UTILISATION OF LANDSAT SATELLITE DATA FOR DISTRICT AGRICULTURAL DEVELOPMENT PLANNING IN THE SOUTHERN REGION OF THE SUDAN

T E Beaumont
Scott Wilson Kirkpatrick and Partners
United Kingdom
Commission VII (W.G. VII/4, No. 118)

Abstract

Deficiencies in the provision of adequate planning information for agricultural development in the Southern Sudan caused by the remoteness of the region and associated problems of inaccessibility have been overcome within the immediate aid financed rehabilitation programme by making use of Landsat satellite data in conjunction with established terrain survey procedures.

1. Introduction

Agricultural development in the Southern Region of the Sudan has been severely affected by the recent turbulent history. Major prolonged conflict over a long period of time has prevented any stabilised settlement of the land and associated agricultural activity or investment. Consequently, with stability only returning to the Region in recent times, after the signing of the Addis Ababa accord in 1972, there has been a continual problem of reinstating subsistence agriculture to sufficiently productive levels to sustain the food requirements of the local population. As food shortages can become critical in prolonged times of drought, the Sudan Government has initiated a programme of agricultural development in the Southern Region, funded through financial and technical aid from the World Bank, United Nations and other aid agencies, in order to rehabilitate and extend subsistence agriculture to a level of production that can meet present and future local food requirements.

One of the major programmes within the development strategy has been to prepare agricultural development plans for specific administrative districts in the Southern Region west of the River Nile. In this joint British Government ODA/ World Bank scheme, financial and technical assistance has been provided to the Regional Ministry of Agriculture and Natural Resources, so that an administrative and operational organisation could be established to collect and coordinate relevant data, and to formulate plans for further investment and project development. It is within the newly created administrative organisation that the Land Use and Physical Planning Unit was established with responsibilities to acquire the physical resource data necessary for district development planning purposes. Similarly, other units were developed to cover all aspects of study relevant to agricultural development planning, and included staff concerned with economics, agricultural statistics, farm management and extension, agronomic research, sociology etc.

As the Southern Region in its entirety is larger in area than the whole of Kenya, priority has been given in the smallholder agricultural development programme to those districts west of the River Nile, where most people are known to be concentrated, and the land resources and climate are most likely to be favourable for agricultural expansion and increased productivity. In the first phase, priority has been given to the Yei, Mundri, Rumbek, Gogrial, Tonj, Wau and Aweil districts. After an initial period of data collection

within the Land Use and Physical Planning Unit, it was realised that acquiring the required information for district planning would pose many problems if only traditional methods were deployed due to the large area of terrain involved; the virtually non-existent infrastructure in the region; the difficulties of logistic support for field operations; and the paucity of adequate mapping, airphoto coverage and background information on the physical characteristics of the terrain.

Consequently, a decision was made to make use of available Landsat satellite imagery covering the region and, after an initial evaluation, a programme was initiated to interpret the existing data in order to provide the required information needed by the unit for district agricultural development planning. This programme also included a substantial element of training of local staff in the use and value of Landsat satellite data, so that on completion of the studies investigations could be continued within the unit in other districts, and on other aspects of physical resource evaluation.

2. Agricultural development planning

The major problem facing the Land Use and Physical Planning Unit, in identifying existing settlement and potential land for smallholder agricultural development within each target district, was the almost total absence of any suitable topographic or cadastral survey information. Great difficulty was even experienced in acquiring the national 1:250,000 scale map sheets covering the region, due to shortages of supply from Khartoum, and sheets being out of print. Once acquired, the national 1:250,000 scale sheets proved to be totally inadequate for planning purposes, as the series had not been updated, except for administrative boundaries, since they were originally produced in the early 1900's by the accumulated efforts of the early explorers.

Consequently, in remote areas the map sheets mainly consisted of empty space, whilst in other areas, the Landsat data eventually revealed great inaccuracies on positional detail, with some rivers being up to 40 miles out of true position. Similarly, village settlements and lines of communication had greatly changed with time. In some instances it was also found that there were anomalies on the graticule of geographical coordinates drawn onto the map sheets. The first requirement therefore, was to produce an up to date base map at a 1:250,000 scale for each district, so that all survey data could be placed in its proper spatial context.

The lack of available airphoto coverage of suitable quality or quantity also proved to be a considerable handicap when attempts were made to acquire information on the nature of the ground surface over very large and remote areas. Existing airphoto coverage was found to be sporadic, of great age and poor quality, with flight diagrams sometimes being unavailable for plotting coverage of flight runs. Consequently, little use could be made of this source of information, except where small blocks of good quality prints could be found to cover areas of interest. As all the photography was at least 20 years old, its use for plotting up to date base maps was very limited, although information on drainage and other physical parameters could be interpreted where adequate quality and cover existed.

In the absence of adequate map and airphoto coverage, the only alternative for acquiring relevant data was to undertake appropriate landrover traverses and field sampling programmes from the Juba base. These proved to be very difficult to undertake due to the vast distances and large areas involved, and the immense problems concerned with organising logistics in this part of Africa. The road system has fallen into disrepair, and in many instances

virtually disappeared due to lack of maintenance and the period of conflict in the Southern Region, and in the wet season many areas are impassable due to flooding and the lack of bridges. Supplies of fuel, spare parts, food and other basic commodities are also most difficult to organise in this remote region. Consequently, the requirement for basic survey data on soils, landforms, drainage, land use, vegetation etc., was severely restricted within the Southern Region by the lack of mapping, difficult terrain, and restricting conditions affecting ground survey methods.

As funding was not available to carry out full topographic mapping, and time constraints were affecting data acquisition for the agricultural development planning programme, a method was required whereby basic maps could be prepared, and field information gathered, with a minimum of ground checking and sampling. In the short term, in addition to adequate base maps, there was also a requirement for up to date land use maps showing where existing agriculture was being undertaken, and where settlements, indicating the highest concentrations of population, were located. Once this information had been collected and presented in map form for each district, further studies were able to be focussed on soils, vegetation, land capability, water resources etc. whilst parallel investigations relating to economics, farm management, extension and other planning requirements could also be undertaken more efficiently.

3. Landsat interpretation programme

After preliminary evaluation of the quality of the available Landsat satellite imagery covering the Southern Region, an interpretation programme, based on the use of the simplest standard photographic products and manual analytical techniques, was implemented as the only viable method for acquiring the necessary basic planning information in the time and costs allowed by the funding agencies. As many of the selected districts extended into the swampy grasslands on the margin of the Sudd, where the grazing of livestock is a dominant factor in the local economy and social practices of the population, an important requirement also existed for information on rangeland, vegetation and patterns of grazing in relation to flooding and water availability in these areas. The repetitive nature of Landsat satellite data similarly provided one of the best and most cost-effective means of acquiring essential data on the seasonal changes which affect these areas and their significance with respect to district agricultural development planning and formed the basis for a separate study programme (Vass 1983). The urgency of the programme however necessitated initial emphasis being placed on preparation of base and appropriate land use mapping.

3.1 District base maps

One of the main requirements within the preparation of base maps for each district was to identify and locate lines of communications, as the main strategy within the overall development planning consisted of concentrating attention on those areas which afforded easy road access. Similarly, in identifying available road access by means of satellite imagery, the study of drainage proved to be most important, both with respect to river crossings, and the extent to which areas would be susceptible to inundation during flooding in the wet season. In the course of undertaking the interpretation programme, it became evident that the quality of the Landsat satellite imagery available for the Southern Region, when enlarged to a scale of 1:250,000, was more than adequate for locating and mapping lines of communication and significant drainage channels which subsequently formed the main features of the base maps. Substantial information was also able to be acquired on flooding regimes within

the region through interpretation of vegetation cover and surface hydrology on sequential and multidate Landsat black-and-white (bands 5 and 7) and colour composite image scenes.

Using the simplest methodology, geographical coordinates were plotted from the appropriate 1:250,000 scale Landsat scenes for each district onto a transparent overlay to which administrative boundaries were transferred from corresponding national series map sheets or other sources. After replacing the overlay on the imagery the following features were able to be identified and plotted:- drainage channels; lakes; all weather main roads and dry season roads (trafficable by lorry, 4 wheel drive or alternative vehicles) with appraisal of current status and likely problems such as bridging sites or river crossings; tracks and cattle trek routes; railway line; villages and settlements; hill areas, rock outcrops and main jebels. Where appropriate, boundaries of national parks, game and forest reserves were also mapped by reference to the Landsat imagery and collateral sources of information. Once plotted, the preliminary overlay maps were then taken into the field for as much checking and subsequent correction as could be achieved within the time available. Similarly, after integrating local knowledge acquired from various sources, additional information was added to the maps on names of villages and rivers and location of chiefs' villages, dispensaries, peoples rural council headquarters, agricultural extension centres and all other relevant data. On completion of this basic programme final base maps were drawn up from the overlays on a master permatrace format within the Land Use and Physical Planning Unit and copied by dyeline for distribution to all relevant personnel working throughout the region on different aspects of the rehabilitation programme. Further revision and improvement of the base maps subsequently became possible as a result of their practical use by different agencies working in the field.

Although planimetric accuracy was not of a high order due to the resolution limitations of Landsat MSS data and the inability to geometrically correct the imagery on the basis of cost, time and available facilities, the base maps, in the absence of any viable alternative, proved invaluable to all concerned with the different aspects of agricultural development planning. In this respect the immediate success of the base maps related to the fact that they provided the first opportunity whereby agricultural and related survey data could be placed and viewed in its proper spatial context. An additional benefit arising from the base mapping programme also concerned the wide range of information interpreted from the Landsat imagery which proved relevant to the associated highway and water engineering studies carried out within the planning programme.

Route alignments, for example, were able to be studied in relation to bridging and materials requirements, areas susceptible to flooding, poor subgrade conditions etc., in addition to overall transport problems associated with rural access and seasonal transhumance. Similarly, the water resources of each district could be evaluated with respect to supplies for village communities and the potential for both small or large scale irrigation schemes. As mentioned above, sequential studies of Landsat data additionally provided information on seasonal flooding which significantly affects many aspects of agriculture, engineering and socio-economic activities within the region.

The base mapping programme additionally provided an excellent opportunity to use Landsat satellite imagery for studying the settlement pattern within the region. Previous studies have demonstrated how satellite data can be used to monitor the induced benefits and change in settlement distribution brought about by road construction (Beaumont 1983). The important relationship between

communications, settlement and agricultural development, so clearly evident on the Landsat imagery of the region, proved most striking in the Mundri district where ribbon development has occurred along the extent of a new road constructed under German aid between Juba, Mundri and Maridi. In this district, the trend to settle along newly constructed or upgraded roads has been continuing to the extent that the satellite imagery revealed that the settlement area of Mundri had greatly expanded at the expense of the old provincial centre of Amadi which occupies a much smaller area to the north, due primarily to the recent construction of the good standard gravel road referred to above. The provision of such relevant planning information emphasises the value of Landsat data in being able to provide a means of producing very much up to date base maps, for on this study the majority of the satellite image scenes were less than one year old.

3.2 Land use maps

On completion of the base mapping programme, the Land Use and Physical Planning Unit needed to acquire immediate information on the nature and extent of cultivated lands as the main strategy within the overall development plans for each district, consisted of focussing attention on those areas already under smallholder cultivation and, for reasons of practical logistics, which also afforded easy access to existing road communications. Although piecemeal information had been slowly gathered on cultivated areas through the agricultural extension programme of the Project Development Unit (PDU), for selected districts this proved to be less than adequate for planning purposes as it was impossible to obtain an overall view over very large areas at one time. It was envisaged that these shortcomings, and the requirement for a simple land use survey for each district of special interest, could only be overcome by using aerial reconnaissance survey methods.

The deficiency in existing map and aerial photographic coverage of the Southern Region, as previously outlined, resulted in two options being available to the Land Use and Physical Planning Unit with respect to aerial reconnaissance. Either a totally new programme of small scale aerial photography had to be commissioned over the areas of interest within the Southern Region, at considerable expense, or use could be made of the recently acquired Landsat satellite data, which covered the agricultural development planning districts, and was available for different seasons throughout specific years. The use of a light aircraft and personal observation was ruled out as a way of producing land use maps, due to the high cost of hiring aircraft, the lack of accurate topographic maps, difficulties of accurate location and area measurement, and the lack of available skilled manpower.

Although some provision was made to commission new aerial photography in specific sites of common interest, the overall expense to fly new photography for all of the districts within the Southern Region, and interpret the data for the provision of land use maps was too high with respect to restricted available budgets. The most cost-effective option was, therefore, to produce the required land use maps through interpreting the Landsat data on the basis of adapting previously developed methodologies specially designed for use with satellite imagery and developing countries (Lock and van Genderen 1978, Anderson, Hardy and Roach 1972).

The basic consideration in devising a suitable land use classification, for the simple mapping of the agricultural development districts in the Southern Region of the Sudan, was to distinguish those areas already under smallholder cultivation, and settled by significant numbers of people, where extension services and development could be concentrated, to improve agronomic practice and increase overall food supplies. In addition to knowing the extent of the cultivated areas, it was also necessary to be aware of the nature and

intensity of the cultivation, as this would be related to the density of settlement, food requirements, and socio-economic factors influencing that particular region. As the other major utilisation of the land, besides subsistence agriculture, is the widespread practice of rearing and keeping herds of cattle, a comparable emphasis was placed on the classification of the use of the rangelands which occur widely throughout the northern agricultural districts.

After establishing that the required land use maps should emphasise agricultural cultivated lands and rangelands the following system of classification was adapted:-

1. Agricultural lands

    1.1 Lands cultivated under natural rainfall

        1.1.A Intensive settlement: frequently 50% or more of land area under cultivation including fallow
        1.1.B Medium settlement: frequently 25-50% of land area under cultivation including fallow
        1.1.C Scattered settlement: usually a maximum of 25% of land area under cultivation including fallow
        1.1.D Settlement with large scale mechanised farming

    1.2 Irrigated lands

        1.2.A Large scale mechanical irrigation
        1.2.B Small scale traditional irrigation

2. Rangelands

    2A Dry season, high intensity grazing
    2B Intermediate and dry season low intensity grazing
    2C Wet season high intensity grazing
    2D All year round high intensity grazing

3. Wetlands

    3A Lakes and permanent open water
    3B Permanent swamp

4. Woodlands

    4A Productive (mainly teak) forest reserves
    4B Non productive forest reserves
    4C Forestry extraction areas
    4D Natural woodland with hunting and gathering only
        4D.i Gallery rainforest
        4D.ii Secondary forest

5. Wildlife reserves

    5A National Parks
    5B Game Reserves

6. Miscellaneous

It will be seen from the above that an initial distinction was made in the classification of cultivated lands between areas supported by natural rainfall and those dependent upon irrigation for the supply of water. On inspecting the most widespread areas supported by natural rainfall, where subsistence agriculture was carried out, it was agreed that the classification should attempt to differentiate the different levels of cultivation intensity, as this would also be related to an associated level of settlement. After an evaluation of available agricultural farm management statistics, and referring to previous studies within the region (Anon 1954, Watson 1977), a decision was made to differentiate intensive cultivation and associated settlement, where frequently 50% or more of the land area was under subsistence agriculture. Medium and scattered categories of cultivation and associated settlement were further defined, where frequently 25-50%, and usually a maximum of 25%, of the land area was respectively under subsistence agriculture. Frequently this classification had to be modified with respect to the district in question, for as in the case of Mundri agricultural development district, the interpretation of Landsat data only enabled a distinction to be made between those areas under cultivation and settlement, and those that were not. The distinction between intensive, medium, and scattered cultivation and settlement, was based in the interpretation process on an arbitrary judgement, and not precise measurement or statistical basis, and as such, was only intended to provide a guide and initial assessment as to intensity of land use. In the longer term however, these mapping units would be able to be refined, and adjusted in light of more comprehensive field data, and available agricultural statistics from farm management surveys.

In those districts such as Gogrial, Tonj and Rumbek where large areas of both Flood Region grasslands and Ironstone Plateau were included within the administrative boundary, the agricultural land use units frequently overlapped with those defining different types of rangeland. This was most evident in the Flood Region, where areas of intensive settlement, isolated above the floodwater in the wet season also become centres for intensive cattle grazing. Similarly, many of the intermediate flooded areas support medium settlement and cultivation, besides low intensity grazing in the dry season. To overcome this problem of overlapping of range and cultivated land use units, a numbering system was given to each land use category, so that the different utilisation of the land could be shown by using the relevant numbers within the boundaries where units combine.

Frequently the numbering system was used to show multiple land usage where it was impossible to distinguish separate categories of use, as for example, where two distinct units merge without a clear boundary being evident, and where the Landsat imagery similarly did not enable such clear differences to be discriminated. Wherever a clear relationship of multiple land use could be established, as for example with intensive settlement and dry season grazing, it was possible to combine the respective symbols, in this case large dots and vertical lines, in order to show the relationship and its distribution on the final map.

As all of the interpretation studies were undertaken in Juba, the preparation of land use maps was dependent on utilising the standard 1:250,000 scale, colour composite and black-and-white, band 5 and 7 imagery, available within the Land Use and Physical Planning Unit, by means of simple manual interpretation aided by a hand lens and basic drawing office facilities. No use was made of computer processing or enhanced image products, and the final maps were limited to preliminary drawing office sheets for each district, which could be copied by available dyeline processing. Except for the initial acquisition of the image products, which could not be produced in the Sudan, the most simple methodology was adapted to match the facilities and local conditions anticipated

to prevail within the Southern Region in the near future. In this way government officials could reasonably expect, with a minimum of training and experience, to enable to continue with similar studies themselves on completion of the programme. The use of such a basic methodology was also appropriate in that it involved the minimum of cost.

Field checking of ground conditions and the final interpreted maps is important in any land use or similar natural resource investigation. In the Southern Region however, a comprehensive field checking programme was difficult to carry out, due to the inaccessibility of most areas; immense problems of supply and logistics; inadequacy of topographic base maps; and most important of all, the constraints of available time. As these factors collectively created a substantial obstacle to undertaking a scientifically viable investigation, to check the reliability and accuracy of the land use interpretation made from the Landsat data in the time available, a compromise had to be achieved, whereby for practical purposes, the field checking element of the methodology could be short circuited or continued within the longer term objectives of the overall agricultural development planning programme.

In order to achieve a respectable degree of field checking, to substantiate the reliability and accuracy of the land use maps interpreted from the Landsat data, a compromise was attained, whereby information collected in previous and ongoing extension and farm management statistical surveys, was utilised in conjunction with limited field sampling and aerial reconnaissance. The latter proved to be particularly useful and cost effective in that the chartered light aircraft, hired to fulfil other requirements within the overall agricultural development programme, became available at various times for survey use. Interpreters were therefore able to check their land use maps in a short space of time over very large areas, by aerial observation from only a few hundred feet off the ground surface.

Most of the cost of the flying programme was absorbed by the logistical requirements of the overall project, as the survey reconnaissance only helped to make fuller use of available aircraft time. The advantages of aerial observation over large areas, and the rapidity of coverage throughout substantial regions of inaccessible terrain, largely compensated for the lack of detailed ground checking. It was also agreed that the land use maps, prepared from interpreting the Landsat data, were needed to fulfil an information gap basic to immediate agricultural development planning activities. However, within the time span of project implementation and attaining development objectives there would be considerable scope to refine the map series, in light of the continual provision of field, air survey and associated resource data. Consequently, for each district, the Landsat, land use interpretation methodology was only deployed to provide a reliable working base, upon which more detailed studies could be later implemented at larger scales, and in conjunction with soil survey and other ground investigations.

The majority of the interpretation was undertaken using the colour composite imagery, whose greater range of colour signatures provided the most information on vegetation, soils and land utilisation. In most areas however, it proved useful to check the preliminary interpretation for specific details with the black-and-white, red, band 5 and infra-red, band 7 imagery, as it was found that the predominance of different colours can often distract the eye from subtle and often significant features. Experience gained in the base map preparation studies, through a sound knowledge of the image data and its record of field conditions and relationships, also greatly assisted the second phase, land use interpretation programme, with a consequent improvement in speed and accuracy of map production.

The basic methodology for land use investigations was similar to that previously used for base map preparation, in that once the district boundaries were defined, different land use categories were interpreted, and plotted at the 1:250,000 scale, by means of different coloured grease pencil, onto a clear film overlay. Initial emphasis was placed on distinguishing cultivated agricultural lands, followed by different categories of rangeland utilisation, wetlands and other relevant features such as rock outcrops etc. Information on gazetted forest and wildlife reserves was later added by reference to official and other local sources of statistics. On completing the draft interpretation of the various land use categories, and checking against field and other sources of relevant information, the different overlay boundaries were transferred in the drawing office onto a permatrace base.

The preliminary map was then drafted by standard cartographic practice, whereby using a selection of hand drawn shadings and symbols in black ink, produced by different sizes of pen, the separate classes of land use were clearly presented. In the cartographic scheme of presentation, emphasis was placed on the categories of agricultural lands, so that this most important feature would be most clearly shown, and immediately identifiable. Similarly, cartographic distinctions were made so that each group of land use categories would be readily apparent, with agricultural lands being portrayed by dot symbols, rangelands by line drawing, and other smaller categories by suitable symbols.

After verification of the land use categories, in as much detail as possible, and the addition of the gazetted forest and wildlife reserves from official Government Ministry sources, the final stage of map production involved standardising on an appropriate legend and map sheet format for each district, and the drawing of the final master sheet on material from which dyeline copies could be produced. Essential base map details on major drainage and communications, settlements etc., were further added to the master sheet in different coloured inks. This was achieved by simply overlaying the respective maps and tracing off relevant features where it was possible without creating too much confusing detail and detracting from the cartographic presentation.

As with the base maps, paper copies of the land use sheets were distributed to agricultural extension officers, and other workers employed in the rural areas, so that they could be immediately put to use, and feedback information could be acquired by the Land Use and Physical Planning Unit, as a basis for future map revisions. In most districts however, these preliminary land use maps, interpreted from Landsat data, provided the only indication of the extent of those areas under cultivation, and as such, established a useful basic reference for evaluating existing farm management and agricultural statistics, acquiring new information, and planning overall development within the smallholder cultivated areas.

4. Conclusions

The strategy for advancement of the Southern Region, west of the River Nile, appears to lie in progressive development of key projects for water control, either through regulation of flooding or irrigation, combined with continuing improvements to the peasant shifting cultivation of the Plateau areas and cattle enterprises within the Flood Region. Sound, coordinated planning required to make a judicious mix of the elements of this dual strategy will have to be based on more information than exists at present especially in respect of obtaining a fuller understanding of the physical and human resources available within the region.

In the current, aid financed rehabilitation programme concerned with district agricultural development planning it has been demonstrated that many of the problems affecting the acquisition of relevant information over large, remote areas, can be overcome in a relatively short period of time by making maximum use of Landsat satellite data. Additional benefits have also included the training of counterpart staff in the use and interpretation of satellite imagery for which a special manual has been prepared to meet local needs and conditions (Beaumont 1982). In view of the successful application of Landsat imagery on this project, and the likely availability of improved data from future satellites, recommendations have been put forward that the utilisation of satellite and other remote sensing imagery should be given a key role in the administrative structure evolved to progress agriculture and regional development planning in the Southern Sudan.

5. Acknowledgements

Grateful acknowledgement is made to Booker Agriculture International Limited, Overseas Development Administration of the British Government, and the Land Use and Physical Planning Unit of the Southern Regional Ministry of Agriculture and Natural Resources, Government of Sudan who gave permission to use the data presented in this paper.

6. References

Anderson, J.R., Hardy, E.E. and Roach, J.T., 1972. "A land use classification system for use with remote sensor data", U.S. Geological Survey, Circular 671, Washington, D.C., 16pp.

Anon. (Southern Development Investigation Team). 1954. "Natural resources and development potential in the Southern provinces of the Sudan", Ministry of Finance, Development Committee, Sudan Government, Khartoum, Vol 1 262p, Vol 2 maps.

Beaumont, T.E., 1982. "A manual for the use of Landsat satellite imagery for district agricultural development planning in the Southern Region of the Sudan", Land Use and Physical Planning Unit, Southern Regional Ministry of Agriculture and Natural Resources, Sudan Government, Juba, 111p.

Beaumont, T.E., 1983. "Satellite data as a basis for planning studies of infrastructure and related rural development in Atacora Province, Benin, West Africa", in Study of Land Transformation Processes from Space and Ground Observations : Proc. Symposium 10 of COSPAR 24th Plenary Meeting (Ottawa), Ed by Ragan, R.M. and Wolman, G., Advances in Space Research 2 (8) 91-96, Pergammon Press, Oxford.

Lock, B.F. and van Genderen, J.L., 1978. "A methodology for employing Landsat data for rural land use surveys in developing countries", Journal of the British Interplanetary Society, 31, 293-304.

Vass, P.A., 1983. "A Landsat study of the vegetation and seasonal livestock grazing in the Southern Sudan", in Remote Sensing for Rangeland Monitoring and Management, Proc. 11th Annual Conference of Remote Sensing Society, (Silsoe), Remote Sensing Society, University of Reading, 51-68.

Watson R.M., 1977. "Sudan national livestock census and resources inventory", Sudan Veterinary Research Administration, Ministry of Agriculture, Food and Natural Resources, Government of Sudan, Khartoum.