts of rural Africa, except in eastern and southern Africa, challenges remain for rural Africans to obtain credit from lending institutions in their bid to improve quality of life.

The production of cadastres is costly and has been a low priority for most African countries and donor agencies, even when there are clear benefits. GPS, used in concert with GIS, may in certain instances produce cadastral data more cheaply than traditional surveying techniques and will facilitate production of cadastres.

***Recommendation*:** Because of the potential of cadastres to address Agenda 21 issues including poverty reduction and land resource management, the U.S. government (USAID and USGS) should assist African countries to develop cadastres.

Decision-Support Systems

The process of accumulating data is in itself insufficient to assess and manage the complex process of sustainable development and its broad implications for the environmental, health, and social issues that confront policy-makers and citizens. These decisions often involve compromises and trade-offs, for example, deciding how much water from a river should be diverted to farming as opposed to industry or housing.

A spatial decision-support system allows a decision-maker to 1) build relationships between different types of data 2) merge multiple data layers into synthetic information, 3) weigh outcomes from potentially competing alternatives, and 4) forecast. Three basic elements are required: 1) data, 2) known relationships between data, and 3) analysis functions and models to test scenarios of different policy or decision-making alternatives.

Geographic information systems provide an excellent medium to analyze relationships among different kinds of data (e.g, environmental and health data) to serve as a basis for spatial decision-support systems. GIS aids decision-making by integrating and displaying data in an understandable form and providing ways to choose among alternative solutions.

A GIS is not an end in itself, however. The desired outcome is not how the world looks, but instead how the world works. For instance, for food-security analysis, it is possible to link a GIS to a model that predicts grain yields from a range of data such as soils, climate and topography. This model can be linked to economic and demographic models showing where people live and grain demand from these settlements. The combination of basic data, yield modeling, and human demand and location analysis provides a way to evaluate food security.

Box 5

Mapping Malaria Risk in Africa (MARA) Project: An Effective Decision-Support System

Human health is a major challenge for African societies and economies. Disease disrupts families, education, and the workforce. For example, there are approximately 110 million clinical cases of malaria worldwide per year, and over 80 % of these occur in sub-Saharan Africa.

The Mapping Malaria Risk in Africa (MARA) project maps malaria risk using data on malaria occurrence in combination with spatial modeling to predict the geographic distribution, seasonality, and endemicity (peculiarity to a locality or region) of the disease. MARA provided the first continental maps of malaria distribution that are widely used for planning, intervention, and prevention by national and international health officials.

The MARA project is a federated network of scientists throughout Africa who are mapping malaria risk at the district level. Five regional data collectors are responsible for obtaining malaria datasets from neighboring countries. Stratified risk maps of the type and severity of malaria transmission are produced from geographic data on demography, climate, elevation, ecological zone, vector distribution, and malaria endemicity.

Although geographic information technologies are used in African countries and elsewhere, they are rarely used in routine support of policy-making, natural resource management, or planning. EIS-Africa concluded from a review of information initiatives in Ghana, Mozambique, Senegal, Uganda, and Zimbabwe that few application-oriented examples demonstrated advanced analysis of geographic information. Information systems were still insignificant in environmental decision-making. Reasons cited include:

- projects are orientated toward data production and updating rather than usage or application
- focus on technical issues instead of data management in support of the decision-making process;
- lack of inclusion of universities in environmental network in several countries.

There are, however, some good examples of effective programs that illustrate different aspects of decision-support system implementation, including FEWS NET, the Mapping Malaria Risk in Africa project (MARA, see Box 5), and the Livestock Early Warning System project (LEWS, see Box 6).

Decision-support in the area of land cover will be one of the most fruitful application areas of geographic data and tools in Africa. The livelihoods of the majority of Africans depend on agriculture and natural resources, and there are many pressing problems within these sectors.

Box 6
Decision-Support System: The Livestock Early Warning System

Food security and famine in East Africa are related to weather variation, expanding human populations, political instability, and changing patterns of land use and land tenure. The Livestock Early Warning System (LEWS) project, which is funded by USAID and is being implemented by Texas A&M University, demonstrates the application of integrated remotely sensed weather data, point-based biophysical modeling, and geographic data on animal and vegetation distribution to serve decision-makers concerned with the welfare of pastoral communities in East Africa.

Typically, early warning systems provide predictive data on rainfall and vegetation condition, whereas on-ground monitoring programs of markets, human conditions, and animal herd situations provide a “post-effect” appraisal. However, many problems affecting livestock (e.g., weight loss, loss of condition) occur before a response is visible, irrespective of personal experience. The problem can only be solved by an early warning system that works on the local level.

To meet this challenge, LEWS applies technologies capable of 1) predicting nutritional status of free-ranging animals, 2) assessing the impact of weather on forage supply and crop production, and 3) linking these data with local, household-level data such as fecal samples from cattle sheep and goats.

***Recommendation*:** An effective land-cover decision-support system should include a standard classification system; baseline data and change detection capabilities; hot spot detection and high risk zone prediction capabilities; analysis and modeling of proximate (mainly human) causes of change; linkages between direct observations, case studies, and models; and established environmental indicators.

Geospatial Capacity Building for Sustainable Development

Africa has a small but growing community of data providers, data processors and analysts, trainers, technicians, data and information users at many levels, and advocates. The community is becoming increasingly coordinated among Africans and international partners from non-government organizations, universities, private companies, and foreign governments including the space and aid agencies that currently are a major source of geographic data, information, training, and support.

The effective use of geographic information to implement Agenda 21 will require sustained investments in human resources development, building public and private organizations, and improving societal capabilities for generating and using new knowledge. These efforts will involve strengthening existing international cooperation and introducing new approaches based on lessons learned from previous efforts.

Partnerships promote sharing of resources, improved communication and cooperation, and acceptance of shared standards required for spatial data infrastructures. Partnerships among universities and the private sector in geospatial capacity building are key to achieving a balance between supply and demand for geographic information, tools, and services in Africa (see Box 7). Research networks that develop as a result of these partnerships promote broad exchange of information on sustainable development including best practices. Development of

Box 7
Partnership Builds Geospatial Capacity

In 1997 the Tanzanian National Environmental Management Council (NEMC) formed a partnership with the University of Rhode Island and USAID to improve coastal management. Another goal was to strengthen the links between local and national coastal management agencies and the University of Dar es Salaam. Working groups were established in priority areas such as sustainable coastal aquaculture, tourism, and environmental monitoring, creating a bridge between coastal managers and the science community.

The partnership has resulted in several new programs. In 2002 the University of Dar es Salaam began offering five courses in coastal applications of geographic information. The partnership also produced a national coastal policy that is under review by the Tanzanian government. The coastal management partners have demonstrated organizational flexibility and commitment to apply geographic information and technology to coastal natural resource management.

effective partnerships requires the support and incentives of both African and international donor governments.

Although indigenous geospatial capacity-building efforts are growing through organizations such as EIS-Africa, international players dominate the application of geographic information science to development in Africa. Traditional capacity-building initiatives can adversely affect the development of local organizations for training and education by undermining local capacity, ignoring local wishes and using expensive methods.

International agencies that build geospatial capacity in Africa have learned from these lessons and are paying greater attention to the central role of local capacity in development. Since the adoption of Agenda 21 in 1992, emphasis on scientific and technical capacity-building has increased in Africa.

Recommendation**:** Data providers, U.S. government agencies, and partners should work closely with African organizations to define and integrate the data needs of Africans into future programs (e.g., for new satellite remote-sensing missions), and to maximize efficiency of new programs through a coordinated approach.

Recommendation**:** In promoting organizational cooperation, emphasis should be placed on fostering innovation and the transfer of geographic data and technology through: (1) partnerships and research networks among government agencies, research and training institutions, the private sector, and the non-governmental sector; (2) international collaboration involving developed and African countries; and (3) cooperation between African and other developing countries.

Recommendation**:** African universities should become a focus for capacity-building including training and research in geographic information science and development organizations should coordinate their efforts to achieve this goal.

Recommendation**:** Continuing and on-the-job training should become an integral part of the process of enhancing geospatial capacity. Organizations that provide professional training in geographic information sciences, such as regional centers and polytechnics, should be strengthened.

For More Information: Contact Paul Cutler or Lisa Vandemark of the National Academies' Board on Earth Sciences and Resources at (202) 334-2744, pcutler@nas.edu. ***Down to Earth: Geographic Information for Sustainable Development in Africa*** is available from the National Academy Press; 2101 Constitution Avenue, N.W, Washington, DC 20055; 800-624-6242 or 202-334-3313 (in the Washington metropolitan area); Internet: http://www.nap.edu.

Committee On The Geographic Foundation For Agenda 21
John R. Jensen, *Chair,* University of South Carolina; **Kwesi Botchwey**, Columbia University; **Ellen Brennan-Galvin**, Woodrow Wilson International Center For Scholars; **Christian J. Johannsen**, Purdue University; **Calestous Juma**, Harvard University; **Akinlawon L. Mabogunje**, Development Policy Center, Ibandan, Nigeria; **Roberta Balstad Miller**, Columbia University; **Kevin P. Price**, University Of Kansas; **Priscilla A. C. Reining**, (*Retired*) International Office Of The American Association For The Advancement Of Science; **David L. Skole,** Michigan State University; **Andrew Stancioff,** Stone Environmental, Inc.; **D. R. Fraser Taylor**, Carleton University, Ottawa, Ontario, Canada; **Paul M. Cutler** and **Lisa M. Vandemark** (Co-Study Directors), the National Academies' Board on Earth Sciences and Resources.

This study was jointly overseen by the National Academies' Committee on Geography and Mapping Science Committee. This study was jointly sponsored by the Environmental Systems Research Institute, National Aeronautics and Space Administration, National Imagery and Mapping Agency, National Oceanic and Atmospheric Administration, National Science Foundation, U.S. Agency for International Development, U.S. Department of State, and U.S. Geological Survey**.** Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the organizations or agencies that provided support for this project.