REMOTE SENSING TECHNOLOGY; A TOOL FOR MONITORING ENVIRONMENTAL DEGRADATION IN WEST AFRICA

K. Nsiah Gyabaah, BA, MSc, PhD
Bureau of Integrated Rural Development (BIRD), U.S.T., Kumasi.

ABSTRACT

The environmental problems facing Saharan and sub-saharan countries - rapid growth of population, seasonal food shortages, malnutrition, poverty, land degradation, drought and accelerated desertification etc are widespread and challenging.

While the fundamental causes of environmental degradation and accelerated desertification are known to include overgrazing, over-cultivation, deforestation, fuelwood collection and commercial logging, unsustainable farming methods, increased poverty etc, the areas affected by desertification and the severity of the problem remain a guesswork because of lack of effective monitoring systems.

This paper focuses on remote sensing technology as an attractive and alternative tool to conventional survey techniques for monitoring environmental degradation and desertification in Sahara and Sub-Sahara Africa. It looks at the potential of remote sensing and its various applications in resource inventory and land use planning.

KEYWORDS: *Remote Sensing, Environmental Degradation, Desertification, Landsat Multispectral Scanner, Aerial Photography*

INTRODUCTION

Saharan and Sub-Saharan Africa which encompass the large band of the arid and semi-arid lands of West Africa have been the focus of considerable public attention over the past three decades as a result of a greater awareness of the damage to life support systems which have resulted in severe droughts and increasing aridity, deforestation and accelerated desertification.

The region experienced a devastating drought from 1968 to 1973 and later in 1982-1984. The drought led to loss of livestock, life, property and accelerated the desertification process. It is estimated that in Africa, south of the sahara alone, about 65 million hectares of productive land have been converted into deserts in the last fifty years.

The region is politically unstable and represents one of the world's least growing economies. It also has the world's fastest population growth rate in the most delicate and fragile ecosystem. In this region, the people especially those in the rural areas, are forced by poverty to exploit fragile lands more intensively under inappropriate management and ecologically unsustainable agricultural practices. These further degrade the resource base, increase the poverty spiral and exacerbate desertification.

The threat posed by the southward march of the desert is believed to be so serious that some observers have suggested that if desertification is not halted, famine in the year 2000 and beyond will make those of the 1970s quite insignificant.

The human component of environmental degradation is unavoidable and so is the spread of the desert, loss of genetic material, which result from man's 'misuse' or mismanagement of renewable and non-renewable natural resources. The main challenge therefore is that of simultaneously meeting basic needs of the growing population for food, fuel, clothing and shelter while ensuring the sustainability of the physical and biological environment.

In the last two decades, international organizations, donor agencies, Non-Governmental Organisations (NGOs) and many environmental groups have been concerned with ascertaining the severity of desertification on the indigeneous population so that relief and poverty alleviation projects could be directed towards affected areas.

Governments in the region have called on their people for immediate action to stem and control the effects of drought and desertification on the ecological, environmental and development process. However, the planning and design of appropriate solutions require data both on the extent and severity of the degradation process. Remote sensing techniques have proven to be useful, efficient and accurate techniques for monitoring and mapping desertification.

K. Nsiah Gyabaah

Remote Sensing Applications

Remote sensing based procedures have been recognised as valuable tools for resource inventory and for monitoring environmental degradation. They have been used extensively in the advanced countries like Britain and the United States of America (USA) for vegetation mapping, as a methodology for land use classification and in other applications.

Remote sensing may be simply described as the study of distant phenomena using various sensing techniques. It is the technique of obtaining data about the environment and the surface of the earth from a distance for example, from an aircraft, or satellite platform. Remote sensing also requires the use of satellites, sensors, display equipment, communication and recording systems, ground-receiving stations, and computer software. Remote sensing information is obtained from the imagery (data) by suitable processing techniques.

Remote sensing imagery may be obtained in many forms. It may be in the form of computer compatible tape (CCT) which can be converted to either a photographic image or video, or it may be obtained in a photograph - true colour or false-colour infrared, or narrow wavelength band, or in black and white.

In the 1970's sideways-looking airborne radar (SLAR) was used for military purposes and for geological exploration. Originally designed for military purposes in the 1950s, SLAR came into civilian use in the 1970s because of its rapid rate of data acquisition and sensitivity to both surface roughness and moisture content.

Remote sensing, especially the use of colour and infrared imagery, have become increasingly important in forest surveys. It has also been used extensively for measuring the extent of deforestation and bush fire. The advantage derived from the application of colour and infrared imagery is in the recognition and evaluation of tree vigor decline, such as that caused by insects and pests.

Recently, remote sensing technology has made it possible for crop temperatures derived from thermal images to be transformed into daily transpiration values with surface balance models [6, 8, 20].

In Africa, where remote sensing applications are limited, it has been used as a low-cost and an efficient method for reconnaissance surveys.

Recent Application of Remote Sensing Techniques.

The American LANDSAT series and the French SPOT are the major satellite systems used in remote sensing. In the early 1970s the National Aeronautics and Space Administration (NASA) sponsored investigations into the uses of remote sensing data in agricultural applications. LANDSAT 1, the first satellite designed to collect data about the Earth's Resources Technology Satellites (ERTS), was launched by NASA. The first generation of LANDSAT series 1,2 and 3 were launched by NASA between 1972 and 1978.

LANDSAT 1, 2 and 3 became an entirely new means of monitoring and analysing the terrestrial environment.It had the advantage of being able to observe large areas simultaneously and providing repetitive data.

The satellite payload consisted of two sensors; (a) a return- beam vidicon (RBV) camera and (b) a four band multispectral scanner (MSS). The brightness of a surface which is recorded depends on both the solar illuminating and sensor viewing angles. Both LANDSAT and SPOT are identical but they were terminated following technical problems with the RBV which limited sun-synchronous Satellites which means that they pass over the same area at the same hour of the day, so that the sun's angle will be the same, thus illumination characteristics will be the same.

Even though the RBV was improved from 80m to 40 m, the spectrally and radiometrically superior MSS became the preferred sensor which has received wider application. LANDSAT 3 was also replaced with LANDSAT 4 and 5 and the French SPOT were launched to provide a complete coverage of the entire globe every 16 and 26 days respectively.

The difference between conventional aerial photography and LANDSAT is that LANDSAT data is digital, not photographic. However, a typical LANDSAT MSS resembles a high altitude aerial photo. In aerial photography, cameras are aimed at the earth and the scene is recorded in one relatively broad portion of the electromagnetic spectrum. LANDSAT images are usually recorded digitally by a multispectral scanner which is transmitted to earth. The ground coverage by a LANDSAT measures 185km by 185 km. Each element of the picture, called pixel, represents an area on the ground which measures 60m by 80m.

LANDSAT MSS remote sensing responses of the earth's surface conditions such as vegetation are recorded in several narrow bands of the spectrum. The type and conditions of the features determine the proportion of incoming electromagnetic radiation or energy reflected, absorbed and transmitted in a particular wavelength. The spectral response curves for green vegetation, dry green brown soil and clear water are shown in Figure 1.

The brightness values from four band of visible and near-invisible region of the spectrum which is recorded for each pixel is shown in Table 1.

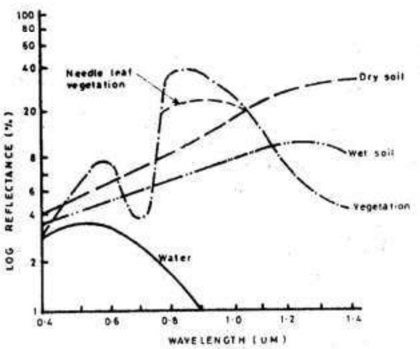

Figure 1. Spectral Response to Surface Features

Source: (a) Lillesand T.M, and Kiefer, R.W.[11], Remote Sensing and Image Interpretation, John Wiley and Sons, 721 pp.

(b) Curran, P.J.[3]Principles of Remote Sensing, Longman, London and New York. 282 pp.

Legend:

---- Vegetation
- - Soil
.... Water

TABLE 1 Description of Landsat Data

Band	Spectral Region	Colour	Brightness Levels
4	.5 - .6um	green	0 - 127
6	.6 - .7um	red	0 - 127
7	.7 - .8um	infrared	0 - 127
8	.8 -1.1um	infrared	0 - 63

The main application of the individual MSS bands are identified as follows:

(a) Band 4 - mapping of sediment ladened water and delineation of reefs in shallow water

(b) Band 5 - identification of cultural features such as urban areas, roads, etc.

(c) Band 6 - vegetation studies and delineation of boundaries between land and water and landforms

(d) Band 7 - vegetation mapping and water/land separation. Band 7 provides the best penetration of atmospheric haze.

LANDSAT products offer complementary small-scale imagery in both digital and photographic formats. It is also available in computer compatible tapes (CCTs), and floppy disks. The digital format of the LANDSAT data allows a wide range of applications. It can be used and interpreted either photographically in a conventional way, or it can be classified by computer.

Computer processing assists in reaching correlations and in producing first look graphical representation. LANDSAT computer compatible tape printouts, for example, can be utilized in coastal zone survey of water quality and even to meet objectives which require high positional accuracy. MSS band 7 (0.8-1.1um) is particularly useful in establishing land-water interface location.

The digital format can be enhanced to a selective increase of contrast. The enhancement technique allows either to accentuate specific landscape features or to make for easy interpretation of landscape features. Until sophisticated softwares made computer analysis of LANDSAT data possible, LANDSAT data was analysed by using the same aerial photointerpretation techniques and equipment.

The appropriateness of each of these types depends upon the data needs of the user and the money available for purchase of LANDSAT data. However, it must be mentioned that despite the advantages, digital data analysis is a complex and costly process, especially when compared with conventional aerial photointerpretation.

The best use of satellite data from LANDSAT missions is achieved when the imagery is interpreted in conjunction with ground verification or when combined with existing information and good knowledge of the area under study [16].

Despite the problem of scale, the use of LANDSAT MSS data for primary survey has great advantages over foot patrols and conventional aerial photography in terms of both time and money. An important advantage of LANDSAT MSS over conventional aerial photography is the scale and resolution which provide the basic difference. At a scale of 1:1,000,000 a single LANDSAT image covers an area of 34,000 square kilometres or 21,250 square miles, which no aerial photo can cover.

Since 1972 when satellite data became publicly available for earth observation from LANDSAT platform, it has become increasingly clear that earth observing systems have a special place in spatial information acquisition and monitoring of environmental degradation at local as well as global levels. LANDSAT MSS data has been used as a cost effective resource inventory technique.

The role and potential of MSS data was clearly established when it was applied to climatology, used to extract quantitative information about global vegetation conditions, agricultural crops, soil management, monitoring relief efforts, river catchment and land use planning [1].

Between 1975 and 1980, NASA, the major world agency which promotes the use of earth observation, began the Large Area Crop Inventory Experiment (LACIE). The internal deficiencies in LANDSAT MSS was reduced when the French invested in Earth Observation Programme (EOP) which resulted in the application of second generation satellite sensor systems, LANDSAT Thematic Mapper (TM) and SPOT.

The TM is a cross track scanner similar to MSS. The TM which was deployed on LANDSAT 4 and 5 in 1982, is a high resolution multispectral scanner. It became a major improvement of the MSS because TM has a spatial resolution of 30m compared with 79m for MSS. The TM also recorded data in seven spectral bands compared to four for MSS. TM has a blue-green spectral data (TM band 1) which enables production of normal colour composite images.

The other bands are band 2 (green), band 3 (red), band 4 (near infrared), band 5 (middle infrared), band 6 (thermal infrared), and band 7 (middle infrared). However, because of technical problems with LANDSAT 4 and with the TDRs system, a relatively limited number of images have been produced since TM was deployed.

In June 1979 satellite data from United States National Oceanic and Atmospheric Administration (NOAA) Polar-orbiting Meteorological Satellites carrying the first Advanced Very High Resolution Radiometer (AVHRR) was launched. An alternative to LANDSAT was found and the potential for monitoring primary production from space became firmly established from 1980 when the NOAA 6 polar orbiting meteorological satellite became operational. Data from the Advanced Very High Resolution Radiometer (AVHRR)[1] has the advantage of providing at least 2 daily-time passes over a particular ground point on the globe during a 24 hour period. The major advantage of the AVHRR is the relatively coarse spatial resolution with pixel sizes of 1km x 1 km (at nadir), sometimes aggregated to 4km x 4km (Geostationary Satellites (GAC) such and LAC modes such as meteosat). Apart from its larger spatial coverage, the high frequency of image collection increases the chances of obtaining cloud free images, especially in the tropics where cloud free days are limited.

The spectral response curves for AVHRR channel 1 (0.55-0.68 um), and 2 (0.73-1.10 um) are strikingly similar to LANDSAT MSS bands 2 (0.60-0.70 um) and 4 (0.80- 1.10 um) whose use in mapping and monitoring the health of vegetation has been well demonstrated. From the NOAA AVHRR data, daily and weekly composite, global vegetation indices are derived on routine basis.

Analysis of results of data sets from saharan Africa, especially in the grassland savannahs of Senegal where the AVHRR was first employed to monitor primary production, show that the high temporal frequencies of measurements result in better observations [22].

Satellite-borne synthetic aperture radar (SAR) has also had a wide application in land use classification and has relevance for monitoring environmental degradation in Sub-saharan Africa. Although the SAR is not affected by cloud cover, the resolution of the radar images is poor at high altitudes. This defect, however, can be improved with special techniques[19].

Recent Studies Using LANDSAT Data and the Problems Associated With LANDSAT Data.

LANDSAT remote sensing, which involves viewing the earth's surface perpendicularly, has proved useful in many applications in Europe and America especially in the potential of assessing resources and monitoring land degradation.

In a study of the coniferous forests in Northern California, for example, Strahler [21] demonstrated that it was possible to obtain a measure of vegetation texture (the spatial arrangement of tonal elements) on LANDSAT images by measuring the standard deviation of brightness values for small groups of pixels. This direct use of the distinctive texture of vegetation provides an additional dimension of space features.

In Indonesia, a variety of remote sensing techniques have been used to study land cover which show areas under extensive use in Sumatera. According to a government report derived from LANDSAT data the area under extensive use is 30 percent compared to 18 percent which is under intensive use (Republic of Indonesia, 1990).

Iverson, Graham and Cook used AVHRR imagery to study the extent of deforestation in the Amazon basin between 1978 and 1987. The study showed that the deforested area in Rondonia increased from 4,200 square kilometres in 1978 to 27,000 square kilometres in 1985 and 35, 000 kilometres in 1987 [7].

Among the few LANDSAT applications for monitoring environmental degradation in Africa south of the Sahara, three studies become significant. In a study, Westman, Strong and Wilcox used LANDSAT Multispectral Scanner (MSS) images derived from two periods- 15 years apart- to measure deforestation in Uganda. They calculated the net reduction in forest cover to be 28 percent during the dacade and a half [24].

In 1988, Lamprey used LANDSAT data to compare the location of the southern boundary of desert vegetation in Western Sudan in 1958 with its location in 1975. He estimated that the boundary has shifted southwards by 90 to 100 kilometres during the 17 year period. He used the data to conclude a desert expansion of 5.5 kilometres per annum.

In 1991, Nsiah-Gyabaah employed LANDSAT MSS to study desertification in the Upper west Region of Ghana. This study revealed the direct and complex linkages between human 'misuse' or abuse of the natural environment and land degradation when it was observed that the degraded areas in the Upper West

Region are areas where human activities such as cultivation, bush burning and grazing have been intensive [16].

From these and other studies which are not mentioned here, monitoring and mapping vegetation at local scales using LANDSAT data have been successfully demonstrated. However, three major problems arise when attempt is made to extend LANDSAT data to larger areas such as a sub-region or the entire continent of Africa. These problems include: (a) cost of imagery (data), (b) frequency of representative coverage, and (c) data handling.

Despite the weaknesses such as the problem of scale and other inaccuracies inherent in LANDSAT data, these applications have provided useful guidelines for assessing the extent of deforestation in the Amazon and in parts of Africa.

Reasons for Limited LANDSAT Application in Saharan Africa

In Africa, especially Sub-saharan Africa, where the threat of drought is severe and desertification is believed to be accelerating, the use of LANDSAT is limited. The impact of remote sensing (LANDSAT data) as an area of scientific investigation which employs more sophisticated analytical techniques such as use of microcomputers is comparatively limited because of political, technical, economic and administrative reasons. In fact, it is only in the last decade that its application has shown interesting results in detecting bush fires, in agricultural applications, in monitoring locust movement and monitoring desertification.

For decades, many scientists and resource planners thought that land cover was not worth mapping because surface conditions changed too rapidly. In poor countries where facilities for mapping and qualified personnel to analyse data are not available, changes in landscape is not treated as a priority item on planning agenda.

Even though the advantages of remote sensing (MSS) and other advanced technologies over conventional aerial photographic mapping have been well established, the number of national research institutions, donor agencies and individuals who apply the technology is limited. Consequently, results of remote sensing applications on land use and vital environmental information for planning are scarce compared to aerial photos for most parts of Sub-Saharan Africa. The major constraint today is perhaps the shortage of trained and experienced remote sensing experts to analyse data.

A large part of the difficulty in application has also been due to lack of equipment and computer facilitities for analysis of satellite data. The fact that remote sensing has been limited thus far in its practical applications is also connected with the high cost of the images and the delay associated with image delivery. Consequently, many countries and researchers are not able to procure them for spatial planning.

Part of the problem also has to do with poor data processing and publication facilities in the research institutes and Universities in many African countries. Typically, satellite data collected are not fully analysed nor are the findings widely disseminated to decision makers.

The United States Department of Agriculture (USDA) has highlighted the limitations of satellite data [23]. In areas where entire crop seasons pass without a single cloud free cover, it becomes very difficult to get images that can be analysed or interpreted. Lack of cloud free images seriously hinder progress in the application of Landsat data, especially in Sub-Saharan Africa and the tropics.

The delays in receiving satellite data from recording stations such as Earth Resources Observation Systems (EROS) data centres in the USA, Fucino in Italy and other regional Offices and the time needed for processing satellite data often mean that the results can only be used as retrospective check on an area estimates derived by conventional systems.

The cost of data acquisition in foreign currency (US dollars and pound sterling) poses a serious bottleneck to governments, individuals and land use planners. These constraints make it difficult for farmers, and decision makers to have timely data for planning.

Aerial Photography.

Several remote sensing techniques may be employed to provide useful information for planning and for a wide variety of needs. Remote sensing techniques include conventional aerial photography, multispectral photography, multistage systems, digital imagery and other systems. These systems have been used to study land use, agricultural and rangeland management, wetland improvement, forestry production population and settlement studies, and mineral and water exploitation.

In Sub-Saharan Africa, the principal remote sensing technique which have been used for resource inventory are foot patrols and the conventional aerial photography. Over the last five decades air photo interpretation has been used as a classic and well proven methodology for topographic mapping. It has also been used in a wide variety of thematic mapping tasks and in monitoring of landscape changes.

In fact, the useful application and benefits of conventional aerial photography in the study of crop disease dates back as far as the 1920s when oblique black and white photographs were used to differentiate living and dead cotton plants and to pinpoint the foci of infection by root-rot fungus 'plymatotrichum omnivorum'.

Brenchley has reported that conventional aerial photography was applied successfully in the study of potato blight (phytopthora infestants) in commercial potato crop in the Fens of East Anglia [2]. Since then aerial photography has proved reliable in detecting changes in crop condition at farm and regional levels

[4, 13]. For example, a more recent application has involved the use of aerial photography to investigate the incidence of sugar beet virus yellow or to pinpoint diseases carried by an airborne insect vector [13].

In Sub-Saharan Africa planners and resource managers, concerned with land use and resource management, have commonly employed the time-consuming and often labour demanding methods for resource inventory and for monitoring land surface conditions. Foot patrols and conventional aerial photography have been used for crop studies. Planners have assembled cartographic outlays of the very wide range of land surface features such as topography, soils for planning using air photos because of the insight the technique offer into a large number of spatial phenomena which satellites cannot obtain with present technology [5, 12, 18].

Although conventional aerial photography was widely used, the actual aerial photographic interpretation and map preparation were not carried out locally but in Britain. There was therefore very little or no opportunity for land use planners and resource managers to learn appropriate aerial photo interpretation techniques.

Conventional aerial photography has the advantage of reliability in large scale mapping. It also allows for consistent and accurate delineation of boundaries and land cover types. It is easy to interprete and offers opportunity for multi-temporal studies (ie. during and between growing seasons). Despite these advantages, conventional aerial photography has a number of limitations. The only spatial records available are map scenes at scales ranging from 1:250,000 to 1:100,000 which are seldom upgraded.

The frequency of data acquisition of between five and ten years interval which is satisfactory to the needs of topographers, geologists, mineralogists and miners may be irrelevant to land use planners and environmentalists concerned with change over short periods. Moreover, the traditional statistical system of production and estimation need a large input of labour. The high labour input requirement in the production of photos does not help in obtaining yield information quickly where labour is unavailable.

Undoubtedly, the use of black and white aerial photography provides a planar perspective for land cover estimation and for delineating broad land cover types, however, the use of stereoscopes, photogrammetric techniques and other modern equipment have greatly improved the mapping procedure. For example, the introduction of colour and colour infrared films with appropriate filter combinations have permitted a variety of vegetation discrimination than black and white photography.

Applications of Remote Sensing to Agriculture

Remote sensing techniques are unique in natural resource surveys. The value of remote sensing, and especially LANDSAT MSS imagery on the syntheses of vegetative cover has well been established [3]. With good quality images and equipment, a lot of information can be gathered from LANDSAT images.

LANDSAT MSS provides a snoptic coverage (ie, large areas could be studied simultaneously) because of the area that one LANDSAT scene covers. This makes it possible to observe one natural phenomenon in a continuous stretch as one physiographic entity.

Moreover, it is repetitive and makes continuous monitoring possible. In particular, the supervised classification technique has been useful for agricultural applications while the unsupervised classification technique has been effectively employed for vegetation mapping. However, LANDSAT MSS is often limited by cost considerations and data handling problems.

Remote sensing techniques have been used to:

(a) map the present extent and distribution of land cover;

(b) formulate land use policy;

(c) speed up soil mapping and produce better quality maps;

(d) monitor soil erosion and soil degradation, factors which undermine food self-sufficiency in Saharan and Sub-saharan Africa;

(e) improve human understanding of the interaction of soil, hydrology and plant growth;

(f) detect bush fires which destroy vegetative cover leaving lands bare and essentially unproductive;

(g) monitor and model air pollution;

(h) give horizontal and vertical wind profiles;

(i) provide information of water vapour gradients, a parameter which is important in drought and desertification studies;

(j) map changes in the extent and distribution of land cover and to assess the effectiveness of various land use policies.

In agriculture and environment, remotely sensed data have been widely applied at a very wide range of scales, for local and global surveys. However, the respective applications of remote sensing are very different from each other in terms of their data requirements. For example, the resolution requirements for agricultural applications with respect to spatial and temporal resolution compared with those other users of remotely sensed data show that interest in agricultural applications are more diverse and growing.

Agricultural applications are particularly characterised by land management and economic features which, in the past, were not possible to be addressed by conventional mapping systems. These together make it easier to suggest that remote sensing data will continue to play an increasingly important role in agriculture, especially at the local level.

The agricultural requirements for remote sensing techniques are for the analyst to understand crop production techniques which will help him to answer four basic questions which include:

(a) what type of crop is growing in the field?;

(b) what is the area of the crop?;

(c) what is the vigor of the crop and its likely yield?;

(d) what is the agent responsible for any loss of vigor?

Answers to these questions are critical in leading to modifications in management systems. The different agricultural applications of remotely sensed data may be summarised as follows:

Scientific Applications

- Crop Science including all surface types of vegetation, hydrology, run-off indices, ground and stress - and water detection;

- agro-climatology;
- land surface climatology;
- agro-ecology;
- soil science;
- global change;
- vegetation science including forest science, and
- terrestrial ecosystem

Management Applications

Agriculture

- agro-ecology;

- crop damage;

- crop condition;

- crop inventory (local, regional, national and global);

- crop classification;

- livestock inventory.

Degraded Land Studies
Land Evaluation
Land Use
Land Degradation (Soil erosion , soil salinity).
Land Drainage
Land Reclamation (Agriculture and urban development).
Pollution (Soil pollution, Vegetation).
Environmental Impact Studies (Agricultural and urban development).
Geographic Information Systems (GIS) Contributions to Regional Agricultural Systems
Irrigated Lands (inventory, monitoring of extent, crop condition, water utilization and regulation of land use

Rangeland management (Rangeland condition, rangeland classification, and rangeland production)
Soil Survey (sheet, rill, gully erosion).

Other Applications

Application of LANDSAT data have been widespread in other fields such as:

- Mineral and petroleum exploitation;
- Geological survey;
- Coastal survey;
- Land and Water pollution

Information appropriate to the application may be useless in another.

Future Direction

The basic concept of disaster such as devastating bush fire, drought and famine preparedness entails a government commitment to intervene effectively in time to protect life and property. Such actions call for more research and environmental monitoring.

Therefore, governments and donor agencies in Saharan Africa should stimulate and encourage social and natural scientists to strive for excellence in research for the purpose of improving understanding of environmental and the socio-economic development of the region.

Since the capacity of governments of Sub-Sahara Africa in environmental monitoring is limited due to technical and economic constraints, the developed countries and donor agencies should support short-term training leading to the upgrading of professional knowledge and skills in remote sensing, particularly for the teaching staff of the Universities and research institutes.

A conscious effort should be made to retrieve, assemble and safeguard all historic air photos in survey departments. Modern scanning techniques should be used to store information from the air photos on optical discs.

SUMMARY AND CONCLUSIONS

There is no doubt among environmentalists, development planners and resource managers that sustainable development of agriculture and environmental rehabilitation in Saharan and Sub-Saharan will require efficient resource management and environmental monitoring techniques.

Although remote sensing technologies have wide applications and have proved to be useful tools for resource inventory and for mapping surface conditions, until satellite resolution improves some subtle landscape features will continue to be identified and interpreted by aerial photographs which are best suited for this task.

Though LANDSAT Thematic Mapper (30m resolution) and SPOT with higher (10m) resolution images have allowed more applications and have become alternatives to the costly ground observations, they cannot be a substitute to foot patrols and aerial photographs. The advantage of aerial photographs which makes its application significant is that it remains the best option in the investigation of many agricultural problems at scales smaller than a football field. Remote sensing techniques based on computer applications must therefore be used in combination with aerial photographics and maps in order to achieve the best results.

There is an urgent need for the advanced countries to bolster environmental research efforts of the developing countries, especially those in fragile ecosystems. The developed countries must continuously disseminate satellite technologies that would give early warning signals, promote soil conservation and fertility maintenance, and curb environmental degradation in the developing countries.

Close collaboration in research is necessary for both the developed and the developing countries. We are in the same boat when it comes to tackling environmental problems such as the green house effect because we all have to either 'swim to safety or sink' together in a global environmental disaster.

The European Ecological Movement's interest in the fate of tropical rain forests, in relation to global climatic change provides the greatest access to environmentally sound technology on equitable and affordable basis.

Remote sensing stations which provide data to the developing countries must know that delays in the delivery of satellite data and the cost of the images prevent operational use of their data. The general availability, timely delivery and low prices of images will help to extend analytical capability to research institutes and individuals interested in remote sensing applications.

While remote sensing technology using computer applications should not be used as a substitute for aerial photos, natural colour photography has an advantage over black and white photos and therefore must be used.

Although Land satellite based systems together with other remote sensing systems have a high potential application as effective monitoring systems, the best of results of all known computer based techniques discussed above can yield the highest potential if they are combined with ground observation.

Notes

1. The spectral response curves of AVHRR channels 1 (0.55-0.68um) and 2 (0.73-1.10um) are strikingly similar to LANDSAT MSS bands 2 (0.60-0.70um\0 and 4 (0.80-1.10).

2. The AVHRR NDVI images were processed in the 1987 growing season by the Centre de Suivi Ecologique, Dakar.

3. The purpose of preparedness plans is to outline the measures that would be taken during emergencies such as drought, floods etc.

REFERENCES

1. **Anon** *Feasibility Study for a Nigerian Natural Resources Information Centre, Federal Ministry of Natural Planning. Government of Nigeria, Hunting Technical Services, Boeham Wood, U.K. (1981).*

2. **Brenchley, G.H.** *'The Aerial Photography of Potato Blight Epidemics' Journal of the Royal Aeronautical Society, 70, pp 1082-1085. (1966)*

3. **Curran, P.J.** *Principles of Remote Sensing, Longman, London and New York, 282pp. (1985).*

4. **Curran P.J.** *Remote Sensing in Agriculture: An Intro ductory Review' Journal of Geography, 86, pp 147-156. (1987).*

5. **Curran P.J.** *'Crop Condition' in Manual of Photographic Interpretation (Second Edition), American Society for Photogrammetary. (1989).*

6. **Hatfield, J.L., Reginato, R.J. and Idso, S.B.** *Evaluation of Canopy Temperature-Evapotranspiration Models Over Various Crops' in Agriculture and Forest Meteorology, 32, pp 41-53. (1984).*

7. **Iverson, L.R., Graham R.L. and Cook, E.A.** *'Applica tion of Satellite Remote Sensing to Forested Ecosystem' Landscape Ecology, 3; pp 131-143. (1989).*

8. **Jackson, R.D., Reginato, R. and Idso, S.B.** *'Wheat Canopy Temperature: A Practical Tool for Evaluating Water Requirements' in water Resources Research, 13, pp 651-656. (1977).*

9. **Lamprey, H.F.** *'Report on the Desert Encroachment Re connaissance in Northern Sudan' in UNESCO/UNEP Desertification Control Bulletin, 17, p 1. (1988).*

10. **Laut Peter** *Remote Sensing and Management (edited by M.J. Eden and J.T.Parry, John Wiley and Sons Ltd. (1986).*

11. **Lillesand, T.M. and Kiefer, R.W.** *Remote Sensing and Image Interpretation, John Wiley and sons, 721pp. (1987).*

12. **Lo, C.P.,** *Applied Remote sensing, Longman, New York (1986)*

13. **MAFF** *Annual Report, ADAS Aerial Photography Unit, Cambridge.(1985).*

14. **Annual Report,** *ADAS Aerial Photography Unit, Cambridge. (1986).*

15. **National Remote Sensing Centre** *(NRSC) Space Department Royal Aircraft Establishment, Famborough, Hampshire.*

16. **Nsiah-Gyabaah, K.** *Environmental Degradation and the Threat of Desertification in The Upper West Region in Ghana. Department of Environment, Wye College, London. (1991).*

17. **Republic of Indonesia**. *The Land Resources of Indonesia A national Overview*. Land Resources Department. Foreign and Commonwealth Office (1990).

18. **Simonett, D.S.** 'The Development and Principles of Remote Sensing' in *Manual of Remote sensing*. 2nd Edition. American Society of Photogrammetry. Falls Church. Virginia. USA. (1983)

19. **Skidmore, A.K., Wood, G.B. and Shepherd, K.R.** 'Remote Sensed Digital data in Forestry: A Review'. *Australian Forestry*, pp 50: 40-53. (1987)

20. **Soer, G.J.R.** 'Estimation of Regional Evapotranspiration and Soil Moisture Conditions Using Remote Sensed Crop Surface Temperatures' in *Remote Sensing of the Environment*, 9, pp 27-45. (1980)

21. **Strahler, A.H.** 'Stratification of Natural Vegetation for Forest and Range Land Inventory Using landsat Digital Imagery and Collateral Data' in *Journal of Remote Sensing*, 2, pp 5-41. (1981)

22. **Tucker, C.J. and Sellers, P.J.** 'Satellite Remote Sensing of Primary Production' in *International Journal of Remote Sensing*, 7, pp 1395-1416. (1986)

23. **Vogel, F.A.** 'Applications of Remote Sensing at the Department of Agriculture of the USA. Statistical Assessment of Land Use' in *The Impact of Remote Sensing and Other Recent Development in Methodology*. Eurostat. (1987).

24. **Westman, E.E., Strong L.L. and Wilcox, B.A.** 'Tropical Deforestation and Species Endangerment: The Role of Remote Sensing' *Landscape Ecology*. 3, pp 97-109. (1989).