

1.2 Study Objectives

The present paper aims at presenting the state of the art in terms of operational applications of space techniques in African continent, particularly in the fields of Geographic Information Systems, Remote Sensing, and Global Navigation Satellite Systems. The Figure 1 presents the countries and regions of the whole Africa, according to United Nations Environmental Program's subdivision of the world.

2. Spatial Data Infrastructure

In this section we will review and present the situation of SDI in Africa particularly: SDI definition, Geodetic Reference Frames, National and Regional Space Programs, National Centers of Remote Sensing, and finally Regional Organizations.

2.1 Concept and Definition

The Bathurst Declaration defines spatial data as "data/information relating to the land, sea or air that can be referenced to a position on earth's surface" (Bathurst Declaration, 1999). The ECA has published a new report on Determination of Fundamental Datasets for Africa. Accordingly the report identifies ten fundamental data themes, which are geodetic control, imagery, hypsography, hydrography, boundaries, geographic names, land management units, transportation, utilities and services, and natural environments (BCA, 2008).

2.2 African Geodetic Reference Frames

2.2.1 The African Doppler survey

The African Doppler Survey (ADOS) project was designed in the 1980's to unify the geodetic Datum's in Africa using Doppler technique as the primary observing tool. This project was based on the United States Navy Navigation Satellite System (US-NNSS), TRANSIT, which was available to the geodetic and surveying community. The system was commonly known as the Doppler Positioning System. Although nearly 300 zero order points were established by the end of 1986, the goal to unify the geodetic datum's in Africa was not met (Wonnacott, 2005). Although ADOS failed to meet its primary objectives, it did serve to provide a number of valuable lessons which will be carried forward into the up-coming AFREF project.

2.2.2 The African geodetic reference frame

The African Geodetic Reference frame (AFREF) is conceived as a unified reference geodetic reference frame for Africa. It is based on the United States

Global Positioning System (NAVSTAR-GPS). It will be the fundamental national three-dimensional reference networks fully consistent and homogeneous with the International terrestrial Reference frame (ITRF). When fully implemented, it will consist of a network of continuous, permanent GPS stations such that a user anywhere in Africa would have free access to and would be, at most, 1000 Km from such stations. Full implementation will include a unified Vertical Datum and the support to establish a precise African Geoid in concert with the African Geoid geodetic project activities (Wonnacott, 2005). Since its formal acceptance by UN-ECA in 2004, AFREF project is rapidly gaining momentum with 22 countries actively involved in various aspect of the project (ALC, 2007). Until 2005, there are at least 15 IGS stations in Africa equipped with GPS receivers. A working group has been established by CODI-GEO to manage AFREF project, which enjoys the support of numerous international organizations that are able to give the technical support needed to the project. The next phase is to install an initial network of about 25 base stations throughout Africa. The cost has been estimated to be US \$ 1.1 million while telecommunication and maintenance costs will be approximately US \$ 50000 per annum (Wonnacott, 2005).

2.3 National Space Programs

Developing small satellites with high capabilities but at low cost and small mass would be accessible and affordable by universities, research organizations, and developing countries whose governments aspired to a space program. This is through particularly in Africa (Gisdevelopment, 2007). We can mention the existence of National Space Programs in the following countries:

- a- Algeria is on track to launch its second satellite system, AlSat-2A, in late 2008 by Algeria's Space Agency (ASA). It will collect high quality images for mapping, forestry, managing agricultural resources and natural disasters, locating mineral and oil for mining, and monitoring locust swarms. The program includes setting up a base in Arzew for image analysis and control of the satellite. The AlSat-2A (2.5 m GSD panchromatic, 10 m GSD multi-spectral, 17.5 km swath, 3 days revisit time) will be launched with French assistance, but Alsat-2B will be launched in 2009, without further French assistance.

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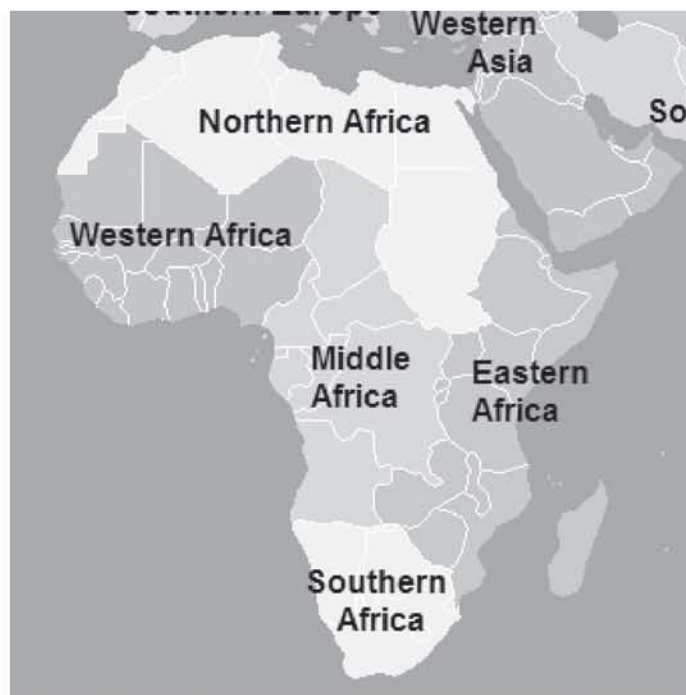


Figure 1: Countries and Sub-Regions of the African Continent
(Adapted from UNEP Website: www.grid.unep.org)

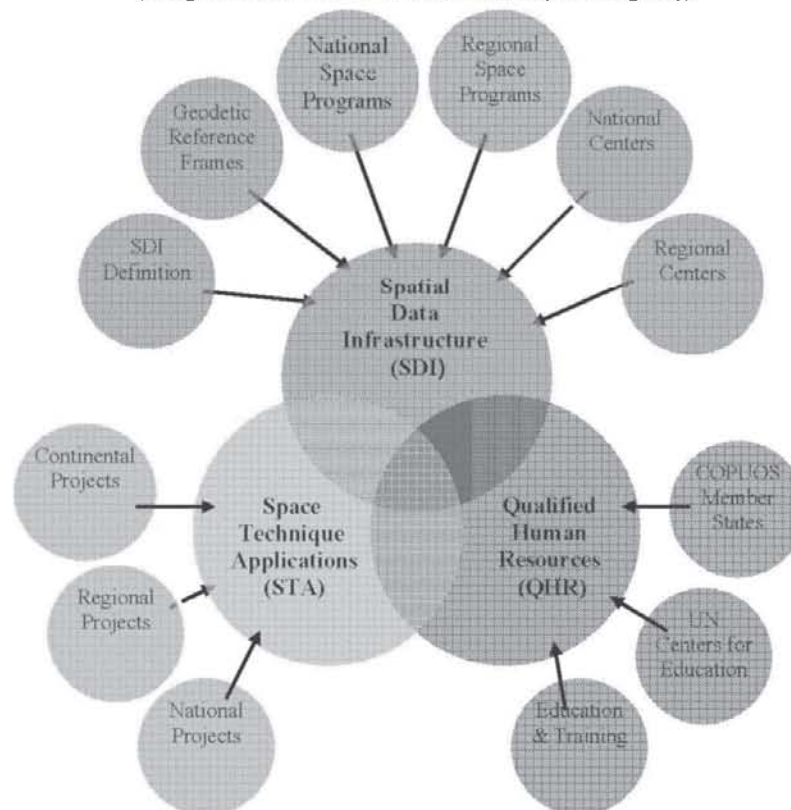


Figure 2: Adopted Methodological Flowchart, Based on the Assessment of Spatial Data Infrastructure, Space Technique Applications and Qualified Human Resources

The total cost of the project could reach US \$ 16-17 million. AlSat-1, Algeria's first satellite was launched 5 years ago (2002) for monitoring disasters (mass 90 kg, 32 m GSD multi-spectral, swath 600 km, altitude 680 km). AlSat-2 is part of the Algeria's space program for 2006-2020, which has been allocated a budget of about US \$ 1.3 billion (SDI-Africa, 2007).

- b- The Egyptian Space Program, by the National Authority for Remote Sensing (NARSS), is to launch and operate 3 satellites: EgyptSat-1, launched successfully on April 2007 with two data receiving stations, EgyptSat-2 planned to be launched in 2012, and finally DesertSat planned to be launched in 2017 for observation of Egyptian deserts. The first satellite EgyptSat-1 (altitude 700 km, 8 m GSD multi-spectral, revisit 70 days) was designed, built and tested by Ukraine with participation of Egyptian engineers.
- c- Morocco has launched in the year 2001 its first micro-satellite MAROC-TUBSAT at the altitude of 1000 km. The satellite was designed and built locally by Moroccan experts and tested in collaboration with the Technical University of Berlin, in Germany. The main scientific objective is to test new technologies. The satellite makes 14 revolutions a day, 4 of which are above Morocco.
- d- The National Space Research and Development Agency (NASRDA) was established in 1999 and approved by the national space policy in 2001. The first observation satellite NigeriaSat-1 (micro-satellite, mass 100 kg, altitude 686 km, swath 600 km, 32 m GSD multi-spectral) was launched in September 2003. In December Nigeria signed a contract with Surrey Satellite Technology Ltd (SSTL) of UK for the development of the second satellite NigeriaSat-2 (2.5 m GSD panchromatic, 5 m GSD multi-spectral, and mass 300 kg). Another communication satellite called (NigComSat-1) was launched to pursue the national policy on ICT, in May 2007 and a ground receiving station. The 25 years space mission road map was approved in 2006 including qualification of Nigerian Astronaut by 2015, Nigerian-made satellite between 2018-2030, Moon mission of Nigerian Astronaut by 2030 (Boroffice, 2007).
- e- The space related activities in South Africa prior to 2000 are mainly: GreenSat Program (late 1980's -1994), and SunSat launched in 1999. The program development since 2000 are a new micro-satellite to be launched in 2007 and establishment of a South African Space Agency

in 2006, contribution to GEOSS project related to Earth observation products for economic development and sustainable development. To be launched Sumbandila (mass 80 kg, altitude 500 km, budget R 26 million, 6 bands multi-spectral, 6.25 m GSD, swath 45 km, revisit within 6 days) (Martinez, 2007).

2.4 Regional Space Programs

- a- African satellite constellation (ARMS) Project. Four African countries involved which are: Algeria, Kenya, Nigeria and South Africa to launch the satellites for monitoring and management of natural resources and environment in Africa. The constellation will include 3 satellites or more with high resolution payload (3 m GSD panchromatic, 12 m GSD multi-spectral), agreement between the countries started in 2006.
- b- Arab satellite for Earth Observation (ASEO). This project will be managed by the League of Arab States, including Arab countries of North Africa and Middle East. The mission is mapping, management and monitoring of natural disasters, and finally management and preservation of natural resources. The constellation will be composed with 3 high resolution satellites (2.5 m GSD).
- c- Disaster Monitoring Constellation (DMC) includes the following micro-satellites: AlSat (Algeria), NigeriaSat-1 (Nigeria), BilSat (Turkey), DMC (UK), and DMC (China).

2.5 National Centers of Remote Sensing

Many national centers of remote sensing exist also at the national level. This is the case almost of every country: CRTS (Morocco), CNTS (Tunisia), NARSS (Egypt), CSE (Senegal), HartRAO (South Africa), etc.. These centers differ from one country to another. Some of them are well equipped by human resources and hardware and software, others are not or slightly equipped. There is also a National Mapping Organization (NMO) in each country.

2.6 Regional Centers and Organizations

At the regional level of Africa, there are many regional centers covering the whole continent. We may mention the following technical centers: the African Association of Cartography (AAC), the Regional Center for Mapping of Resources for Development (RCMRD, Kenya), Regional Center for training in Aerospace Surveys (RECTAS, Nigeria), l'Organisation Africaine de Cartographie et de Télédétection (OACT, Algeria), (AGRHYMET, Niger). African administrative organizations are the following: Arab Maghreb

Union (AMU), Common Market for Eastern and Southern Africa (COMESA), Community of Sahel-Saharan States (SEN-SAD), East Africa Community (EAC), Economic Community of Central African States (ECCAS), Economic Community of West African States (ECOWAS), Intergovernmental Authority on Development (IGAD), and Southern African Development Community (SADC).

3. Space Technique Applications

In this section we will present the economic development projects conducted at continental, regional, and national levels in collaboration either with United Nations Organizations, or with European Commission, or using indigenous support.

3.1 Continental development projects

The United States for International Development (USAID) requested the United States Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) to conduct a review of current and potential capabilities at regional remote sensing centers in Africa to use remote sensing applications for societal benefit. For the purpose of the study three regional centers were assessed by the process: AGHRYMET specialized institute of Permanent Interstate Committee for Drought Control in the Sahel (CILSS), in Niamey, Niger; Regional Center for Mapping of Resources for Development (RCMRD) in Nairobi, Kenya; and the Southern African Development Community (SADC) regional remote sensing unit (RRSU) in Gaborone, Botswana. Finally, 9 major recommendations were presented in order to increasing, improving, and/or achieving the sustainability of remote sensing in Africa (Rowland et al., 2007): national budgets, capacity building, data availability, data portals, education program, international cooperation, data infrastructure, regional coordination, and finally planning for future activities. FAO's AFRICOVER Project: is addressing the lack of information on vegetation cover and land use change by compiling digital maps at a scale of 1:250 000 and 1:100 000 (1:100 000 for small countries) for the whole Africa, using remote sensing data and GIS technology. The project aims to enhance the long-term capability of African institutions to provide and utilize reliable information to predict crop yields and pest habitat distribution. Until now, Africover has been implemented in three main regions in Africa through FAO Nile Basin Water Resources project (FAO Nile), Regional Environmental Information Project for Congo Basin (REIMP) with support from the World Bank and GEF, and finally National Land Cover Database Project for South Africa

(Land Cover Mapping of South Africa). The East African component is now fully operational at the RCMRD in Nairobi with funds from the Government of Italy (US \$ 5.5 million). Africover main partners are: UNEP, GSDI, USGS, EIS-Africa, etc.. More detailed information about this project, its status and achievements may be found at the following website: www.africover.org

ARTEMIS: monitoring environmental conditions in Africa for food security; since 1988, the service has been operating the Africa Real Time Environmental Monitoring Information System (ARTEMIS). The system acquires and processes routinely in real time hourly estimates of rainfall and near-real time vegetation index (NDVI) images, using Meteosat and NOAA data. The system covers the whole Africa and the products are produced on ten-day and monthly basis for use in the field of "early warning for food security" and "desert locust control". Related technology transfer is being implemented through remote sensing projects in the SADC and IGAD regions with financial assistance from the government of The Netherlands and France and in West Africa through FAO regional office in Ghana.

TREES: Tropical Ecosystem Environment Observation by Satellite. A joint program of the ESA and JRC "oriented towards the study of tropical forest dynamics at regional to global scales using remote sensing techniques".

FRA: Forest Resources Assessment, a large number of Landsat sense (120) have been used in a multi-temporal analysis for the Global Tropical Forest resources inventory, since 1990, as part of the FAO forest resources assessment (FRA 1990 project, conducted by the forestry department, FRA 2000 in preparation).

GRID: Global Resource Information Database is a joint project of UNEP, Global Resource Information Database (GRID), and the Consultative Group for International Agriculture Research (CGIAR). The main objective of the project for the "Use of GIS in Agricultural Research Management" is to establish long-term cooperative links between UNEP and CGIAR system to effectively integrate natural resources and socio-economic information into agricultural research activities. www.grida.no/prog/global/cgiar/index.htm

GEO: Global Environment Outlook, initiative by UNEP. The UNEP meta-data Directory serves as a library/catalogue of environmental information. www.grid.unep.org/

GEOCOVER Data: United Nations for Outer Space Affairs (UN-OOSA) within the framework of United Nations Program on Space Applications is providing African institutions free of charge with global Landsat satellite data sets donated by the Government of USA. The UN affiliated African Regional Centre for Space Science and Technology in French Language (CRAST-LF), in Rabat, Morocco, has been selected to act as a focal point for the distribution of the data sets to African institutions.

3.2 Regional Development Projects

Currently the total government economic cooperation amounts to about US \$ 60 billion, of which the USA, Japan, France and Germany contribute more than 50%. One third of this amount goes to the Sub-Saharan Africa, the poorhouse of the world. These governmental funds are supplemented by private investments of the same order of magnitude, which in the age of globalization are difficult to trace. Example of regional project: the Environmental Information Systems in Sub-Saharan Africa. The World Bank has created an advisory committee for EIS in 1990 consisting of African individuals, donor's countries or agencies. It was suggested to establish a National Environmental Action Plan (NEAPs). A number of countries have followed the procedure (8 countries); others have adopted the procedure partially. The Advisory committee has now been transferred into a non-governmental organization called EIS-Africa, which serves as an African Network (Konecny, 2000). In terms of considering space imagery as a source for new topographic mapping, the Sahel countries and North East Africa are the prime areas for its possible application, except Zaire with its extensive areas of dense tropical vegetation which may pose special problems. Elsewhere in Africa, the revision of extensive existing topographic coverage is the main concern of National Mapping Organizations (NMOs), especially if we consider that the existing topographic coverage are relatively old and many changes may occur during 15 to 40 years since the basic map were completed. During 1980s, the mapping of Djibouti at 1:200 000 scale was carried by the French IGN from 16 Spot stereo-pairs using a Matra analytical plotter. The Ethiopian Mapping Authority (EMA) is using Spot stereo-pairs for parts of its 1:50 000 scale mapping program. The Algerian Cartographic Institute (INC) for a similar mapping program aimed at the production of ortho-images at 1:200 000 scale in the Saharan Desert area of South Algeria. Furthermore, the Federal Survey of Nigeria has been utilizing Spot imagery for the revision of its existing 1:50

000 scale maps. Spot stereo-pairs were also used for mapping the North of Cameroon at 1:50 000 scale in cooperation with private companies from France and Poland. Beside this use of Spot stereo-pairs, it is also worth noting the use of monoscopic Spot multi-spectral and panchromatic imagery for the revision of the existing 1:50 000 scale maps in Nigeria with support from Sweden, and in Uganda with technical support from Norway and funds within the framework of the United Nations Development Program (UNDP) project (Petrie, not dated).

CAMELEO: Changes in Arid Mediterranean Ecosystems on the Long Term and Earth Observation. The principal objective of CAMELEO is to set-up and demonstrate an integrated concept for an operational Earth observation system to operationally monitor desertification processes at regional scale in the arid parts of the Mediterranean basin (i.e. mainly North Africa), in order to contribute to the fulfillment of the UN Convention to Combat Desertification (CCD) and to support sustainable land management to mitigate desertification. CAMELEO project has investigated 27 geo-referenced satellite images of Landsat taken from 1972 to 2001 in order to study land use changes. The figure 3 presents CAMELEO Project indicating the countries involved and the Study Areas in the form of small boxes.

WATERMED: project is conducted for water use efficiency associating the countries of North Africa and is supported by the European Commission (Sobrino et al., 2000). ROSELT project has been conducted by Sahara and Sahel Observatory (SSO).

GRFM: Global Rain Forest Mapping to acquire data sets of the major rainforest areas on the earth by the L-band SAR on JERS-1. Rainforest area mapped included the whole Amazon Basin, Central and West Africa, Congo River Basin, South East Asia and Northern Australia.

SAVANNAS: Research in Southern African Savannas based in London. The Research is currently funded by the European Commission and involves the collaboration between 4 Southern African countries (South Africa, Zimbabwe, Botswana, and Mozambique) and 3 EU countries (Italy, UK and Spain).

3.3 National Development Projects

AGRIMA: in 1993, this project was sponsored by the UNDP with participation from the Ministry of Agriculture and the Royal Center for Remote Sensing (CRTS) of Morocco.

This project has been aimed at developing the infrastructure to utilize more remotely sensed data and geographic information systems in crop monitoring and in the dissemination of agricultural statistics. In 1995, USDA-NASS and USDA-ARS also started to participate by providing some technical assistance for the project (Bouzaïfour and Hanuschak, 1998). GEOSTAT Project related to vegetation mapping and rangelands monitoring in Morocco, in collaboration between CNES (France) and Royal Center for Remote Sensing (CRTS) and the Ministry of Agriculture of Morocco (Ait Belaid and Gargir, 1998). The figure 4 below shows some selected development projects conducted at the country level about the following topics: desertification studying, rangelands monitoring, and finally urbanization assessment. Nigerian Government to check land fraud: the Abia State Government has introduced Abia Land Information System (ALIS) project to check anomalies in all land transactions in the state (GIS development, 2008). Guyana Forestry Commission (GFC) integrates remote sensing and Bar-coding system into its existing log tracking program in its promotion of sustainable forestry development. The GFC project is funded by the International Tropical Timber Organization (ITTO) at a cost of US \$ 100 million. It uses modern tracking devices to combat illegal logging activities (GIS development, 2008).

AGRA: a five-year, US \$ 180 million project to revitalize the soils and agricultural sector of sub-Saharan Africa has been launched in Nairobi, Kenya. The Alliance for a Green Revolution in Africa's (AGRA) Soil Health Program will work with 4.1 million farmers to regenerate 6.3 million hectares of farmland, which have been degraded by unsustainable farming practices in the last few decades. Currently, farm yield in Africa is one-quarter of the global average, and one-third of Africans face chronic hunger.

4. Qualified Human Resources

In this section we will highlight the situation in terms of education and training, regional centers for education, and finally COPUOS member states.

4.1 Education and Training

Although there are 23 Universities offering surveying program in Sub-Sahara countries, where up to 11 universities offer surveying and geomatics at degree level, it is not as popular as other professions. In Africa the remuneration does not match the effort put in the work. Another issue is the high cost of modern surveying equipments and

software. Furthermore, the situation of geomatics education is very problematic especially in Central and South Africa, due to the lack of student and the closing down of some programs. This is true at both university and school levels. African Brain Drain is another problem: 30% of Africa's university trained professionals live beyond the borders of the continent; up to 50 000 Africans with PhDs are working outside Africa and the university departments of geomatics are closing or losing their staff. Some education programs in Africa have been developed in cooperation with developed countries. This is the case of Nigeria and Zimbabwe. In Zimbabwe, the university of Zimbabwe and Midland State University offer surveying education. Midland offer a 4 years B.Sc. honors degree in surveying and geomatics (GIS development, 2007). In Nigeria, the University Development Linkage Program (UDLP) supported by USAID, has allowed to extend cooperation between 4 Nigerian institutions with 4 universities (Iowa) in the USA. In the same context, the University of Ibadan has developed a GIS program at a Master level (Yusuf, 2004).

4.2 Regional Centers for Space Sciences and Technology Education

The United Nations Regional Center for Space Sciences and Technology Education in Africa is been in operation since the year 1998 one in Morocco (for French speaking countries), and other one in Nigeria (for English speaking countries). Their mission is to build high quality capacity and critical mass of indigenous educator in both in English and French-speaking African countries for application of space science and technology for sustainable national, regional and continental development. Their goal is the utilization of research results for peaceful uses of outer space. The curriculum includes 4 applications in addition to outreach activities (Jegede, 2005):

- Remote Sensing and GIS;
- Satellite Communications;
- Satellite Meteorology; and
- Basic Space and Atmospheric Science.

4.3 COPUOS Member States

The United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS) is composed currently of 69 member states, 13 of which are from the African continent. The African member states of COPUOS include: Algeria, Benin, Burkina Faso, Cameroon, Chad, Egypt, Kenya, Libyan Arab Jamahiriya, Morocco, Niger, Nigeria, Senegal, South Africa, and Sudan.

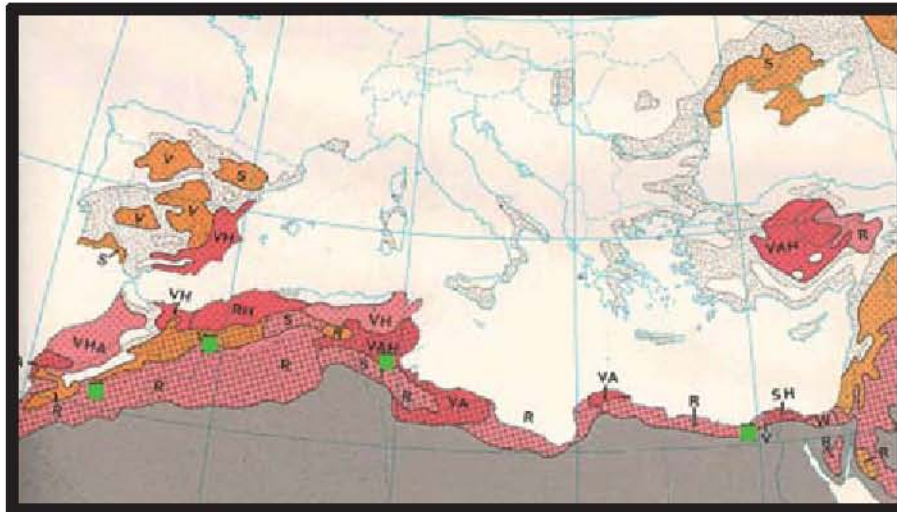


Figure 3: CAMELEO Project Indicating the North-African Countries Involved and the Study Areas (Small Squares) for Studying the Desertification in Arid Ecosystems, Using Earth Observation

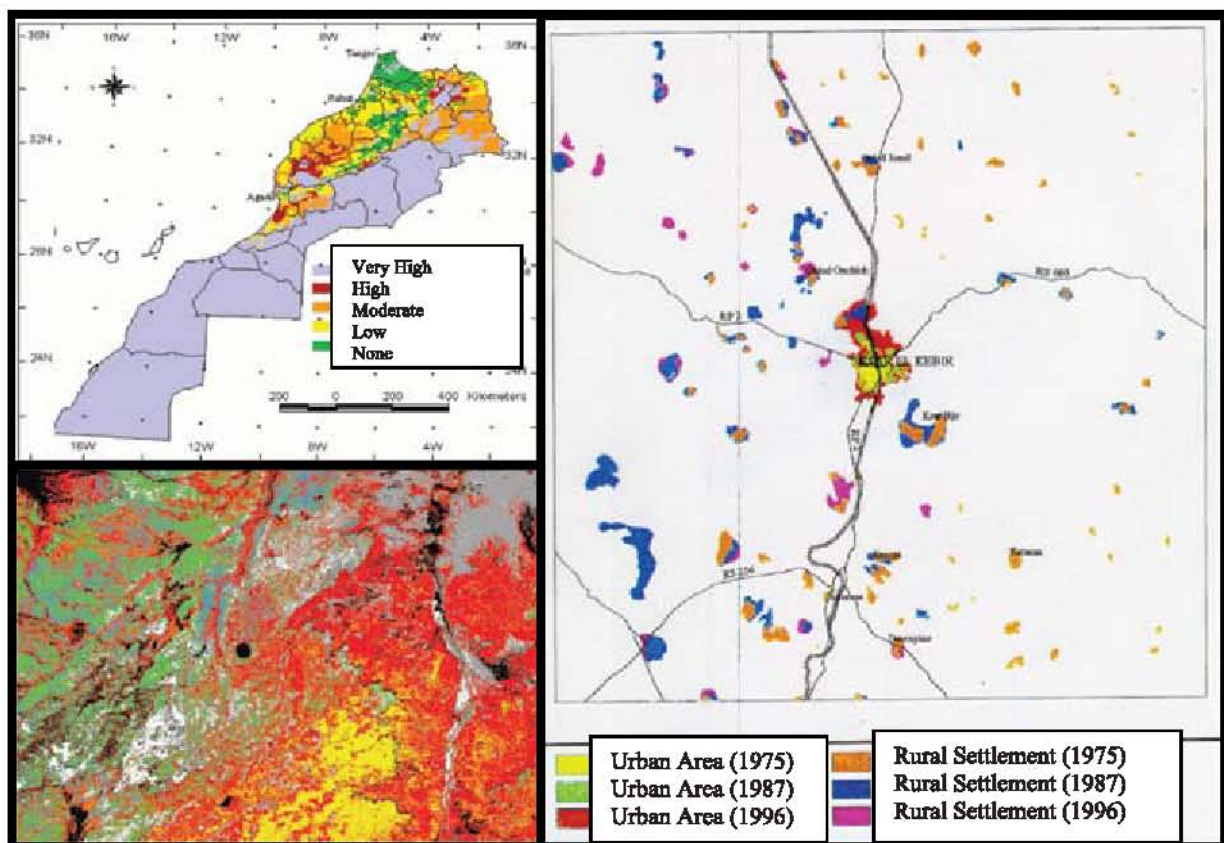


Figure 4: Selected Development Projects Conducted at the Country Level (Morocco), Related to Desertification Risk, Rangelands Monitoring and Urbanization Management Using Earth Observation and Geographic Information System

5. Summary and Conclusion

In terms of spatial data infrastructure in Africa, we can highlight the following initiatives:

- The ADOS project was designed in the 1980's to unify the geodetic datums in Africa. Although nearly 300 zero order points were established by the end of 1986, the goal was not met.
- Since its formal acceptance by UN-ECA in 2004, AFREF project is supported by 22 countries. Until 2005, there are at least 15 Base Stations in Africa equipped with GPS receivers. The next phase is to install about 25 base stations.
- It is worth to mention the existence of national space programs in some countries particularly in Algeria, Egypt, Morocco, Nigeria, and South Africa. It exist also other space programs at global level for disaster monitoring (DMC), continental level (ARMS), and at regional level (Arab countries (ASEO)).

Economic development projects are conducted at various levels in collaboration with UN organizations and other countries namely, European Commission, Japan, China and USA:

- At continental level, FAO has conducted a series of huge project like AFRICOVER, implemented so far in three regions in Africa; ARTEMIS for early warning and locust control; TREES for tropical forests, and FRA global tropical forest resource assessment. UNEP has conducted two major initiatives GRID database in collaboration with CGIAR; and GEO reporting and meta-data directory. OOSA has provided African institutions with Landsat satellite donated by USA.
- At regional level, EU has supported many projects such as, CAMELEO to study desertification in North Africa; WATERMED for water use efficiency; GRFM for global rainforest mapping; SAVANNAS for studying African savanna. WB has supported the development of EIS in Sub-Saharan Africa. ROSELT for ecological monitoring conducted by the SSO.
- At national level, AGRIMA project has been conducted for crop inventory in Morocco with support from UNDP; promotion of sustainable forestry in Guyana supported by ITTO; ALIS for development of land information system in Nigeria; AGRA to revitalize the soil of Sub-Saharan Africa in Kenya.

Space education and training of qualified human resources show the following facts:

- There are 23 Universities offering surveying program in Sub-Sahara countries, up to 11 offering degree level. The situation of geomatics education is problematic in Central and South Africa. Nigeria and Zimbabwe have developed education programs in cooperation with USA. It is found that RS/GIS are the most attractive option.
- The two UN Regional Center for Space Sciences and Technology Education in Africa are been in operation in Morocco and Nigeria, in order to build critical mass of indigenous educator for application of space science and technology for sustainable development. Only 13 African countries out of 53 countries are member states of UN-COPUOS, 4 of which are very active.

6. Recommendations

The following recommendations are highlighted, in order to enhance the operational applications of space techniques for sustainable development in the African continent and to overcome the major problems confronting African countries, which are mainly low income, lack in funds and projects, lack of experts, limited education and finally social problems:

- Ensure that African governments provide national budgets for space science and technology.
- Institutionalize capacity building and awareness for the development of space techniques for economic development at national, regional and continental levels.
- Improve data accessibility and distribution by inexpensive data policy, particularly development of spatial data infrastructure.
- Development of space technique curricula at universities and other specialized institutions, in order to qualifier human resources in Africa.
- Strengthen the cooperation with regional and international organizations, in order to mobilize external funds and conduct development projects and provide better education and training.
- Initiate better policies and provide incentives, in order to overcome the problem of African brain drain and create a pool of experts in the fields of space techniques and applications.
- Development of national and regional space programs, based on small satellites technology, which is affordable by African countries.

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