REMOTE SENSING AND FIELD STUDY OF DROUGHT-RELATED CHANGES IN THE INLAND NIGER DELTA OF MALI

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ABSTRACT

Remote sensing and field mapping of a portion of the upper Inland Niger Delta indicate that the Sahelian drought years 1968-1985 have had a significant effect on the soils and morphologic processes of the region. Changes include a decrease in the surface area of lakes, ponds and swamps mapped as permanent water bodies in the 1950's. Analysis of Landsat data and 1985 field work also confirmed the desiccation of channels distributary to the main rivers in the region, the Bani and the Niger. Some distributary channels have been abandoned, and both the Niger and Bani Rivers presently are underfit. Sapping was observed in the soils of the combined Niger-Bani floodplain and fluvial erosion has been invigorated. Widespread reactivation of previously stabilized linear dunes has occurred, and modern dunes and sand stringers are evident over portions of the field area.

1. INTRODUCTION

The upper Inland Niger Delta of Mali is characterized by a complex of anastomosing distributary channels formed on the broad, joint flood plain of the Niger and Bani Rivers. Duneforms and aeolian transport of sediments derived from the local fluvial system are widespread. The region represents a complex interaction between fluvial and aeolian processes.

The lack of rainfall in the Sahel since the onset of drought in 1968 has resulted in observable damage to both vegetation and soils in the

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area, with a corresponding dramatic increase in soil erosion. Although the unique water resources of the Niger River have helped to buffer the Inland Niger Delta against the Sahelian drought, the continued lack of rainfall has resulted in changes to the morphology and soils of the area. As a means of addressing the complex changes to the morphologic processes of the region as a result of the Sahelian drought, multitemporal digital Landsat MSS data were analyzed and used as a base for mapping the landforms and soils of the upper Inland Niger Delta (Fig. 1). This was followed by field mapping and sampling to provide a basis for assessing contemporary changes in the field area.

2. PREVIOUS STUDIES

Several authors have provided extensive reviews of prior geomorphologic work in the Sahel. A thorough discussion of Quaternary studies pre-1968 is provided by Grove and Warren (1968), while Talbot (1980) provides an extensive synthesis of studies of Quaternary Sahelian paleoclimate through 1980. More recently, a summary review of work on the morphology and climatic history of the sub-Saharan West Africa and the Inland Niger Delta specifically was published by McIntosh (1983).

The role of albedo in relation to desertification and/or surface changes was suggested by Otterman (1974, 1977) and has been discussed by other authors (Charney, 1975; Charney and others, 1977; Ellsaesser and others, 1976). A number of authors have used remote sensing data to determine albedo and albedo change (Otterman, 1977; Byrne and others, 1980; and Richardson, 1984).

Otterman (1977) calculated surface reflectance from Landsat MSS data using an atmospheric correction developed in earlier work (Otterman and Fraser, 1976). He determined a 13% albedo reduction within a fenced exclosure in the northern Sinai. Robinove and others (1981) calculated albedos in co-registered multitemporal Landsat data and assessed changes from the differences between images. An extension of the use of multitemporal data is developed both in Byrne and others (1980) and Richards (1984). In these papers, albedo changes are detected through the use of a principal components transformation of co-registered scenes. Courel and Habif (1983) applied similar albedo calculations to assess and classify surface cover changes between 1972 and 1979 for a region in northwest Senegal.

3. METHOD OF INVESTIGATION

The study consisted of field mapping, sampling, and analysis of Landsat images in digital format and acquired on February 7, 1976 and August 6, 1984 and February 14, 1985 (Landsat MSS I.D.'s 8238109564500, 85015810073X0 and 85035010082X0 respectively). The latest image was coincidental with field work in the area. Statistical analysis of two earlier scenes was performed in conjunction with visual interpretation and preliminary mapping. This was followed by five weeks of field study including morphologic mapping, sampling of major surface units, and field checking of landforms and changes observed in the remote sensing data. All remote sensing data were geometrically corrected and coregistered with to facilitate direct comparisons among scenes. In addition, a nominal atmospheric correction was made through the use of village control areas. In the field, the central areas of villages were observed to contain little or no vegetation. These areas were presumed to show minimum change in color and brightness through time. Observed changes in brightness to these areas in satellite data were presumed to indicate uniform atmospheric conditions rather than ground conditions. Excess brightness then was subtracted from the Landsat data, thus facilitating direct comparisons in areas of apparent surface change.

Following geometric and atmospheric correction of data, albedo images were constructed based on the corrected digital data for each Landsat scene of the field area, after the method of Robinove and others (1981). These estimates are scaled so that image brightness represents surface albedo, and the differences between images calculated from separate Landsat scenes indicate albedo change over time (Fig. 2).

A five-week field investigation of the study area was conducted during January and February, 1985, during which a network of foot and vehicle traverses were taken over the study area. The purpose of the field work was to document soil and vegetation associations and to verify map units and interpretations based on the remotely-sensed information. Representative samples were obtained for major surface units and estimates were taken of the density as well as type of vegetative cover. The condition of surface materials (disturbed or undisturbed) also was noted. Where active erosional processes were observed, an attempt was made to document the dominant agent (wind, water or both), and to estimate the areal extent and severity of the erosion.

4. RESULTS AND DISCUSSION

Albedo changes calculated between February, 1976 and February, 1985 indicate localized albedo increase over portions of the study area. In the field, areas with these high albedo increases were observed to have less than 10% vegetation cover and strongly disrupted soils with surface degradation and lowered cohesion. These areas showed active aeolian transport of sand and soil. Remobilized dune crests showed similar disruption and disaggregation. A correlation was found in the field between landforms and soil type, and the severity of damage and percent albedo change. Levee deposits consistently exhibited the strongest changes, followed by aeolian landforms. The most dramatic changes in albedo over the 10 year interval studied consisted of areas formerly occupied by permanent water bodies but now occupied by water only during the rainy season. During field visits in 1985 these areas were completely dry. Nearby, evidence of recent sapping, possibly related to ground water withdrawal, was observed along with surface disruption, soil disaggregation and vegetation destruction. Levee deposits, noted before as exhibiting among the highest albedo changes through time, were observed in the field to be dessicated and to have strongly disrupted, trampled surfaces with mechanically disaggregated soils. Aeolian features showed less net albedo change, although damaged aeolian areas representing remobilized crests of formerly stable linear dunes showed a moderate increase in redness, and sand encroachment was observed in the northwestern portion of the field area (northwest of Jenne).

The satellite data also show that the Bani and Niger Rivers have become more turbit which is consistent with a calculated increase in sediment yield from local devegetated and destabilized areas. The combination of these effects is one of reinvigoration of both aeolian and fluvial erosion processes within the region as a function of decreasing soil moisture and protective vegetation cover. Reduced stream flows during the drought years have resulted in the lowering of sediment transport competence of the Niger and Bani Rivers, with resulting deposition of sediment in the numerous bars and beaches observed along the Niger in 1985 Landsat data.

Between 1976 and 1985, bright aureoles were observed to have developed around villages in the field area. These bright halos represent areas of bare soil, with essentially no vegetation. These areas were constricted and well-defined in 1976 Landsat data, but are expanded and diffuse in data for 1985. They are typically on the order of a kilometer in radius; in some parts of the delta, individual bright halos have coalesced into broad irregular regions of disrupted and devegetated soils (Fig. 3).

In conclusion, satellite data of the upper Inland Niger Delta of Mali show significant changes to surface color and albedo between 1976 and 1985. Albedo changes greater than 15% were observed for specific landforms in the region and may be separated from increases due to atmospheric parameters. An increase in atmospheric turbity was observed in the satellite data and a high concentration of atmospheric dust was observed in the field in January 1985. This increase can be related to increased aeolian activity over disaggregated and damaged soils in the study region, which in turn is related to invigoration of fluvial erosion across the region.

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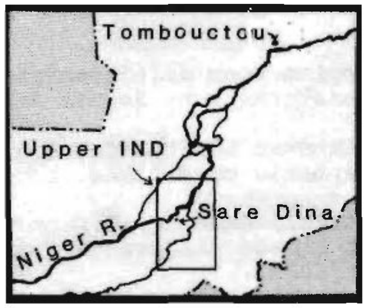

Figure 1. The Inland Niger Delta occupies an area of approximately 120,000 square kilometers of the central Malian Sahel. The region is characterized by a system of anastomosing channels distributary to the Niger River, and extends from Jenne in the south to Tombouctou at the border of the Sahara. The area under consideration in this paper is the upper portion of the Inland Delta as shown.

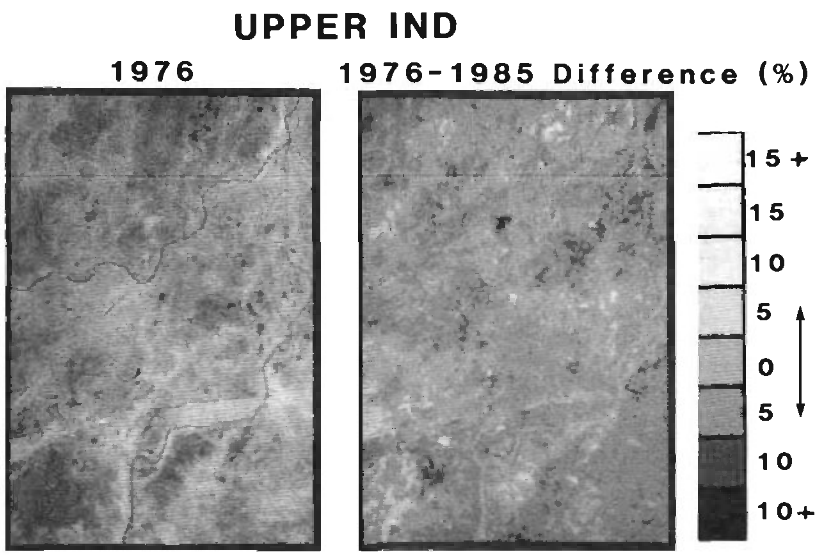

Figure 2. The change in relative brightness calculated from 1976 and 1985 MSS data range from localized areas of decrease (largely associated with c construction of new water impoundments) to areas with greater than 15% net brightness increase. The highest increases are associated with complete or partial desiccation of water bodies. Intermediate increases correlate with soil damage to specific landforms, especially natural levees along the Niger and major distributaries, and with mobilization of dune sands.

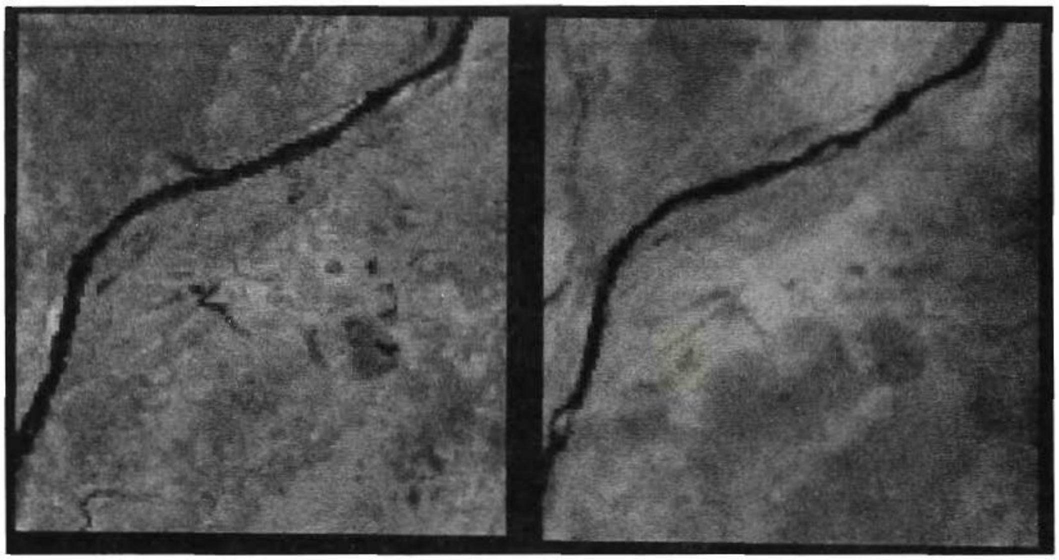

Figure 3. Bright soil halos are characteristic of villages in the study area. These halos are circumscribed and well-defined in 1976 data, as exemplified by the left-hand image of Sare Dina. The corresponding data for 1985 are shown on the right. In this image, the halo has spread and coalesced with other similar areas, leaving a large diffuse region of damaged soils.