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LINKING ARCHIVAL AND REMOTE SENSED DATA FOR LONG TERM ENVIRONMENTAL MONITORING

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Abstract:

The broad objective of this paper is to illustrate how archival/historical and remote sensed data can be used to complement each other for long term environmental monitoring. One of the major constraints confronting scientific investigation in the area of long term environmental monitoring is lack of data at the required temporal and spatial scales. While remote sensed data have provided dependable change detection databases since 1972, long term changes such as those associated with typical climate scenarios often require longer time series data. The non-availability of data in readily accessible/usable formats for periods predating the conventional satellite data traditionally accessible to the public has for a long time restricted the scope of environmental studies to synoptic overviews covering short time scales. As a result, our understanding of different ecosystem processes has been informed by thin data incapable of yielding plausible explanations.

One way to improve our understanding of ecosystem processes is by cross-linking different forms of data at different temporal scales. Unfortunately however, most research work has tended to marginalize the utility of the latter in environmental monitoring. While the accuracy of data from these records is often source-specific, varying from place to place depending on circumstances under which the same data were created, carefully conducted searches can yield useful information that can be effectively used to extend the temporal coverage of projects depending on time series data. Based on an ongoing project on environmental monitoring in the Okavango Delta, which has created a database covering 80 years between 1921 and 2001, the specific objectives of this paper are to: a) outline how modern remote sensed data (Corona and Landsat) can be complemented by historical in-situ observations (Travellers' records and maps) to extend temporal coverage into the historical past; b) illustrate that different forms of post-conflict intelligence data (Corona) can be constructively exploited for the furtherance of scientific understanding; c) provide some useful pointers on the type/s of data potentially recoverable from archival records; and d) provide a framework for a networking arrangement to facilitate the sharing of data at regional and international levels by converting data into electronically transmittable formats.

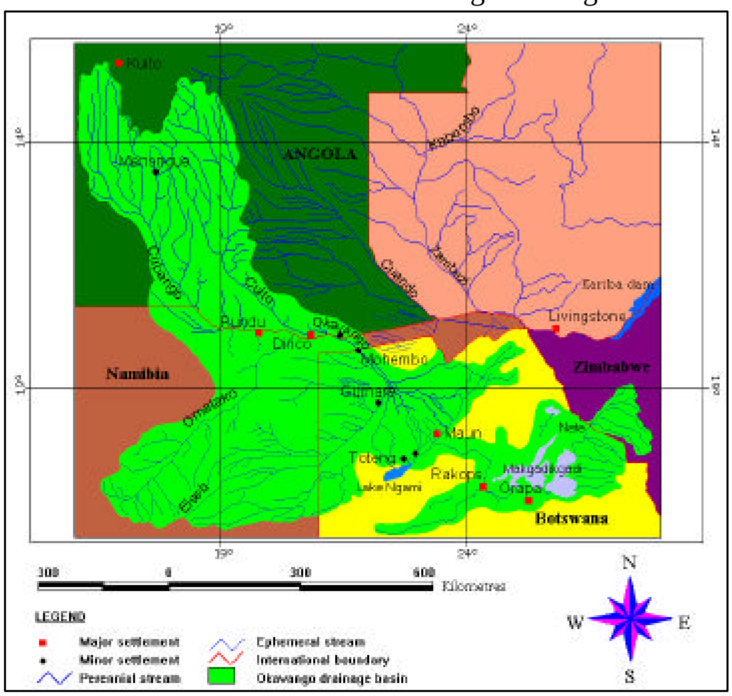
1.0 Introduction

In terms of long-term environmental monitoring, little has to date been done on trend based analysis of environmental changes in the Okavango Delta. Most change detection studies in the area have tended to be of either, *broad spatial focus* without providing detailed analysis of conditions in the Okavango Delta (Tlou 1972; Ringrose, 1997; Shaw, 1985; Hutchins *et al*, 1976; Conservation International, 1999) or *temporally restricted* to snap-shots offering inadequate time series coverage for comprehensive trend analysis, (Gumbricht, and McCarthy, 2000; Eastend Investments, 1997; IUCN, 1992; Sekhwela and Dube, 1991; Potten, 1975; SMEC, 1989; UNDP, 1975). Our understanding of long-term environmental processes thus remains constrained by lack of relevant data at appropriate temporal and spatial scales. In attempting to address these problems, we expanded n over the time horizon into the past by putting together data available in different forms. By selectively drawing on an ongoing project on long term environmental monitoring in the Okavango Delta, we attempt to illustrate how, archival/historical data and records can be put together to create a geo-database capable of extending temporal coverage by several decades into the historical past beyond the normal range offered by conventional satellite data. Our database covers a period of 80 years between 1921 and 2001. Comprising **historical records** by early travelers/explorers and hunters, **archival maps**, declassified United States cold-war intelligence satellite photographs (**Corona**) and the more recent **Landsat** images, this database offers significant opportunities to enhance our understanding of environmental processes.

2.0 The Study Area

Figure 1 shows the geographical location of the Okavango Delta and the extent of its drainage basin. The Okavango Delta is an inland wetland area with an active and nominal catchment area estimated to be 2.65m km^2. The former includes the Panhandle section of the Okavango River, representing the proximal reach of the Delta and stretching from Mohembo (the point where the Okavango enters Botswana) to Seronga. The latter includes immediate fringes of the perennial swamps coinciding with the Delta's nominal catchment area in the west and extended southward to include the distal reaches that represent the terminal extension of this wetland ecosystem whose inundation area varies seasonally.

Fig 1 Geographical Location of the Okavango Delta and Extent of the Okavango Drainage Basin

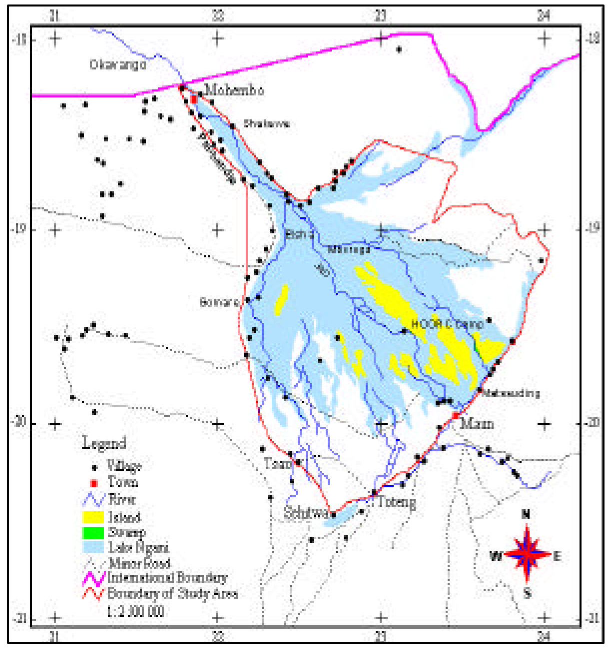


Source: Hamandawana, 2003.

Though ranked as the world's largest Ramsar site (Kabii, 1997), the present size of the Okavango Delta (~10 000km^2) has dwindled from an undetermined size in the past (much in excess of today's seasonally inundated area) as drying sequences have transformed a sizeable proportion into emergent floodplains under different stages of colonization by dry-land vegetation. While recent attempts have been made to monitor variations in water-spread area over time (McCarthy, J 2002; McCarthy, T .S. *et al.,* 2000), these have been constrained by restricted temporal coverage (post 1972 period) due to lack of suitable data at appropriate temporal and spatial scales. Recognizing the importance of time series data over suitable temporal scales, the database offered here provides opportunities for objective reconstruction of environmental trends in the Okavango Delta between 1921 and 2001.

In this study, the Okavango Delta (Fig 2) is defined as comprising the active and fossil sections of this Delta's drainage basin in Botswana**.** On entering Botswana at Mohembo, the Okavango River (the Delta's principal water supply channel) subdivides in fan-like pattern into a maze of channels that flow southward over gentle gradients averaging 0.25m/km between Shakawe and Maun (Hutchins *et al.*, 1976) to inundate at very shallow depths an estimated 10 000 km^2 at the peak of the normal flood season (July-August). The combined effect of low gradient and negligible input of dissolved nutrients makes the Delta a low energy oligotrophic system that is sensitive to changes in nutrient input, the water balance situation and different forms of external perturbation both human and natural (NRP, 2001).

Fig 2 Working Boundary of the Okavango Delta

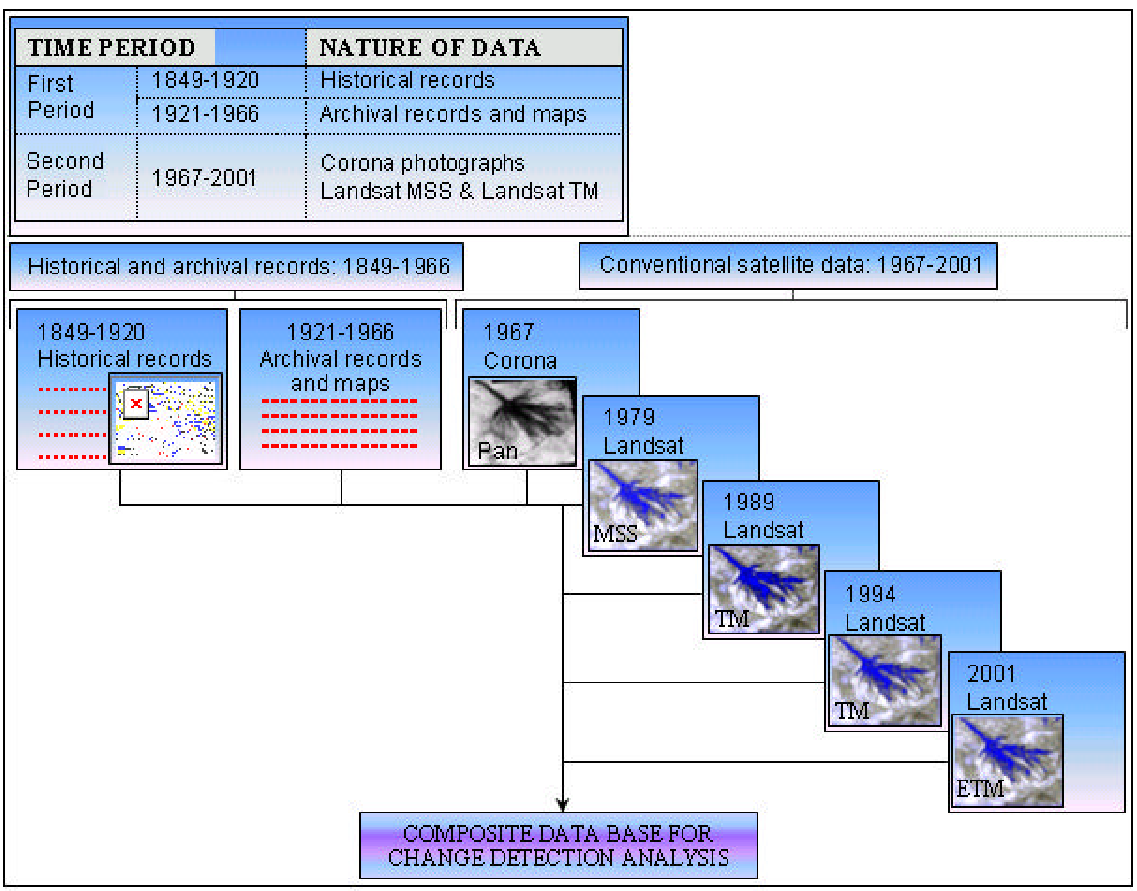


Sediment delivery into the system mainly comprises coarse and fine-grained sand fractions. Though the flood season commences around March in the proximal reaches around Mohembo, gentle gradient delays arrival of the flood-peak in the distal reaches around Maun to between early July and mid August after which it subsides. This cyclic variation on an annual basis drives a flood regime that creates permanent and seasonally flooded areas, which make up the Okavango Delta. Driven by the combined effect of water delivered by the Okavango River with its source in the highlands of southern Angola and recharge from normal rainfall, the Okavango Delta is a unique and fragile ecosystem that is very sensitive to both short and long term variations in water input. Inflow into the Delta via the Okavango River ranges between 7 x $10^9 m^3$ to 15 x $10^9 m^3$, with a 23% coefficient of variation (SMEC, 1989). This inflow contributes more than 90% of the Delta's water supply. Local rainfall, contributes a negligible and variable amount (±10%) with marked fluctuations between wet and dry years. Representing a natural oasis in a semi-arid environment with rainfall averaging 450mm/annum and evapo-transpiration averaging 2172mm (McCarthy and Bloem, 1998) the Delta has been declared an international heritage site. Climatic changes over the recent past have imposed persistent drying sequences that have been fast-forwarded by negative human interference. Evidence from the *recent* past (fossil channels and lakes) indicates progressive desiccation of the entire system with more recent decline in the Delta's water-spread area suggesting deteriorating climatic conditions. Tenuous evidence links this desiccation to several factors among which are; increased evaporation due to changes in solar energy, declining rainfall over the Delta and its immediate hinterland, decreased inflow into the Delta occasioned by declining rainfall in Angola and increased infiltration due to recrudescent tectonic activity (Hutchins *et al.*, 1976:14). Loss of water through infiltration along lines of neo-tectonic activity is strongly felt to be one of the main causes of desiccation (Hutchins *et al.*, 1976) coupled with floodplain emergence induced by sagging of the axial system under progressive sedimentation (Mallick *et al.*, 1981). While the foregoing have become favoured explanations of deteriorating conditions, human interference has increasingly come to be considered one of the major drivers of change (Campbell and Child, 1971; Tlou, 1971; Bendsen and Gelmroth, 1983; SMEC, 1989; Sekhwela and Dube, 1991; IUCN, 1992; Kabii, 1997). Though the above provide theoretically grounded explanations of deteriorating conditions, trend analysis has been constrained by inadequacies in time series data at appropriate temporal scales. By providing a database dating to as early as 1921, the present work offers as alluded to in preceding sections, opportunities for broader and objective reconstruction of environmental scenarios.

3.0 Database Structure

Figure 3 provides a schematic outline of the structural layout of the database that has been compiled for monitoring environmental changes in the Okavango Delta. This database can be collapsed into two main datasets each covering a distinct period. Data for the first period include archival records and maps and geocoded information compiled from historical and colonial records. Conventional remote sensed data (satellite photographs and images) providing blanket coverage for the Delta over five time-slices, constitutes the second data-set. Taking Livingstone's 1849 records as the first data set and the 2001 Landsat images as the last, the data available provide substantial information over several decades. However, because most information available before Stigarnd's archival maps in 1921 is not geocoded in the conventional sense of a GIS system, pre-1921 records are considered as auxiliary to data retrieved from related historical/archival records.

Fig 3 Complementary use of Archival/Historical Records and Satellite Data for Long-term Environmental Monitoring in the Okavango Delta: 1849-2001



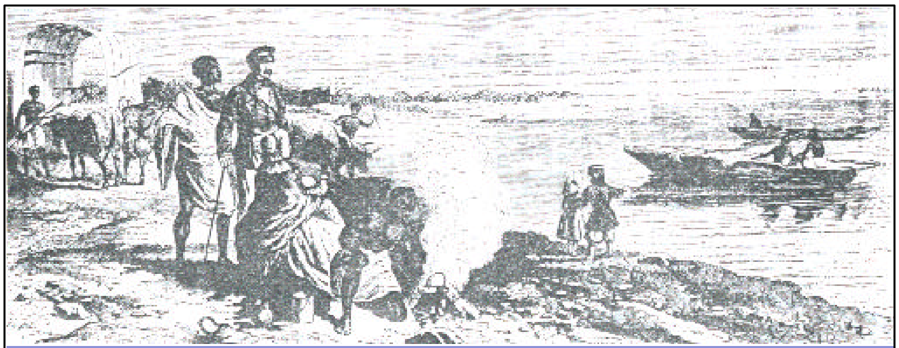
4.0 Historical/Archival Records: 1849-1966

As illustrated in Fig 3, data for this period are subdivided into two sub-periods. This section looks at how historical/archival records can complement the remote sensed data at our disposal by extending the time horizon to periods predating satellite photographs and images. Historical/archival records can be in the form of sketch drawings and archival maps or published and unpublished records by early travelers, hunters, missionaries and explorers.

4.0.1 *Sketch drawings*

Sketch drawings and maps where available provide vital sources of information and can be used to complement conventional satellite data. Drawings such as Fig 4 below can provide useful pointers on general environmental conditions, allowing meaningful inferential analysis.

Fig 4 Sketch Drawing Showing David Livingstone and his Family on the Shores of Lake Ngami in 1849



David Livingstone and his Family at Lake Ngami in 1849. Boats in the extreme right of the drawing confirm the presence of substantial water volumes to some reasonable depth. After Alfred Rider.

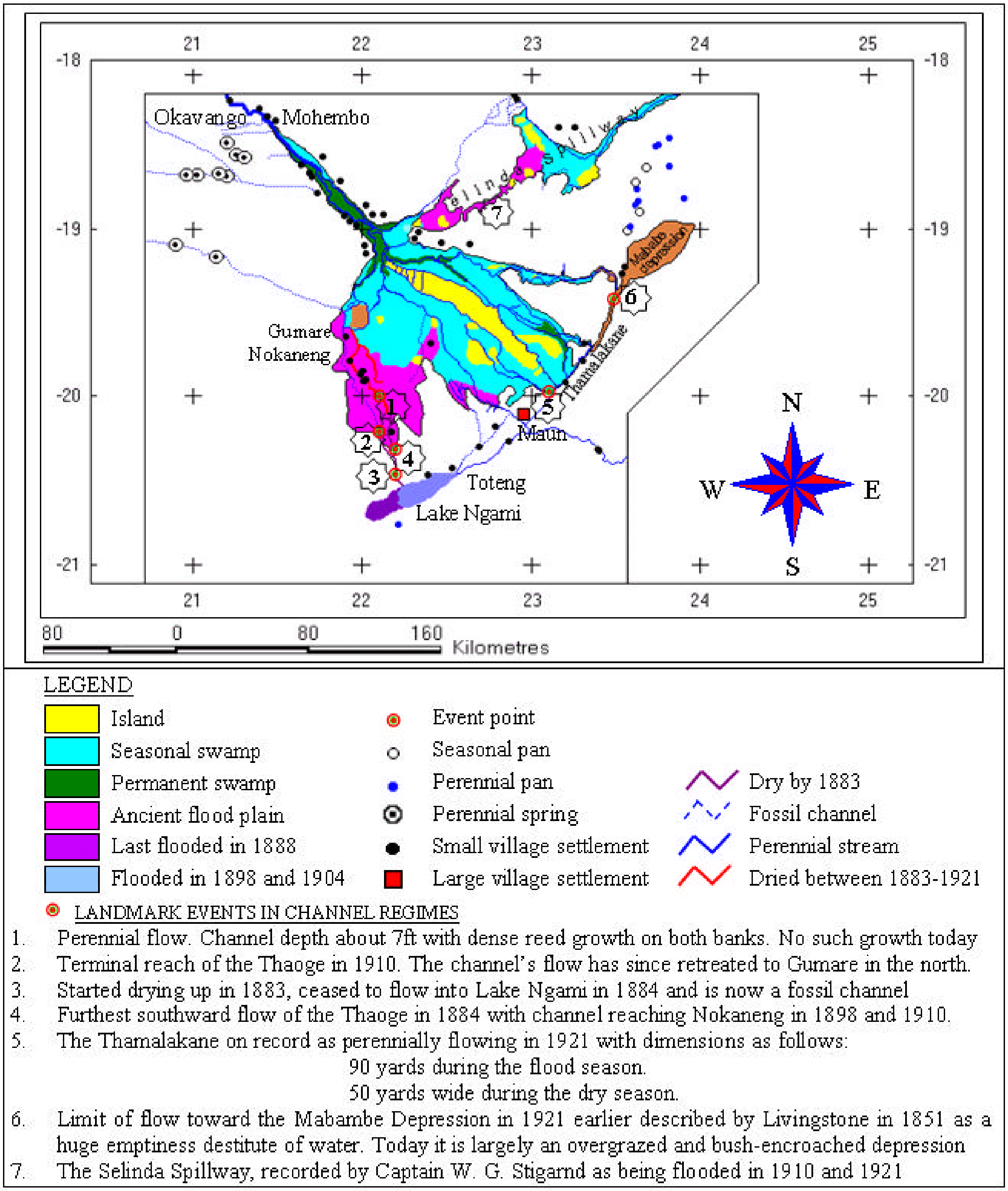
Source: Ransford, 1978.

Used in conjunction with historical information from published and unpublished records, it is quite possible to extend temporal coverage by several decades in terms of data acquisition to periods predating conventional remote sensed data from different platforms. Though information of this nature is mostly qualitative, the same information can be captured in a GIS system to provide spatially referenced datasets. Sub-section 4. 0.2 below provides an example of how historically sourced qualitative information of the nature summarized in Table 1 can be incorporated into a GIS system to provide useful datasets for objective reconstruc tion of trends in environmental conditions.

4.0.2 *Archival Maps: 1921*

Archival maps (Fig 5) often ignored because of the tedious efforts required to capture them in a GIS system provide a readily accessible source of fairly accurate information. The illustration was reconstructed from two maps sourced from the Botswana National archives. Hard copies were acquired, digitized and mosaiced in PC-ArcInfo to produce one composite map. The maps (completed in 1921 and published by the Ordinance Survey Office, Southampton, 1925) were -- *surveyed with prismatic compass and trochometer* mounted *on wheel of travelling cart by land and boat and canoe by water timed with stop watch by Capt. A. G. Stigarnd* (an early traveller) *between 1910 and 1921*. Details appended to the map in the form of Landmarks in Channel Regimes, were post-scripted to Stigarnd's maps on the basis of information sourced from historical records.

Fig 5 Composite Reconstruction of the Surface Water Situation during the 1st half of the 20th Century Based on Archival Maps and Historical Records



Source: Hamandawana, 2003.

4.0.3 *Travelers' Records*

Early travelers' records (Table 1) provide an additional source of valuable information on the general state of the environment. Systematically added to a spatially referenced information system, historical information of this nature helps to shed more light on environmental conditions in the past.

Table 1 Highlights on the surface-water situation in the Okavango Delta based on Travellers' records and historical documents: 1849-1922

Traveller	**Observations of Lake Ngami and the Thaoge River**	**Comment**
Livingstone Aug 1849	Estimated circumference of Lake Ngami to be 70-75 km. Recorded use of mekoros in the lake, reluctance of inhabitants to venture deep into lake from the shore and imperceptible flow of the Thaoge	Convincing evidence of a flowing Thaoge in the past and substantial flow sustaining Lake Ngami
Oswell Aug 1849	Estimated Lake Ngami's dimensions: Length = 30km, Width = 14km	Tenuous evidence suggesting possible flow of the Thaoge.
Mcabe Aug 1852	Crossed the Thaoge and estimated its width to be 3.2 km and 1 m deep a mile upstream from Lake Ngami.	Cross sectional dimensions of the Thaoge and its depth indicate a fairly active channel
Andersson July 1853	Estimated Lake Ngami's width at 7-9km, circumference 60-70km. Shape of lake described as resembling pair of spectacles. Records submerged tree stumps and former hippo territory colonised by vegetation.	Evidence of channel dynamics (possible avulsion and inception of drying sequences) suggested by relocation of floodplain areas
Andersson 1853	Sailed up the Thaoge. In his words, ((*The main course of the river is northwest--, and is so serpentine that in thirteen days of ascend--I only made 1 degree latitude due north*...(The river's width) *never --exceeds forty yards--but is deep--depth less than five feet only in three places*)).	Meandering and anastamosis under low gradient conditions but channel fairly active; substantial bed-load transportation building a mouth bar that later plugged the river as confirmed by Brind (1951).
Chapman 1859	Length of Lake Ngami estimated to be 36-37km. He circumnavigated and measured its circumference to be 100km using *trochometer* and observed direct flow of the Boteti into lake Ngami as confirmed by Livingstone in June 1858	Reliable measurement of Lake Ngami's extent. The Boteti flow into Lake Ngami suggests high water levels in the Delta. Such conditions suggest substantial inflow via the Okavango and high rainfall in Angola
Baines 1861	Estimated Width of Lake Ngami: 10-12km.	Decrease in lake size.
Chapman 1863	Notes that: '*all the country on either side of the Teouge from its junction with the lake upwards is a land of swamp and reeds, infested by buffaloes and elephants which are constantly in water or reeds and have to be hunted from boats*' (p.176)	Evidence of a productive environment, reliable flow and abundance of game. The same record also suggests westward flow of the river's sub-channels into the desert
Stigarnd 1910-1921	Recorded local people's tales of both higher lake levels and dry bed in recent past. His map, produced between 1910 and 1921 shows: • Seasonal flooding of the floodplain to latitude 21 ^{0}S and perennial flow to the same latitude • Dense reed growth on both sides of the channel • Aug and Sep 1921, the Thaoge flowed as far south as Tsao	Decline documented by Baines accurately captured by oral traditions. Stigand's map; PLAN BP – 122, (a historical masterpiece by all standards and perhaps the earliest on record and produced according to acceptable mapping conventions) is obtainable from Botswana National archives and can also be acquired from Botswana's Department of Surveys and Mapping.

Compiled from: Oswell, 1849; Chapman, 1849-63; Anderson, 1856, Chapman, 1866, Stigarnd, 1921, Ransford, 1978, Mackenzie; 1946, Livingstone; 1849; Shaw, 1985.

Environmental variables useful for purposes of long term monitoring often captured in historic documents include wildlife, vegetation and water distribution. In most cases, diarized information has been compiled and is often accessible in published form in archival records. Though the accuracy of such information is often difficult to ascertain, individual records can be crosschecked against each other to provide dependable reconstructions of environmental conditions in different places. Additional information is also retrievable from colonial documents that often provide reliable records on a wide range of environmental factors such as population distribution, the occurrence of droughts and disease outbreaks in different areas.

4.0.4 *Colonial Documents*

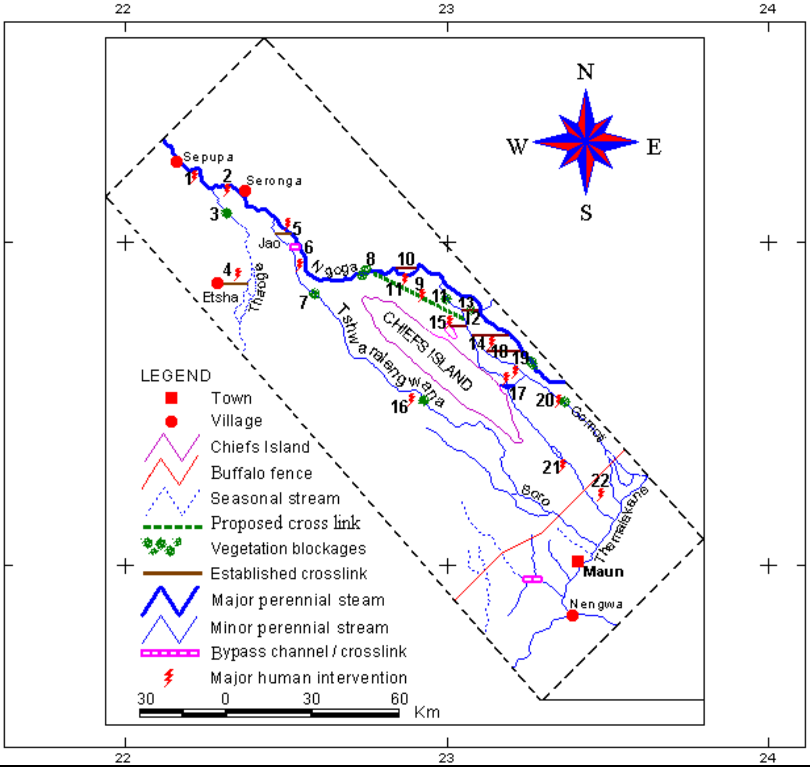
The basic composition of data for this period has been outlined in preceding sections. This section illustrates how written historical records can be incorporated into a geo-database and used to complement conventional forms of remote sensed data.

While preexisting maps as illustrated above can be captured and updated to include features and observations of interest, it is also possible to create new maps on the basis of historical information. Mappable historical information might be in the form of specific events whose exact location is captured in written form. In this study, one of our primary objectives is to investigate the role of human factors in influencing the direction of environmental change. With historical information on various forms of human intervention accessible to us in the form of written records, we devised a methodology in which scattered information for specific areas was compiled and captured in maps to give a spatially georeferenced record. Fig 6 shows the extent of human intervention during and after the Ngamiland Waterways project of the early 1950's and naturally induced vegetation blockages in the Okavango Delta's distributary channels in the east. While human interference is often considered to have little influence on changes in the Okavango Delta, evidence captured in this illustration suggests that planned diversion of channels in order to redirect water flow toward specific settlements (Maun in particular) might have accelerated the desiccation of the Mababe Depression (Fig 5). Capturing written information in a GIS system in this manner facilitates aggregation of data in a way that allows empirical evaluation of natural and non-natural processes.

In remote sensing applications, geocoded data provides a graphical backdrop for confident identification of features that that might not be readily interpretable without additional supportive information. In this example, the area shown in the map has been repeatedly affected by channel avulsions. While natural factors (mainly vegetation blockages) have in most instances been invoked to explain this phenomenon, overlaying this map on a Landsat image for example assists the researcher in pinpointing the exact location of specific events thus allowing objective analysis in investigating landscape processes. Overall, the technique substantially improves remote sensing information extraction. Depending on the nature of data converted from written into graphic form, the researcher's ability to discriminate between natural and human induced factors can be substantially increased.

With geocoded information on occurrences of events such as those captured in Fig 6, change detection analysis informed by such data improves our understanding of environmental processes by allowing a wide range of factors (natural and non natural) to be factored into the analysis thus facilitating holistic investigative analysis of short, medium and long-term environmental changes. While the merits of the approach render its use overwhelmingly appealing, its utility depends on the accuracy of written records used which, as mentioned in preceding sections, can be improved by comparing different sources where these are available.

Fig 6 Historical Reconstruction of Channel Regimes and Human Intervention Along the Jao, Gomoti, Ngoga and Thaoge Rivers in the Okavango Delta



Explanation

1 Bypass channels cut by WANLA below Sepupa between 1940 and 1950.
2 Bypass channels cut by WANLA to access Seronga between 1940 and 1950.
3 Thaoge mainstream blocked by sediment and/or papyrus initiating natural avulsion.
4 Crosslink to Thaoge from Etsha cut by WANLA or locals between 1940 and 1950.
5 Access channel to Teeke cut by WANLA between 1940 and 1950 for improved navigation.
6 Crosslink to Jao cut by WANLA or locals (agent uncertain) between 1940 and 1950.
7 Jao mainstream above Xhamae repeatedly blocked by sediment between 1980 and 1990 and bypass cut by the Department of Water Affairs in 1989.
8 Xaega-Hanamozeyo stream aggraded and Islands submerged between 1980 and 1990.
9 Peter Smith's proposal to transfer water to Maun via the Thamalakane.
10 Natural avulsion crosslink between Hanamozeyo and Moanatshira in 1937.
11 Hamoga-Hanamozeyo mainstream blocked by sediment between 1970 and 1990.
12 Navigation crosslink to Moanatshira cut by the Agriculture Research Department in 1973 causing avulsion of the Moanatshira.
13 Reblockage of the bypass between Hanamozeyo and Mboroga earlier cleared by Martinus Drotsky during the 1930s and eventual desiccation of the stream between 1960 and 1990.
14 Two crosslinks to Mboroa cut by the Department of Water Affairs between 1970 and 1980.
15 Access to Xharaga Island cut by a private Safari company in the 1980s.
16 Vegetation blockages periodically cleared by the Department of Water Affairs.
17 Dam at Santantadibe's headwaters built by Naus in the 1930s.
18 Crosslink by Naus in the 1930s and clearing of blockages by Department of Water Affairs between 1970 and 1990.
19 Gomoti in the 1990s initiating avulsion and drying up of the river's lower floodplains.
20 Gomoti blocked by vegetation in the 1930s despite Naus' campaigns to destroy vegetation.
21 Santantadibe's mainstream altered by Naus' dams and bunds in the 1930s.
22 Local farmers, the Agriculture Department, MDP/GTZ, De-Beers and Naus adversely manipulated the area below the Buffalo Fence. Remnants of Naus Dams (dam walls) can still be seen today in the area above the Thamalakane bridge on the Maun-Shorobe road.

Source: Hamandawana, 2003.

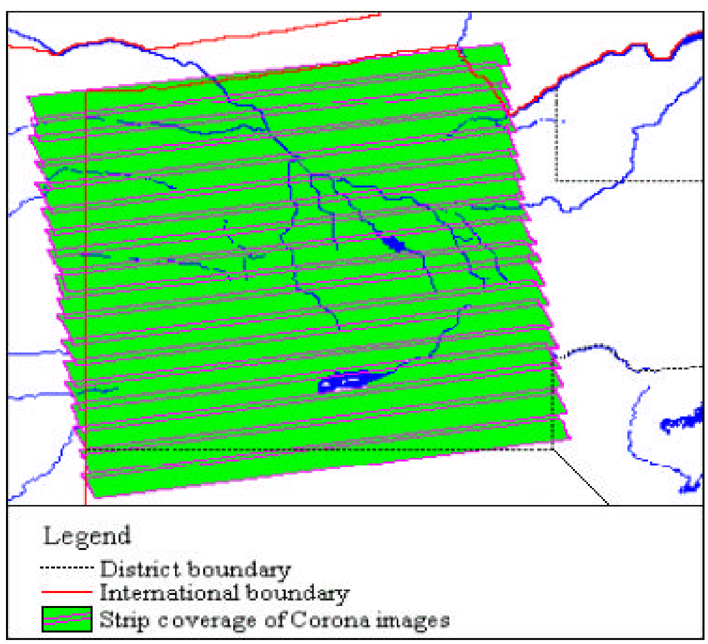
5.0 **Conventional Satellite Data: 1967 – 2001**

Conventional satellite data for this period comprises Corona photographs and Landsat images.

5.0.1 Corona Photographs: September 1967

Aware of the declassification of Corona and Argon intelligence satellite photographs (McDonald, 1995; Gray *et al.*, 2000) it was felt necessary to take advantage of this development by incorporating Corona data into a historical baseline dataset. A thorough search of the archives was carried out and links established with Kelly Caylor of the University of Virginia who assisted in acquisition of Corona photographs dated September 1967[1]. Figure 7 shows the spatial coverage of the Corona photographs over the Okavango Delta. The photographs were made available as a 2.25 x 30-inch negative film (Quality rating - Excellent) and were the first 1-2m-resolution observations of the Earth from panoramic satellite-borne-cameras. The negatives thus provide very high-resolution data and can be viewed in stereo to provide excellent viewing because both the fore (forward-looking) and aft (backward-looking) cameras were used (Gray *et al.*, 2000). Keyhole (KH) designators and mission numbers were used by the intelligence community to describe and index the data. The available data are from KH-4B, acquired on 15 September 1967 and rated the best film of the entire mission. The area covered by a single KH-4B strip is 188km x 14km (2632 km^2) which would require more than 200 aerial photographs at the 1: 20 000 scale to provide stereoscopic coverage of the same area. Compared to conventional aerial photographs therefore, Corona's most significant advantage is wide spatial coverage in a single snap-shot. However, the photographs have their limitations as discussed below.

Fig 7 Coverage of Corona Photographs For the Okavango Delta: September 1967

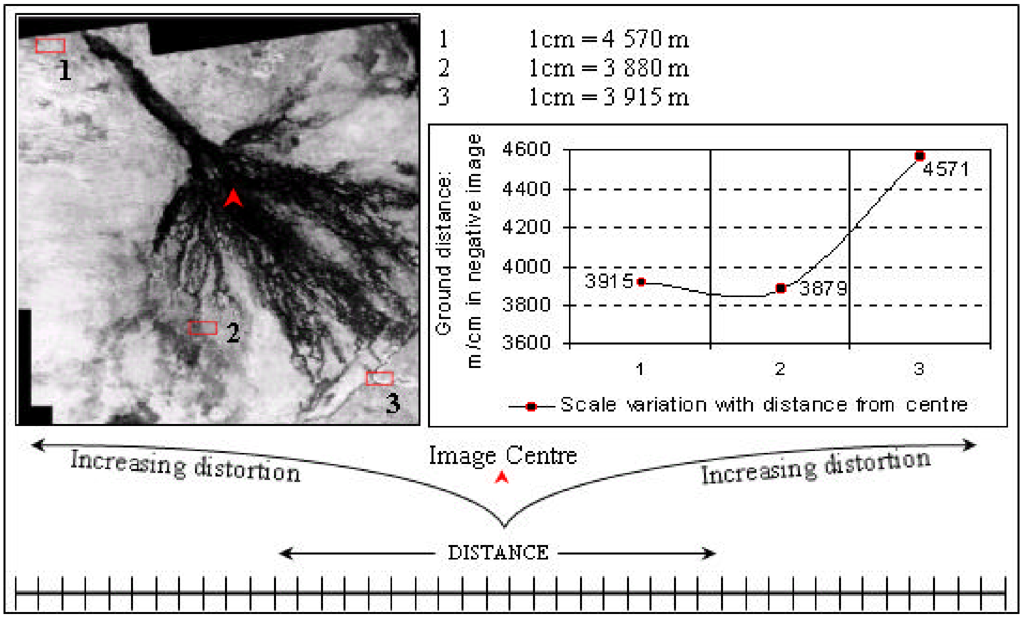


First, the overlap, (averaging 2km or 14%) is inconsistent, indicating substantial yaw variation and an unstable path for the satellite. Second, the large field of view involved increases radial distortion from the centre and also adds to variations in illumination with the edges tending to be dark and blurred. The third limitation arises from the obliquity of off-nadir viewing that gives rise to systematic variations in lateral scale (Fig 8). Notwithstanding these limitations, the photographs still provide excellent resolution compared to Landsat. Most of the radial distortions can be corrected to give satisfactory results. Table 2 shows identification details and the quality rating of Corona negatives covering the Okavango Delta. The negatives were scanned at 1200dpi using a Geosystems Delta Scanner made available by Botswana's Department of Surveys and Mapping. After scanning, the

[1] Corona photographs are available from the USGS: http://edcwww.cr.usgs.-gov/webglis/

negatives were inverted, trimmed to remove noisy edges, georeferenced, and colour balanced, resembled to 2m resolution and mosaiced in Erdas Imagine (Figure 9).

Fig 8 Non-rectified Photo Distance Measurements illustrating Scale Variations



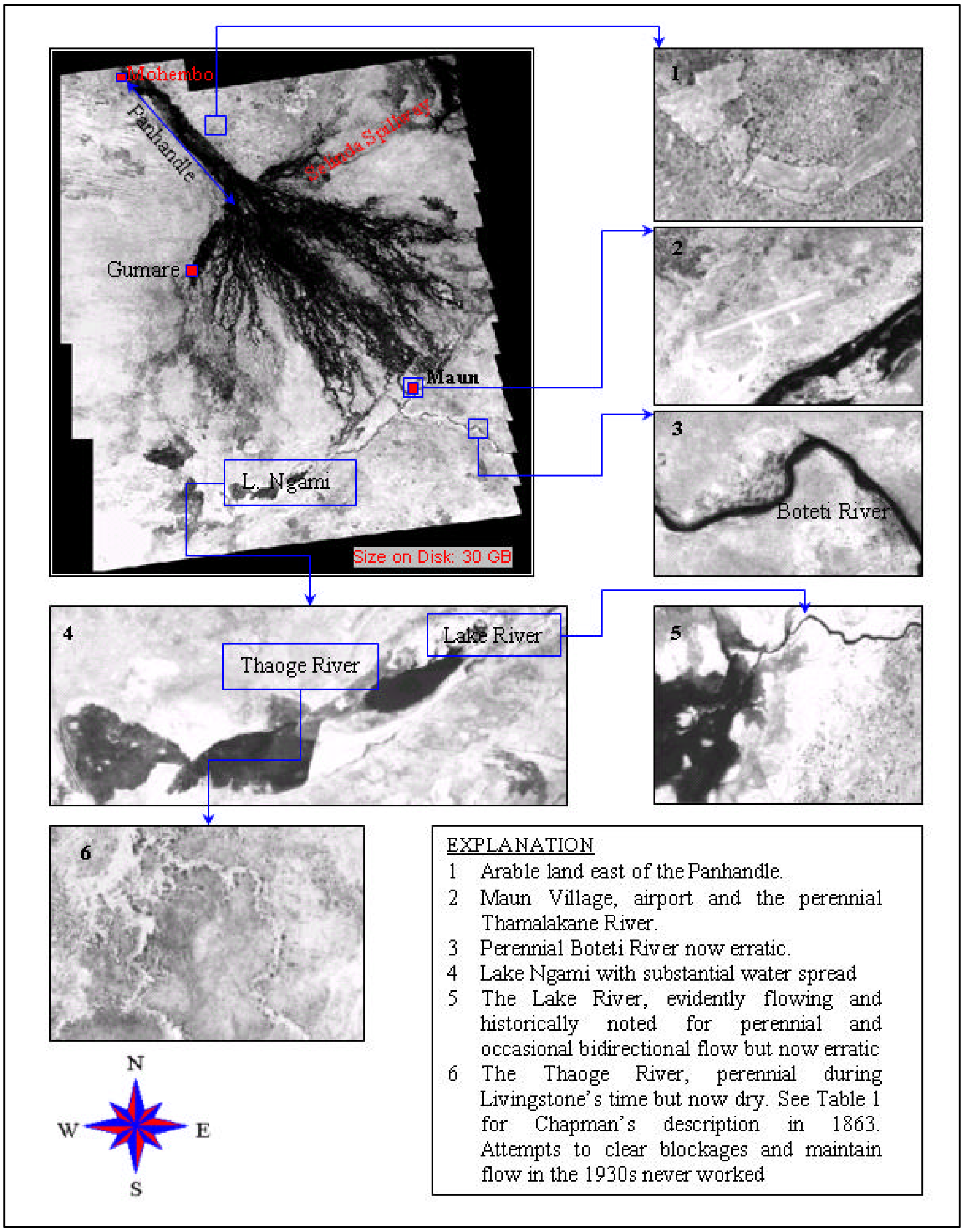
Source: Hamandawana, 2003.

Table 2 Identification Details of Corona Photographs covering the Okavango Delta

Ordering Identifier	Dimensions	Medium	Ordering Identifier	Dimensions	Medium	QR
DS1101-2153DA056	2.25" x 30"	Neg Film	DS1101-2153DF030	2.25" x 30"	Neg Film	E
DS1101-2153DA057	2.25" x 30"	Neg Film	DS1101-2153DF032	2.25" x 30"	Neg Film	E
DS1101-2153DA058	2.25" x 30"	Neg Film	DS1101-2153DF033	2.25" x 30"	Neg Film	E
DS1101-2153DA059	2.25" x 30"	Neg Film	DS1101-2153DF034	2.25" x 30"	Neg Film	E
DS1101-2153DA060	2.25" x 30"	Neg Film	DS1101-2153DF035	2.25" x 30"	Neg Film	E
DS1101-2153DA063	2.25" x 30"	Neg Film	DS1101-2153DF037	2.25" x 30"	Neg Film	E
DS1101-2153DA066	2.25" x 30"	Neg Film	DS1101-2153DA033	2.25" x 30"	Neg Film	E
DS1101-2153DA067	2.25" x 30"	Neg Film	DS1101-2153DA034	2.25" x 30"	Neg Film	E
DS1101-2153DA068	2.25" x 30"	Neg Film	DS1101-2153DA036	2.25" x 30"	Neg Film	E
DS1101-2153DA070	2.25" x 30"	Neg Film	DS1101-2153DA037	2.25" x 30"	Neg Film	E
DS1101-2153DA071	2.25" x 30"	Neg Film	DS1101-2153DA065	2.25" x 30"	Neg Film	E
DS1101-2153DF051	2.25" x 30"	Neg Film	DS1101-2153DA069	2.25" x 30"	Neg Film	E
DS1101-2153DF052	2.25" x 30"	Neg Film	DS1101-2153DF050	2.25" x 30"	Neg Film	E
DS1101-2153DF053	2.25" x 30"	Neg Film	DS1101-2153DF054	2.25" x 30"	Neg Film	E
DS1101-2153DF057	2.25" x 30"	Neg Film	DS1101-2153DF060	2.25" x 30"	Neg Film	E
DS1101-2153DF058	2.25" x 30"	Neg Film	DS1101-2153DF064	2.25" x 30"	Neg Film	E
DS1101-2153DF061	2.25" x 30"	Neg Film	DS1101-2153DF062	2.25" x 30"	Neg Film	E
DS1101-2153DF062	2.25" x 30"	Neg Film	DS1101-2153DF056	2.25" x 30"	Neg Film	E
DS1101-2153DF063	2.25" x 30"	Neg Film	DS1101-2153DA064	2.25" x 30"	Neg Film	E
DS1101-2153DF065	2.25" x 30"	Neg Film	DS1101-2153DF059	2.25" x 30"	Neg Film	E
DS1101-2153DF066	2.25" x 30"	Neg Film	DS1101-2153DF061	2.25" x 30"	Neg Film	E
DS1101-2153DA072	2.25" x 30"	Neg Film	DS1101-2153DF026	2.25" x 30"	Neg Film	E
DS1101-2153DF055	2.25" x 30"	Neg Film	DS1101-2153DF031	2.25" x 30"	Neg Film	E
DS1101-2153DF027	2.25" x 30"	Neg Film	DS1101-2153DF036	2.25" x 30"	Neg Film	E
DS1101-2153DF028	2.25" x 30"	Neg Film	DS1101-2153DF035	2.25" x 30"	Neg Film	E
DS1101-2153DF029	2.25" x 30"	Neg Film	Dimensions in inches, Quality Rating (QR), Excellent (E).			

Source: USGS

Fig 9 Corona Mosaic Showing the Okavango Delta in September 1967



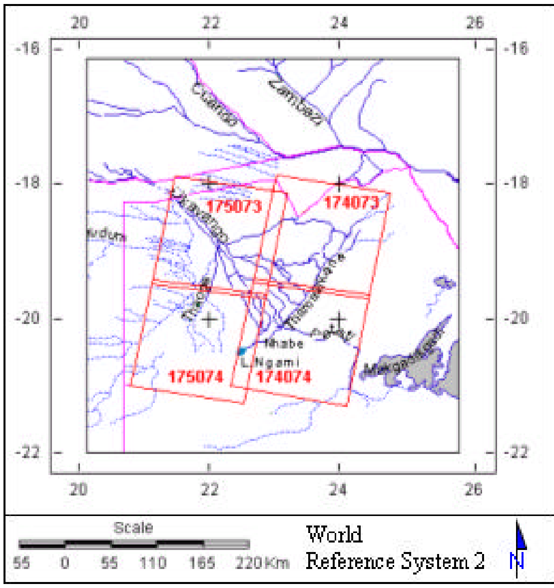
Source: Hamandawana, 2003.

The matching procedures that were used in mosaicing are rather involving and they are described elsewhere (Hamandawana, 2003). Because of the extremely high spatial resolution of Corona photographs, large amounts of disk space are required. The above mosaic represents the first use of Cor ona photographs in long term environmental monitoring in Botswana in conjunction with a Landsat database details of which, are provided in section 5.0.2 below.

5.0.2 Landsat Images

All images with the exception of MSS scenes for 1979 were purchased by the University of Botswana. The latter were acquired from the Department of Geography, Kings College, London. Archival searches for suitable images were guided by the percentage of cloud cover in each scene and the quality rating as provided by the different data centres. Figure 10 shows identity details and the footprint of Landsat scenes acquired. Though the project was initially conceived with the intention of building a dry season database to minimise the problem of phenologically dissimilar images, this requirement was relaxed for the 1979 images which were sourced from collaborating partners. However, confinement of the wet season to the months between October and March minimizes phenological differences because early cessation of rains around March places June outside the rainy season making all images satisfactorily comparable.

Fig 10 Footprint and Identity Details for Landsat Scenes Covering the Delta



Date	Image Id
June 79	1740073
June 79	1740074
June 79	1750073
June 79	1750074
Sep 89	1740073
Sep 89	1740074
Aug 89	1750073
Aug 89	1750074
Aug 94	1740073
Aug 94	1740074
Aug 94	1750073
Aug 94	1750074
Aug 01	L71174073 07320010828
Sept 01	L71174074 07420010913
Oct 01	L71175073 07320011006
Oct 01	L71175074 07420011006

5.0.2.1 *Landsat Image Characteristics*

Table 3 shows the spectral range and spatial resolution of bands in Landsat MSS, TM and ETM.

Table 3 Spectral Range and Spatial Resolution of Bands in Landsat MSS, TM and ETM

	Landsat MSS		**Landsat TM**		**Landsat ETM**		
Band	W-length in µm	Pixel size	W-length in µm	Pixel size	W-length in µm	Pixel size	**Principal band use**
1	0.5-0.6	57	0.45-0.52	30	0.450-0.515	30	Water, soil, vegetation
2	0.6-0.7	57	0.52-0.60	30	0.525-0.605	30	Green vegetation
3	0.7-0.8	57	0.63-0.69	30	0.630-0.690	30	Species identification
4	0.8-1.1	57	0.76-0.90	30	0.750-0.900	30	Vegetation types and water
5			1.55-1.75	30	1.55-1.75	30	Vegetation & soil moisture
6			10.4-11.7	120	10.40-12.50	60	Thermal mapping i.e. fire
7			2.08-2.35	30	2.09-2.35	30	Mineral exploration
8					*0.520-0.900	15	High resolution mapping

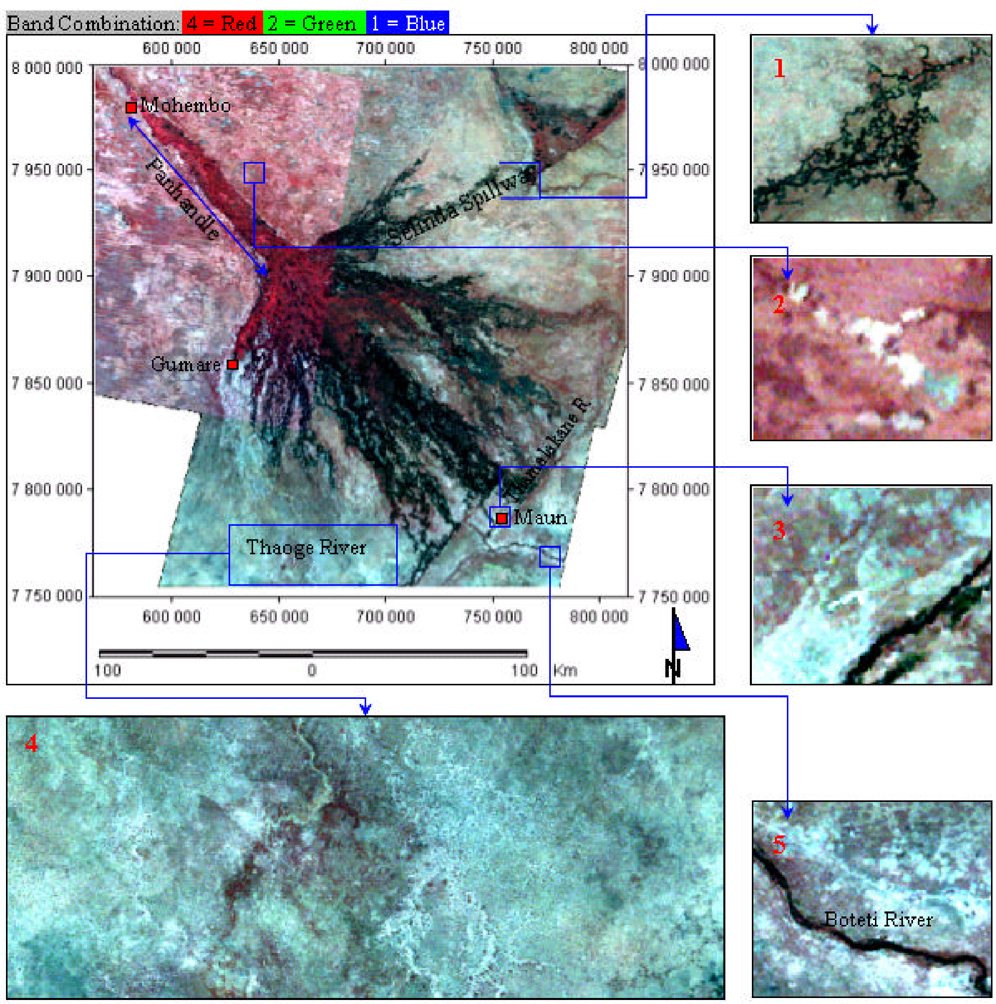
Source: Mather, 1996; Lillesand, 2000. * Panchromatic band.

These characteristics are important because they determine how individual datasets can be used. The coarse spatial resolution of Landsat MSS means less detail compared to Landsat TM and Landsat ETM. A similar radiometric resolution of the MSS sensor compared to its counterparts, with all four bands narrowly restricted to the range between 0.1µm and 1.1µm means that MSS data are less fine tuned to enhance feature identification and discrimination with TM and ETM data representing substantial improvements in this regard. Though these internal variations have significant implications on what each dataset can yield, these differences can be reconciled through appropriate project design.

5.0.2.2 *Landsat Mosaic Series*

Figures 11-14 show the mosaics covering the Okavango Delta for the years 1979, 1989, 1994 and 2001 respectively with embedded captions highlighting scenarios in selected areas to illustrate how the database can be used for change detection and analysis.

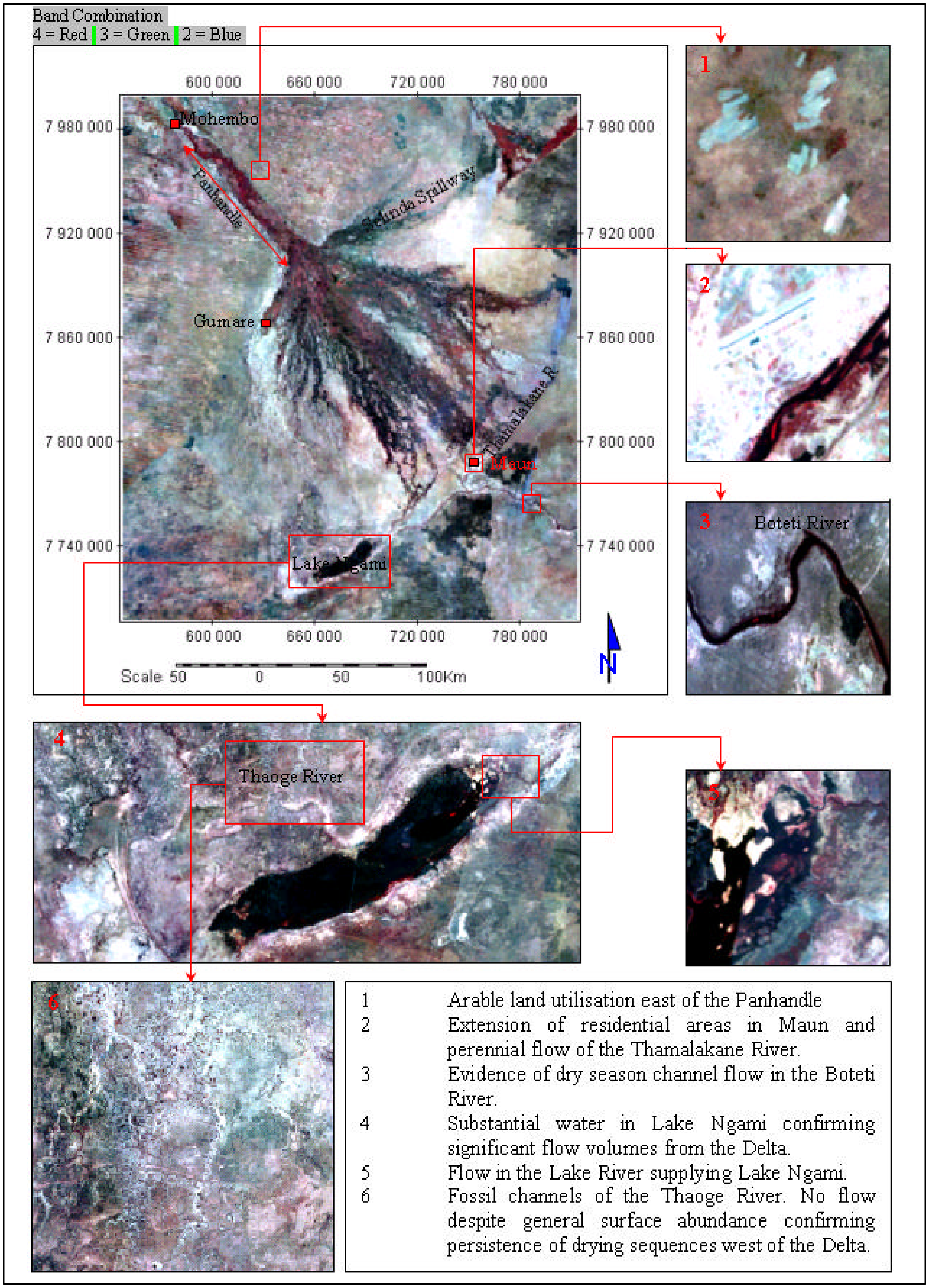
Fig 11 Landsat Mosaic Showing Arable Land-use and the Surface Water Situation in selected areas in the Okavango Delta: June 1979



1 Furthest terminal reach of the Selinda Spillway never reached since then as confirmed by.
2 Active and inactive arable land suggests fallowing/abandonment for reasons to be investigated.
3 The effect of coarse resolution, the airport clearly visible in all other images is hardly identifiable.
4 The dry Thaoge River; persistence of dry conditions and continued retreat of the channel to Gumare (compare with Corona and Stigarnd's map) suggest irreversible deterioration.
5 Exceptionally high floods this year explain the Botei's flow further south than it does today.

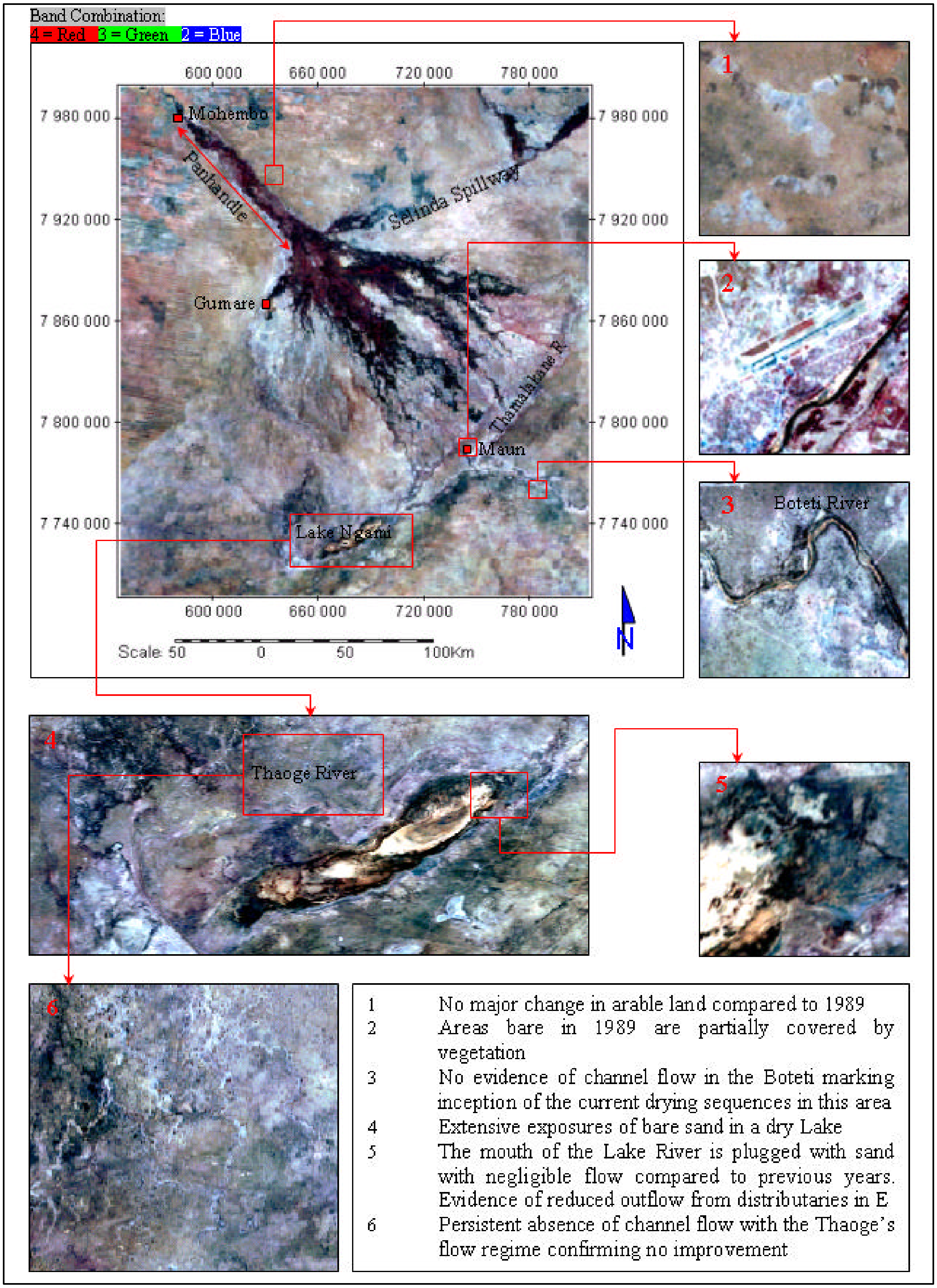
Source: Department of Geography, Kings College London.

Fig 12 Landsat Mosaic Showing Arable Land-use and the Surface Water Situation in selected areas in the Okavango Delta: September 1989



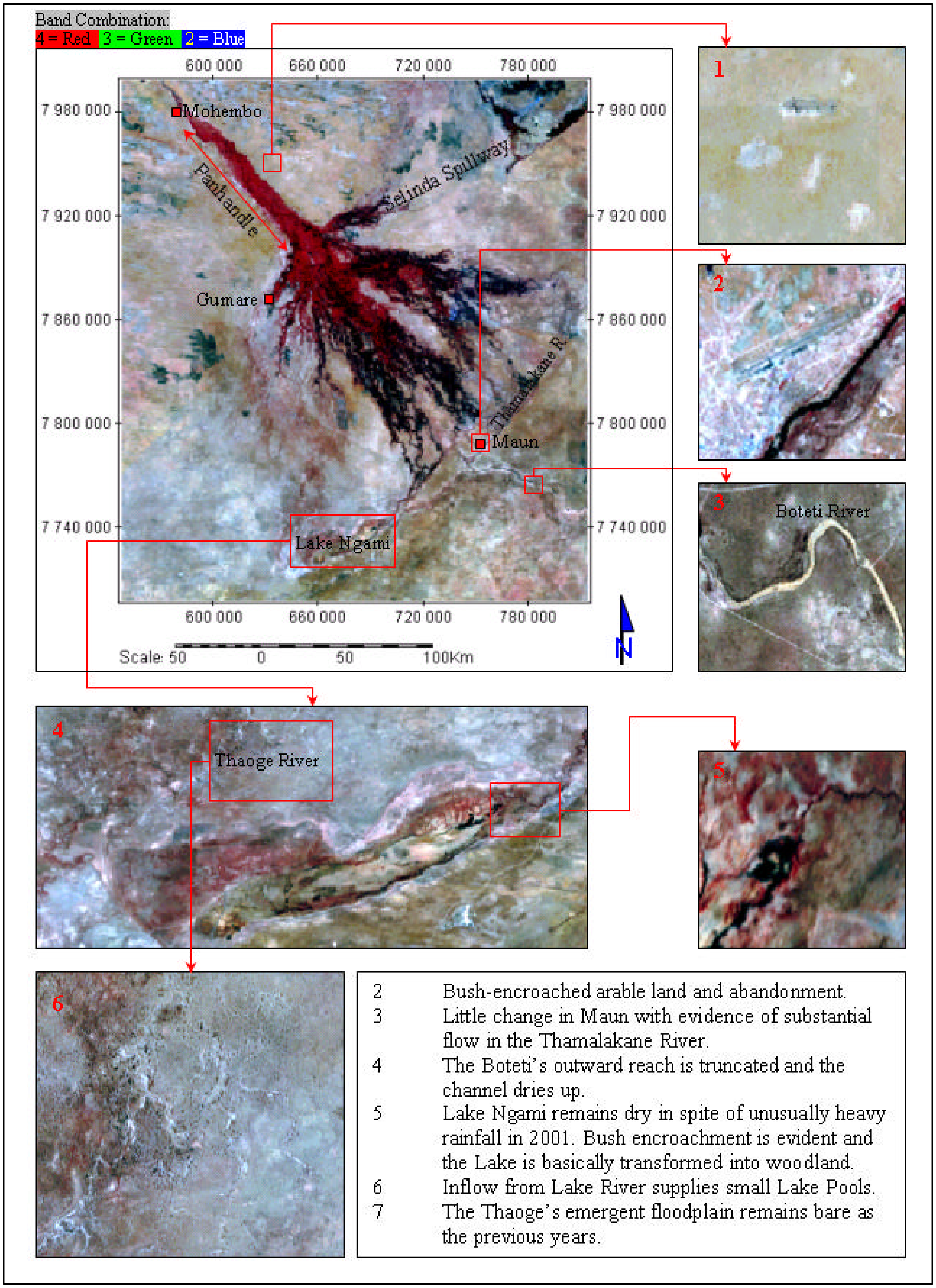
Source: Hamandawana, 2003.

Fig 13 Landsat Mosaic Showing Arable Land-use and the Surface Water situation in selected areas in the Okavango Delta: August 1994



Source: Hamandawana, 2003.

Fig 14 Landsat Mosaic Showing Arable Land-use and the Surface Water situation in selected areas in the Okavango Delta: August 2001



Source: Hamandawana, 2003.

Conclusion

Though the use of conventional remote sensed data has significantly aided time series environmental change investigation, blending remote sensed data with information from other sources offers additional scope for extending temporal coverage into the distant historical past. Suggestions on how a hybrid approach tapping on different data sources ranging from archival to historical have been given and examples offered to indicate how for practical purposes, a multidisciplinary approach can be used to create new and update existing databases for purposes of long term environmental monitoring. Pre-Landsat data from different satellites exist (ARGON and LANYARD photographs are also available) and there is need to widen our search-horizons beyond the normal temporal boundaries associated with the Landsat programme. In long-term environmental monitoring, the major advantage of Corona photographs for example is that they can be used to extend the temporal coverage of conventional satellite images by more than a decade since; the programme was operational between 1960 and 1972 when the final mission was flown. Additional advantages emerge from the fact that Corona's retirement coincided with the launch of Landsat 1, making it possible to build a continuous database from 1960 up to the present. These opportunities need to be exploited by identifying what is recoverable from the archives. In a similar vain, historical/archival records offer substantial amounts of potentially recoverable information for the period predating Corona photographs. Scattered information can be carefully put together to complement conventional remote-sensed datasets from different platforms.

While the how-to-create part of the exercise has been partly addressed, what needs to be given further consideration is how such information once incorporated in a database can be made accessible to the scientific community. The easiest way would be through the electronic media. The way forward in building useful databases thus appears to hinge on two central issues namely; what kind of information to look for, and how to store and disseminate such information. Having dwelt to some extent on the former, it is necessary to reflect on the latter since compiling information that ends up inaccessible is a futile exercise. Judging by the size of files potentially constructible as illustrated in preceding sections, it is apparent that substantial resources (technical, hardware etc) have to be committed if data sharing at levels commensurate with the growing requirements of global change analysis is to be realised.

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