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APPLICATIONS OF REMOTE SENSING (ERTS) TO RESOURCE MANAGEMENT AND DEVELOPMENT IN SAHELIEAN AFRICA (REPUBLIC OF MALI)

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ABSTRACT

The primary resource management problem in Sub-Saharan Africa (the Sahel) is increasing aridity or desertification. Space observations of sand streams, dune orientations, moisture and vegetation changes and other factors associated with desertification have been made. It is not yet known whether the process is caused by human activities or climatic changes or both.

A second major interest is grazing of cattle, sheep and goats which is associated with major movements of people and animals twice yearly to obtain forage -- from the savannah in fall and winter, and from huge areas of marsh (the Inland Delta) in spring and summer. These movements (transhumance) pass through more settled cultivators and into regions occupied by fishermen. The changes in available forage are being observed. The location of the cultivators is also being mapped from ERTS imagery -- for the first time. Field burning after rains is widely practiced and has been observed and the extent measured in ERTS imagery. In some areas of Mali, this measurement is an estimate of area to be planted to grain in the next season -- an unmeasured parameter heretofore.

Hydrological analysis is being carried on in the Niger and Bani River watersheds. The size, timing and areal extent of the annual flood is of particular interest. So far, good imagery of the maximum flood stage has been obtained and assessed.

Geologic information on fault zones, sand dune formations, scarps, tectonic basins and focal points of faulting (points from which fractures appear to radiate) are all visible and heretofore mapped inaccurately or not at all. The information on possible areas in which

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mineralization has occurred are being mapped and noted for Malien officials carrying on their own ERTS investigations.

At the present time, the countries in the semi-arid zone of West Africa -- the Sahelien Zone -- are faced not only with the problems of economic development, but also with ecologic deterioration which they perceive to be a major and rapidly intensifying hazard.

The Republic of Mali in West Africa has recognized the problems of economic development and has also recognized that the data base of fund of knowledge concerning their natural resources is very meager. Maliens also recognize that the productive potential of the Sahelien Zone may bring their economy to a position of a major grain and live-stock producer if they can control desertification and combine hydro-logic and agronomic resources. They also recognize that their entry into world markets will be hastened by the discovery and development of mineral ores, energy sources (including geothermal), ground for crop and livestock production, water, and petroleum resources. Further, they realize their technical services, though staffed with able people, are inadequate for the performance of the necessary miracles.

Mr. Mamadou Konate, Director, Geological and Mining Services of Mali, in conjunction with U.S. AID, USGS and NASA technicians and members of the Malien technical services, is Principal Investigator of an ERTS-1 investigation through which the government of Mali (GOM) hopes to establish the necessary data base or resource inventory for long-range development planning in geology, hydrology, forestry, agriculture and grassland management. (I am speaking today both as a co-investigator in the GOM study and as a Principal Investigator for the U.S. "counterpart" ERTS investigation -- UN431). I have just returned from Mali, and I have the following report on our progress in analysis of the ERTS-1 imagery in relation to Malien development goals.

First, progress is being made in developing a detailed geologic map of the country (Figure 1). Overlays of geologic features drawn from the imagery of the Gao region are compared with recent maps drawn from French field studies. The major additions from the ERTS imagery are fault lines; more specific delineation of sand fields; and mapping of sedimentary pediments in the area. The Niger River, in this and other areas, follows lineaments apparently controlled by these. The Gao graben (a downfaulted block) is a feature of major interest because of its potential as a petroleum or water source. The western boundary of the graben has now been quite precisely mapped from the space imagery.

In the next sets of figures of the southern Inland Delta of the Niger River -- a tectonic basin (Figure 2), and the frame to the west, which contains a major irrigation scheme installed by the French (also

a tectonic basin), and the so-called Delta Mort or Dead Delta -- we can point out some major advances in understanding of the hydrologic and vegetation regimes. We find that the Niger and Bani Rivers follow courses which are similar in orientation to the major lineaments -- possibly fractures found throughout southern Mali. These lineaments have been described in the Bandiagara Highland to the east, but not in the lowlands. We had thought the arrow-shaped, light-colored structures were dunes. They have been mapped as such -- dunes which are thought to be several thousand years old. An aerial reconnaissance, coupled with a ground observation at Mopti (located at the arrow in Figure 2), showed these were barren flats -- actually laterite covered by less than a meter of sand. These flats are cultivated in some villages. They are flooded each year and are thus supplied with water. Millet, rice, and cotton are the major local crops. The presence of the lineaments has an interesting relationship to ground water supplies in the region -- a resource which the Malians wish to develop for livestock production. In years of below-normal precipitation, the flow of water out of the Inland Delta is greater than can be accounted for by precipitation alone. The excess outflow must come from ground water. The question is where is that reservoir of ground water? We feel that the fractures may be either the reservoirs themselves, or that they act as channels for the aquifers supplying the extra outflow. These hypotheses can be rather inexpensively tested by drilling into the lineaments.

The Niger River floods each year as it carries off the precipitations associated with the north and south advance and retreat of the Intertropical Convergence (ITC) each summer. The flood crest takes about six months to flow downstream. On 22 September 1972, the date of this image, the flood crest was in the southern Inland Delta, shown here, and thus its aerial extent can be measured from this image. This is an important measurement for nomadic animal husbandrymen who bring their cattle into the Delta each year to forage, for the Bozo fishermen who harvest 50,000 tons of fish from the Niger each year, and, of course, for the cultivators in the Delta.

The question of desertification can also be examined in this image. The soil is sandy in most of the area, but one would like to examine what appear as deposits of dunes or regions of sand to determine the mode and time of their origin. One particularly intriguing area is that between the Niger and Bani Rivers where an unwatered river channel can be seen. There is no vegetation or water in the channel -- it is not a wadi or channel for an ephemeral river, for it would be watered at this time of peak runoff if it were. No one knows the answers, but the stream was not previously mapped. Is there no water because of increased aridity, or has the watershed been captured by the Bani or Niger Rivers? Why is there no vegetation? The discovery of the existence of this and other such unwatered drainage systems in southern Mali pose major hydrologic problems worthy of much further study.

In the northwest corner of the image, one can see a cuspid pattern of tones. This is an area of range for the Peul, a cattle-owning people. The different tones are caused by differences in the type of vegetative cover -- the darker tones correlating with scattered trees and shrubs, the lighter with open grassland. Color additive techniques can be used on successive images to determine the changes in available forage during the rain-free season and the zones of highest productivity.

In Figure 3 the irrigation scheme, Office du Niger, is a prominent feature. By digital analysis we have mapped the pattern of irrigation channels, irrigated fields, and the adjacent cultivator fields. We have also mapped temporal changes in vegetative cover and soil moisture in the region.

Surface runoff patterns are peculiar in the region west of the irrigation scheme. In the imagery we find some areas devoid of surface drainage-ways. Aerial reconnaissance showed us that this is indeed the case. We feel that soils are very porous in the area and that there is some hope of finding aquifers shallow enough to be developed for livestock water-points so that the range may be better utilized by nomadic cattlemen.

We were particularly pleased to find the lineaments trending northeast and northwest from the northern part of the Office du Niger. By bringing together our data resources, we found that the northwest lineament (which has a water-formed channel in it) leads to a large circular depression -- the Hodh -- on the Mali-Mauretanian border. In 1964 the depression was so filled with water that it became a lake -- even now there is surface water detectable in the imagery. However, no one knew the source of the lake water -- it was a "gift of God." So it was, but we have found the channel -- that to the northwest of the Office du Niger. It can be filled using existing structures by controlling water flow into the Office du Niger from the Niger River during the Niger flood.

A dry-bed stream channel is located in the west-central portion of the image. Obviously, a large flow of water was required to form the channel, which continues northward to the Hodh and beyond. In the Hodh region of the channel is more than two miles wide and is located in the Sahara Desert itself. Further studies must be carried on; but the stream beds, the lake bed, and the lineaments make an intriguing combination for one interested in mapping and developing surface and ground water resources in that region.

All of the Mali images are full of interest for many disciplines. We have not fully addressed the question of desertification, but the ability to map sand from the imagery has been demonstrated. We also are able to map much of the vegetation of Mali to set a baseline condition for further development of extensive, intensive, and irrigated

agriculture.

There are still fascinating questions remaining concerning the lineaments, some of which control the course of the Niger, the Bani, the shape of the Delta and the Office du Niger, and relationship of the lineament to the former drainage channels. The answers can be sought now that a data base is becoming available to reveal the nature of the land surface.

While these comments merely brush lightly over the concerns of development, merely stating some of the discoveries without fully considering their implications for improvement and without conveying all that has been done in analysis, one may surmise that at least the inventory of resources has begun. Just this beginning has already affected the planning processes of the Malien government and of aid-donor agencies. We are also acquiring an appreciation of the dynamics of the cultivator-nomad relationships, the climate and land-use, and a more quantitative approach to the desertification problem.

A further immediate outcome is the emerging understanding by all participants in the project -- Malien and U.S. -- of the regional nature of problems confronting Malians in evolving a new kind of economy and the interwoven fabric of her natural resources -- geologic, hydrologic, biotic, and human -- that can be mustered for the development.

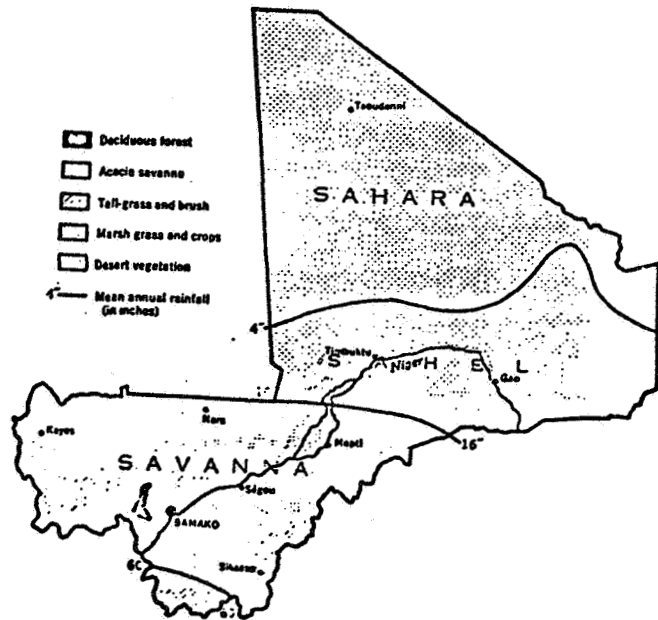


Figure 1 Republic of Mali

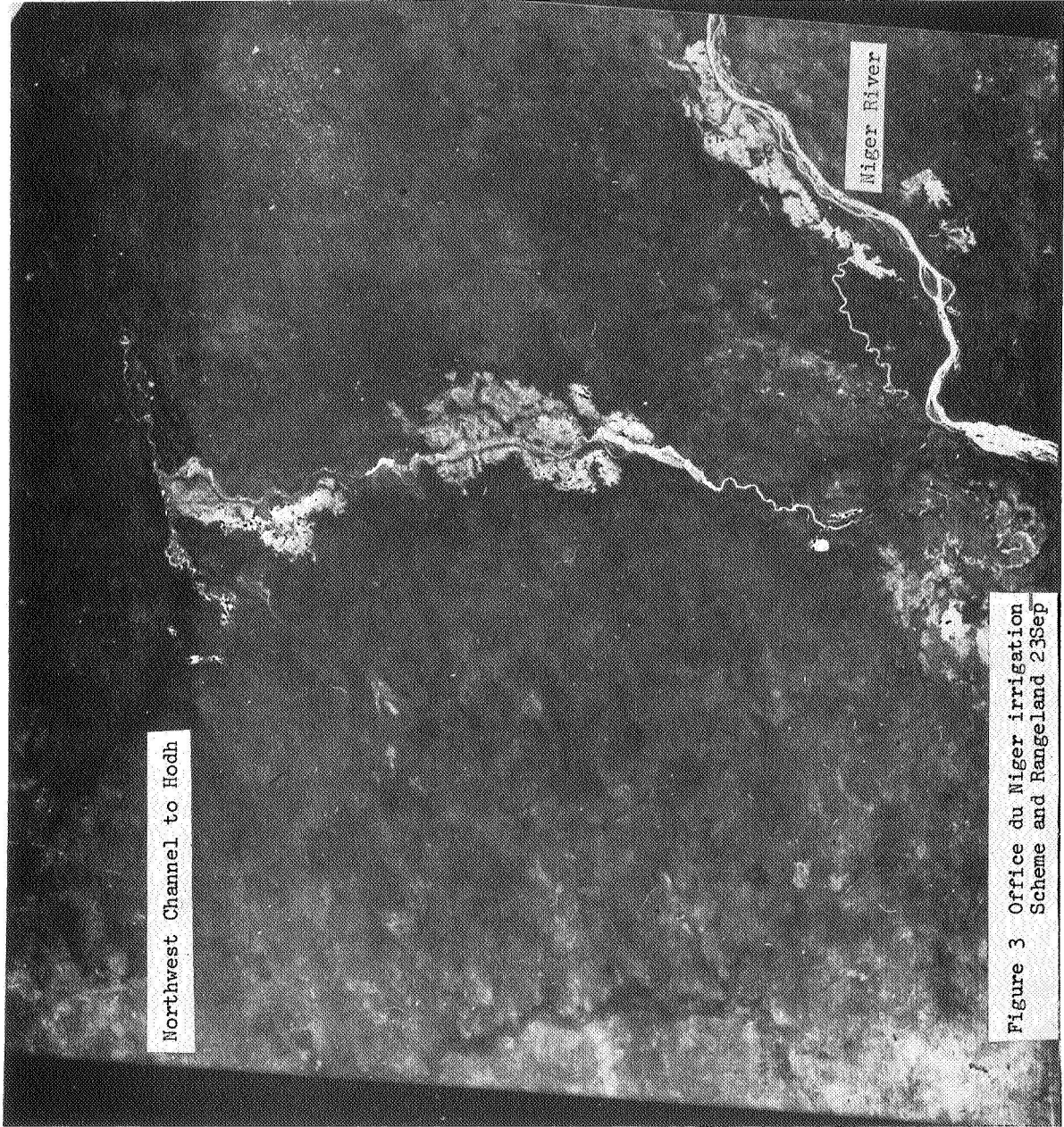


Figure 3 Office du Niger irrigation Scheme and Rangeland 23Sep

