The role of human factors in the degradation of natural resources in and around the Okavango Delta, Botswana

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This paper draws on archival information, anecdotal evidence from local communities, *in situ* observations during field investigation and multi-date remotely sensed satellite imagery. The authors investigated the role of human factors in the degradation of natural resources in and around the Okavango Delta. Their study concerned a period slightly in excess of 140 years between 1860 and 2001. Environmental changes in this sub-region appear to be the convergent outcome of interaction between natural and non-natural factors. A sustained decrease in rainfall appears to have instigated downward trends from a wide range of factors whose adverse effects were aggravated by human agency. The evidence points to progressive deterioration in the form of sustained contraction of surface water sources and grazing resources. Mistakes of the past need to be avoided by formulating appropriately informed human response and adaptation strategies.

Keywords: Environmental change; Okavango Delta

1. Introduction

The Okavango Delta is a landlocked wet fan situated on the north-eastern fringes of southern Africa's Kalahari-Namib desert in northern Botswana. Because of continental location in the interior of southern Africa and latitudinal position outside the normal southward limit of tropical disturbances (NSLTD), the entire sub-region experiences a semi-arid climate, with rainfall averaging 477 mm/annum [1]. In terms of physiography, this wetland consists of three subsystems that include permanent swamps, seasonal swamps and intermittent floodplains. The permanent swamps comprise the Panhandle, which represents the Okavango River and its primary tributaries below its entry point into Botswana and perennially flooded wetland bounded by the Gumare fault in the north and the Thamalakane fault in the south. Fringing areas bordering these sub-systems are flooded during the peak flood period between March and July to form the seasonal swamps. During years of exceptionally high floods, spasmodic over-flow inundates areas beyond these seasonal swamps to form the intermittent floodplains in the peripheries of which are fossil floodplains that mark the coterminous extent of a more extensive wetland during the historical past. The Panhandle area and transitional environment between the Gumare and Thamalakane faults, respectively, represent the Okavango Delta's proximal and intermediate reaches. Water flow in these areas is generally imperceptible owing to gentle gradients averaging 1: 5140 in the Panhandle and 1: 3610 in the intermediate swamps [2]. Upon delayed arrival of seasonal floods in the Delta's southern extremes around July; water flows into receiver channels such as the Thamalakane and Boteti and when floods are high enough, this flow inundates riparian lowlands and local depressions such as Lake Ngami. These subsystems collectively con-stitute the distal reaches of the Okavango Delta. Figure 1 shows the Okavango Delta's location in northern Botswana, approximate extent of its major subsystems and, the NSLTD.

Over time, during the historical past, a number of settlements evolved in the Delta's immediate peripheries, with reliable access to surface water providing the major initial attraction for sedentary human occupation. In the proximal reaches, marginal areas between the Panhandle and the northern Buffalo Fence and the more extensive western uplands support agro-pastoral activities that provide the main source of livelihood for local communities. Areas east of the intermediate reaches largely consist of protected wildlife habitats where human settlement is restricted to tourism camps and lodges while the western peripheries support numerous villages strategically located in the past for convenient access to surface water in the Thaoge River and its floodplains. Though surface water influenced the location of human settlements, equally important was the distribution of tsetse which restricted pioneer settlement to outlying margins of the permanent and seasonal floodplains. After successful eradication of tsetse during the 1970s, human settlement gradually advanced toward the Delta's immediate peripheries. While tsetse and surface water distribution directly affected the location of settlements, the latter's influence was mediated by naturally induced changes in surface hydrology. These changes, comprising persistent channel failures, progressive surface-water contraction and sustained floodplain desiccation [4], necessitated the relocation of scattered homesteads to designated villages where borehole-water was provided after the early 1970s. The advent of boreholes implied broadened opportunities for permanent occupation of areas marginalised by drying sequences. Boreholes facilitated year-round exploitation of resources in localities distant from perennial surface water supplies. This dynamic partly explains the location of more recent settlements in the Delta's distal reaches. Surface water distribution prior to floodplain desiccation explains pioneer settlements. The major insight from this synopsis is that single-cause explanations do not seem adequate to explain environmental changes. Accordingly, we adopted a multi-causal investigative approach that acknowledges the interaction of natural processes and human agency in determining the direction of environmental change.

2. Materials and methods

Materials used in this investigation include: 1) time-line historical evidence from published and unpublished records; 2) material artefacts and field observations portraying surface water distribution and human–environment interactions during the recent past; 3) oral histories and

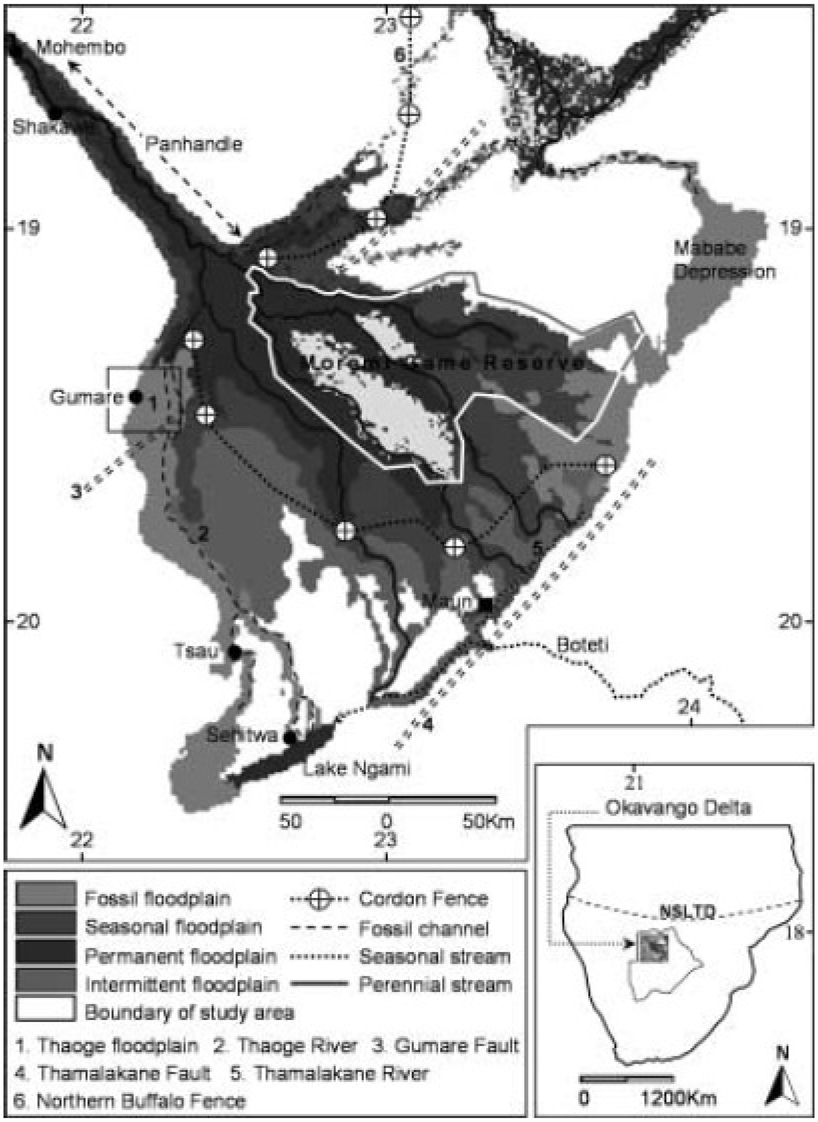

Figure 1. Geographical location of the Okavango Delta and approximate extent of its major subsystems. *Source*: [3].

local people's perceptions of environmental changes in their localities; and 4) satellite imagery for the years 1967, 1989, 1994 and 2001. These datasets were part of a geo-database [5] specifically compiled to monitor long-term environmental changes in and around the Okavango Delta [3]. Time-line historical evidence includes non-spatially referenced information from the archives and, geolocated observations from field investigation. The former was systematically tabulated to provide a chronological sequence of events. This provided a reliable reference for inferential reconstruction of environmental conditions at different time periods. The latter were incorporated in an illustrative map (not shown in this paper) by capturing the same in database files that were subsequently converted to point themes in ArcView. Oral histories and local people's perceptions were compiled from long-standing residents of Gumare village above 50 years of age. Gumare was selected for its representative inclusion of sub-ecosystems that allowed significant investigation of the role of human factors in the degradation of natural resources in and around the Okavango Delta. Respondents above 50 years of age were preferred because they were reasoned to be capable of providing reliable accounts from memory on conditions during the recent historical past. Material artefacts comprise field observed relics/features of known provenance and use that were used to identify geographical localities associated with specific events. Satellite imagery includes CORONA and Landsat mosaic-subsets providing footprint coverage of a 900 km^2 sample site around Gumare. The CORONA mosaic was compiled from 2 m-resolution intelligence panchromatic photographs [6] acquired by the same satellite on 15 September 1967 [7]. Landsat datasets include Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper (ETM) mosaics of 1989, 1994 and 2001 respectively, compiled from dry season coverages to enhance close temporal correspondence with like-season CORONA photographs.

CORONA photographs were classified on the basis of an improvised procedure in which step-wise density slicing was used to extract information classes at levels of detail and spatial accuracy that allowed this dataset's map outputs to be meaningfully compared with corresponding products from Landsat imagery. Landsat images were classified on the basis of standard supervised classification procedures, with more information classes being extracted from these datasets in order to facilitate the detection of trends in individual woody species that could not be mapped from CORONA photographs. Details on field investigation procedures, step-wise density slicing and how Landsat images were classified are provided elsewhere [8]. For each map output, spatial accuracy assessment was carried out by calculating the global accuracy and kappa (K) coefficient using geolocated information from field investigation and collateral information from aerial-photo mosaics of 1991 and 2000. The procedure used included tabulating this information and assigning field-determined class labels/codes in Excel. The tables compiled from this process were then converted to ASK II file format and imported as user-defined points into ERDAS Imagine's image classification-accuracy environment. Thereafter, map derived information class codes corresponding to each of the user-defined points were automatically added to a corresponding column provided by default thus allowing compilation of summary tables with field-observed and map-derived class codes for each x-y point. This information was then summarized to give confusion matrices that were subsequently used to calculate the global accuracy and the K statistic. Table 1 provides a sample illustration of how global accuracy and K were calculated for the 2001 time period.

The level of accuracy for the 1967 CORONA map output was 76.3%, K = 76.1%. Accuracy levels for the 1989 and 1994 Landsat TM and, 2001 Landsat ETM map outputs were 72.8%, K = 72.6%; 71.6%, K = 71.4% and 72.7%, K = 72%, respectively. The next section (section

Table 1. Sample illustration of matrix tables used to calculate the global accuracy and kappa (K) coefficient.

	Bare ground	Scrub and shrubs	Mixed bush	Mixed woodland	*Terminalia*	Papyrus	Water	Acacia woodland	Overgrazed grassland	Open grassland	Totals
Bare ground	18	3	1	0	0	0	0	0	0	0	22
Scrub and shrubs	1	4	1	0	0	0	0	0	0	0	6
Mixed bush	0	1	10	2	0	0	0	0	0	0	13
Mixed woodland	0	0	0	6	1	0	0	1	0	0	8
Terminalia woodland	0	0	1	1	6	0	0	1	0	0	9
Papyrus	0	0	0	0	0	3	0	1	0	0	4
Water	0	0	0	0	0	0	4	0	0	0	4
Acacia woodland	0	0	1	1	0	1	0	5	0	0	8
Overgrazed grassland	1	0	0	0	0	0	0	0	4	1	6
Open grassland	1	1	1	0	0	0	0	0	1	4	8
Totals	21	9	15	10	7	4	4	8	5	5	88

Correctly classified observations

Percentage correct = sum of diagonal entries/total observations = 64/88 = 72.73%

Expected agreement by Sum of diagonal entries = 88 = 0.0114
change = Grand total 7744
K Observed - expected = 0.7273–0.0114 = 0.7159 = 0.72
= 1 - expected 1–0.0114 0.9886

Source: [3].

3) discusses the role of human factors in the degradation of natural resources in and around the Okavango Delta between ~1860 and 2001.

3. Discussion

Though evidence antedating instrumental records is scarce, it is still possible to reconstruct environmental conditions during the historical past on the basis of historical evidence from published and unpublished records, material artefacts observed during field investigation and oral histories and local people's perceptions.

3.1 Environmental trends from historical evidence

Table 2 provides a chronological sequence of evidence. This offers a dependable basis for reconstructing environmental conditions in this sub-region during the historical past.

From the earliest information available, the first observation relates to Chief Moremi's dam construction around 1860. This suggests reliable flow-regimes capable of sustaining perennial reservoir storage. This proposition is supported by historical evidence [11,14,15], with Chapman's observations in 1863 [16] and later interventions by Headman Keatamense around 1919 (table 2) suggesting a productive environment and the role of human agency in modifying floodplain hydrology. While these observations indicate perennial flooding before 1900, successive decades during the 20th century were characterized by progressive channel failures and persistent floodplain desiccation. Evidence of progressive deterioration comes from Stigarnd's archival map of 1921 [12] and the numerous blockage clearing campaigns after the 1930s (table 2), designed to maintain flow to village settlements such as Tsau in the distal reaches of the Okavango Delta (figure 1). Nevertheless, none of these interventions was able to restore perennial flow in the dying Thaoge River. Although the long-term effect of channel failures was widespread desiccation, the antecedent outcome of this phenomenon was increased grazing in emergent floodplains. This unprecedented change allowed short-lived relocation of livestock from dryland into floodplain grazing areas. This led to overstocking, overgrazing, increased erosion and, localised siltation [17]. These adverse trends were interrupted by the outbreak of trypanosomiasis during the late 1930s that forced farmers to relocate cattle to tsetse-free areas. Though climate change appears to have been the main cause of floodplain desiccation [4,18], evidence suggests that human interventions accelerated natural deterioration by interfering with the transmission of flow. While the range of channel manipulations described in table 2 indicates human agency in modifying floodplain hydrology, the role of human factors is further illustrated by the widespread use of papyrus rafts, introduced by the BaYeyi during the 18th century [13,19]. From the time of early travellers such as Anderssen in the 1850s [20], they were used in large numbers for transporting grain from the north to southern markets and as a means of transport by colonial administrators during the 1930s [13]. On arrival at destination, they were simply abandoned.

Though the severity of their impact remains speculative, it is logical to suggest that indiscriminate disposal of these vehicles contributed to channel blockages and transformation of perennial swamps into the 'sea' of papyrus observed by Brind during the early 1950s (table 2). Because of the impenetrable nature of dense papyrus cover, conventional manual clearance became increasingly difficult. This difficulty compelled colonial authorities to explore new strategies. A papyrus-clearing machine was improvised by Brind between 1951 and 1953 and put to use.

Table 2. Historical evidence of environmental conditions in the Thaoge River's intermediate reaches: ~1860–1992.

Instigating agent/ observer	Major observation and location in Thaoge floodplain	Comment on observation
Chief Moremi: ~1860.	**[*]Upper and [**]Middle floodplain reaches**	
	Dammed the Thaoge River for his people and livestock.	Tsetse infestation and reliable flow of the Thaoge River and a productive floodplain during first quarter of the 20th century.
Chapman: 1886.	Described the Thaoge's floodplain as 'a land of swamp and reeds, infested by buffaloes and elephants – constantly in water or reeds that had to be hunted from boats.	
Headman Keatamense: ~1919.	Dammed the Thaoge River ~12 miles north of Nokaneng to water livestock in a tsetse-free area and sever supplies to his downstream rivals.	
McKiernan: September 1877.	Attempted to sail up the Thaoge River from its entry point into Lake Ngami.	Evidence of flow up Lake Ngami.
Stigarnd, A.G: 1910–1921.	Surveyed and mapped the Okavango Delta region according to conventional standards. His map (1921) shows truncation of the Thaoge River to Tsau by ~60km from its terminal destination in Lake Ngami.	Evidence of drying sequences and initial floodplain desiccation.
Martinus Drotsky: 1932–1942.	Clearing of papyrus blockages along Gumare's Thaoge floodplains.	Perennial surface water and natural checks against human expansion.
Trypanosomiasis outbreak: late 1930s.	The Thaoge floodplains were evacuated of cattle leading to overgrazing of tsetse free areas.	
Colonial authorities: 1930s–1950.	In 1938, the Thaoge was blocked as far as 25 miles north of Tsau. Immediately thereafter manual clearing started by the Colonial Administration. In 1941 water reached Tsau. By 1950, the restored channel had dried up.	Deteriorating floods, sustained decrease in the Thaoge's flow.
Brind: 1951–1953.	**Upper floodplain reaches**	
	Described the Thaoge below its exit at Ikoga as a sea of papyrus. 31 December 1951, a major blockage observed below Ikoga, 28 April 1952, the same blockage had advanced by 1.5 miles upstream to vicinities of the Guma lagoon.	Deteriorating floods, channel failures, decrease in outflow from Delta.
Brind: 1951–1953.	**Middle floodplain reaches**	
	Observed settlements north of Tsau on the Thaoge's western margin, eastern margin uninhabited because of tsetse, damming and irrigation of river loops; 1953 Brind assembled a 40 ton papyrus-cutting machine at Thale.	Avoidance of tsetse. Weight of machine confirms substantial flow volumes.
Government of Botswana (GOB): 1967.	Inception of tsetse eradication by persistent use of insecticides, and destruction of vegetation. Establishment of the refugee village of Etsha.	Expansion of human settlement toward the Delta.
CORONA: 25 September 1967.	First synoptic image coverage of the Okavango Delta Thaoge's floodplains completely flooded.	Evidence of sustained flooding.
GOB: Early 1970s.	Aerial spraying of tsetse and opening up of Thaoge's floodplains for present settlements.	Sedentary human occupation.
Dept of Water Affairs and German Volunteer Service: 1985–1992.	Major channel straightening and canal works in Gumare's Thaoge floodplains to increase flow for planned irrigation of the Nokanaeng flats.	Failure to restore downstream flow in the Thaoge River.

3.2 Environmental trends from material artefacts and field observations

Figure 2 shows remains of Brind's machine, a papyrus swamp in the present Delta's perennial floodplain and a portion of the now-dry Thaoge River, with the latter two illustrating the magnitude of changes associated with floodplain desiccation.

Apart from pointing to climate-induced hydrological failures, brief operation of Brind's machine by floating it in the Thaoge River indicates a perennial deep-water environment. With natural and non-natural factors reinforcing each other, mechanical clearance failed to provide a viable means of clearing vegetation blockages as channel flow retreated upstream. Although the Thaoge's northward retreat opened up new grazing frontiers, effective use of these grazing areas was delayed by the presence of tsetse-fly. After the early 1960s, repeated use of aerial spraying led to eradication of tsetse fly and by the early 1970s the Thaoge valley was tsetse-free and open for permanent human settlement [10]. Habitat conditions were now favourable for sedentary occupation. Farmable areas began to be regularly cultivated. Herders exploited the victory against tsetse by re-colonizing grazing areas used earlier before the outbreak of trypanosomiasis. Over time, consolidation of these livelihood activities imposed additional stresses by accelerating climate induced changes. But most of the local people appear to be convinced that these adverse changes are not caused by human resource use practices.

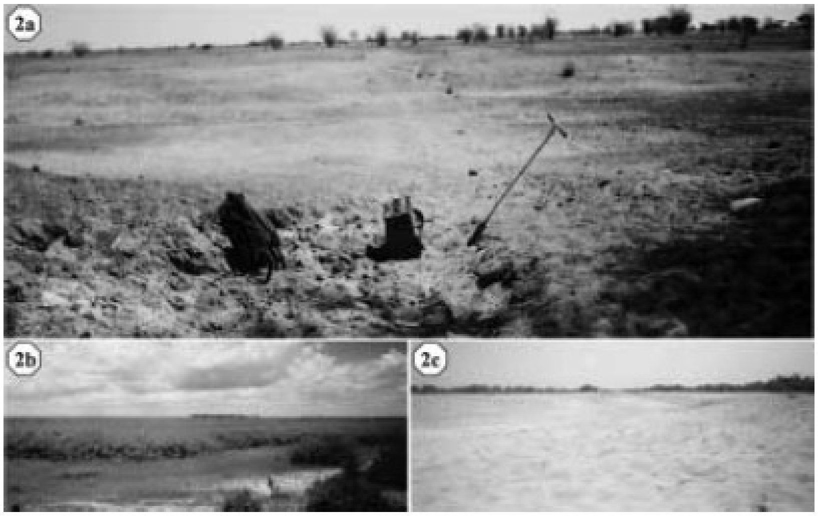

Figure 2. Remains of Brind's papyrus clearing machine used during the 1950s, a papyrus swamp in the present delta's permanent swamps and a portion of the now-dry bed of the Thaoge River's floodplain: 2a) one of Brind's twin-engine blocks (middle centre) for his papyrus cutting machine on the banks of the Thaoge River; 2b) dense papyrus in permanent swamps east of the Thaoge River's emergent floodplain (March 2001), much like the sea of papyrus observed by Brind in the 1950s; 2c) the now-dry Thaoge River, 7 km below its exit point from the Okavango Delta. This environment was similar to what is shown in figure 2b during the early 1950s. *Source*: [3].

3.3 Environmental trends from oral histories and local people's perceptions

Table 3 summarizes local people's perceptions of environmental changes in their localities around Gumare.

Table 3. Local people's perceptions of environmental change/s around Gumare.

	Percentage of responses by direction of change			Trends and perceptions by local people	
Variable investigated	No change	Increase	Decrease	Perceived cause/s of trend	Perception by majority
Surface water			100	4+9	11
Ground water			100	4+9	5
Grazing			100	3+4	5
Rainfall			100	4+9	5
Woody cover		85	15	9+10	2
Crop harvests			100	4+11	5
Arable agriculture			100	4+11	5
Reeds and papyrus			100	5+9	5
Thatching grass			100	3+5+9	5
Medicinal plants	42		58	3+5+9	10
Protected wildlife	9	84	7	7+9+18+15	3
Non-protected wildlife			100	5+12	5

Key to perceived cause/s of observed trend by individual respondents				**Key to major trend perception by majority of respondents**		
1	Increase	10	Natural increase	1	No change, 2 minor increase	
2	Decrease	11	Flood failures	3	Major increase	
3	Overgrazing	12	Increased human presence	4	Minor decrease	
4	Rainfall failures	13	Decreased forage availability	5	Major decrease	
5	Increasing demand	14	Abandonment of arable land	6	Uncertain, 7 variable	
6	Decreasing demand	15	Conservation protection	8	Minor deterioration	
7	Increasing numbers	16	Increasing livestock numbers	9	Major deterioration	
8	Shrinking habitat	17	Decreasing livestock numbers	10	Marginal scarcity	
9	Natural change	18	Increasing wildlife & predators	11	Severe scarcity	*n* = 33

Source: [3].

In general, the majority of local people are in unanimous agreement on persistent surface water contraction, and similar decrease in groundwater and grazing resources, with natural change in the form of declining rainfall and flood failures being cited as primary causes of these downward trends. There is an overwhelming conviction that these climate driven changes are largely responsible for recurring crop failures and increasing scarcity of homestead construction materials such as reeds, papyrus and thatching grass (table 3). Although most of these submissions agree with historically reconstructed trends that point to flood and rainfall failures (table 2), what seems to be lacking in local people's perceptions is a conscious acknowledgement that human resource use practices tend to reinforce adverse changes initiated by natural factors. For example, overgrazing as an inciting factor behind bush encroachment is generally beyond the range of most people's appreciations, although the same phenomenon is widely considered to be a major cause of deteriorating grazing conditions. The tendency to externalize blame is further apparent in reluctance to acknowledge human over-exploitation of natural resources such as thatching grass, medicinal plants and non-protected wildlife species; with conservation being singled out as a major factor accounting for the increase in 'problem' animals such as elephants. While conservation partly explains the latter phenomenon, full recognition of the role played by man-made habitat changes is lacking. Although there is a disproportionate tendency to associate deteriorating conditions with natural factors, local people's perceptions, together with what is inferable from historical evidence, including artefacts, suggest that the direction of environmental change in this area is the combined outcome of interaction between natural and human factors. This assertion is supported by trends that emerged from the interpretation of satellite imagery for the period between 1967 and 2001.

3.4 Environmental trends from satellite imagery: 1967–2001

Trends in the distribution of different land cover types between 1967 and 2001 confirm that environmental conditions continued to deteriorate during the second half of the 20th century. During this period, surface water distribution in the Thaoge River's floodplain east of Gumare contracted by 12.8%, with over 98% of this decrease occurring during the 22 years before 1989 (figure 3).

Since this is the same area targeted for mechanical blockage-clearance and channel dredging during the early 1950s and mid 1980s (table 2), with the Thaoge River never recovering up to the present, validity of the climate hypothesis becomes apparent, although human agency cannot be completely ruled out. In terms of livelihood strategies, drying sequences prompted a wide range of human responses. These substantially influenced the direction of environmental change. For the village of Gumare, progressive retreat of the waterfront distanced perennial surface water sources, while floodplain desiccation deprived local people of a vital source of livelihood, because drying sequences reduced the viability of flood recession cultivation. Although these impacts appear to have been of direct relevance during and immediately after the 1970s, these adverse effects were precursors to downward trends, accelerated by negative human interference. Flood and rainfall failures had far reaching consequences for people whose livelihoods depended on livestock farming, dryland cultivation and flood cropping. Arable land could not be mapped because of the inability of Landsat's coarse 30 m-resolution to detect the small land-holdings used by farmers in this area, but trends in the distribution of wetland provide informative insights. In the two decades after 1967, the amount of wetland significantly declined (figure 3) with this unprecedented decrease drastically reducing the viability of *molapo* (i.e. in local language, flood recession,

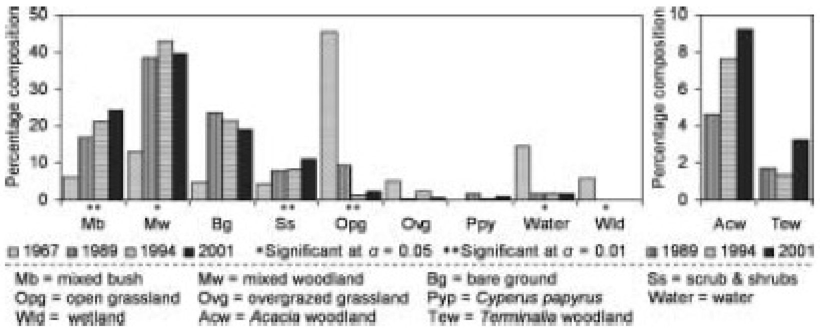

Figure 3. Composite illustration of temporal variations in the distribution of all cover types (1967–2001) and woody information classes by species type (1989–2001) that were mapped from satellite imagery for the Gumare study area. *Source*: [3].

cultivation) cultivation. In an environment where unreliable rainfall made rain-fed crop production inherently risky, flood cropping broadened adaptation by providing some form of insurance against drought-induced crop failures. As flood and rainfall failures persisted, farmers were forced to shift emphasis from crop to livestock farming. Initially, this worked well. Livestock farmers simply re-distributed their grazing resources, dispersed their herds, and relied on grazing in the Delta's seasonal floodplains. Although these coping strategies allowed livestock to survive periods of prolonged drought, the introduction of cordon fences, designed to control the spread of diseases by separating livestock from wildlife, imposed drastic restrictions on traditional herding practices [3]. These fences greatly reduced options for adaptation: livestock farmers had to over-exploit confined grazing resources while drying sequences imposed reduced access to homestead construction materials found normally in wetland, especially *Phragmites australis* and *Cyperus papyrus* (table 3). This forced people to adjust by exploiting dryland grasses. Although data on the contribution of wetland materials for homestead construction are not available, deprivation of these resources caused competition between man and animals for veld-grasses. These competing demands entailed overexploitation of substitute materials and substantial increase in woody cover as grazing areas contracted.

Between 1967 and 2001, mixed bush and mixed woodland significantly increased by 18.2% (á = 0.01) and 26.4% (á = 0.05) respectively, with the latter's increase appearing to have been mostly a narrow range of individual species. After sub-sampling and excluding *Acacia* species and *Terminalia sericea*, it was found that mixed woodland declined by 5% between 1989 and 2001 while mixed bush maintained its significant upward trend. This observation suggests that most of the increase in mixed woodland was accounted for by *Acaci*a species and *T. sericea* while the uninterrupted increase in mixed bush indicates rapid bush encroachment at rates exceeding trans-generational shifts to woodland. The fast increase in mixed bush can be explained by causes that released potentials previously inhibited by specific factors. Candidate factors providing plausible explanation include overgrazing and drought-induced abandonment of arable land. Evidence from field investigation revealed numerous landholdings under different stages of bush encroachment within the village's perimeter margins with persistent rainfall failures (table 3) providing the most plausible explanation for the abandonment of arable land. To enhance objective assessment of human-environment interactions, gradient graphs (figure 4) were used to investigate the localized influence of population concentration, on the hypothesis that the intensity of human resource use is inversely related to distance from the village centre.

While the 0–2 km buffer zone exhibited a marginal 3% increase in mixed bush between 1989 and 2001, mixed woodland declined by 12% (figure 4). While drying sequences impose widespread abandonment of arable land, demands for brush-wood fencing to protect crops from livestock and wildlife as in other crop producing areas like Shakawe, fail to provide a relational explanation for the localized decrease in mixed woodland around Gumare. Although the fuel-wood foraging hypothesis might partly explain the observed decrease in mixed woodland [21], rapid population growth illuminates the most likely cause of this spatially confined decline.

During the 20 years between 1981 and 2001, Gumare's population increased by over 51% from 3653 to 7478 [22]. This growth implied corresponding increases in the demand for residential plots and amenities such as schools, clinics, administrative offices and a new airstrip as the old one was abandoned. In this regard, wide ranging factors rather than firewood exploitation *per se* offer a more plausible explanation for the sharp decrease in mixed woodland between 1989 and 2001. Trends in outlying areas show that the effects of land use

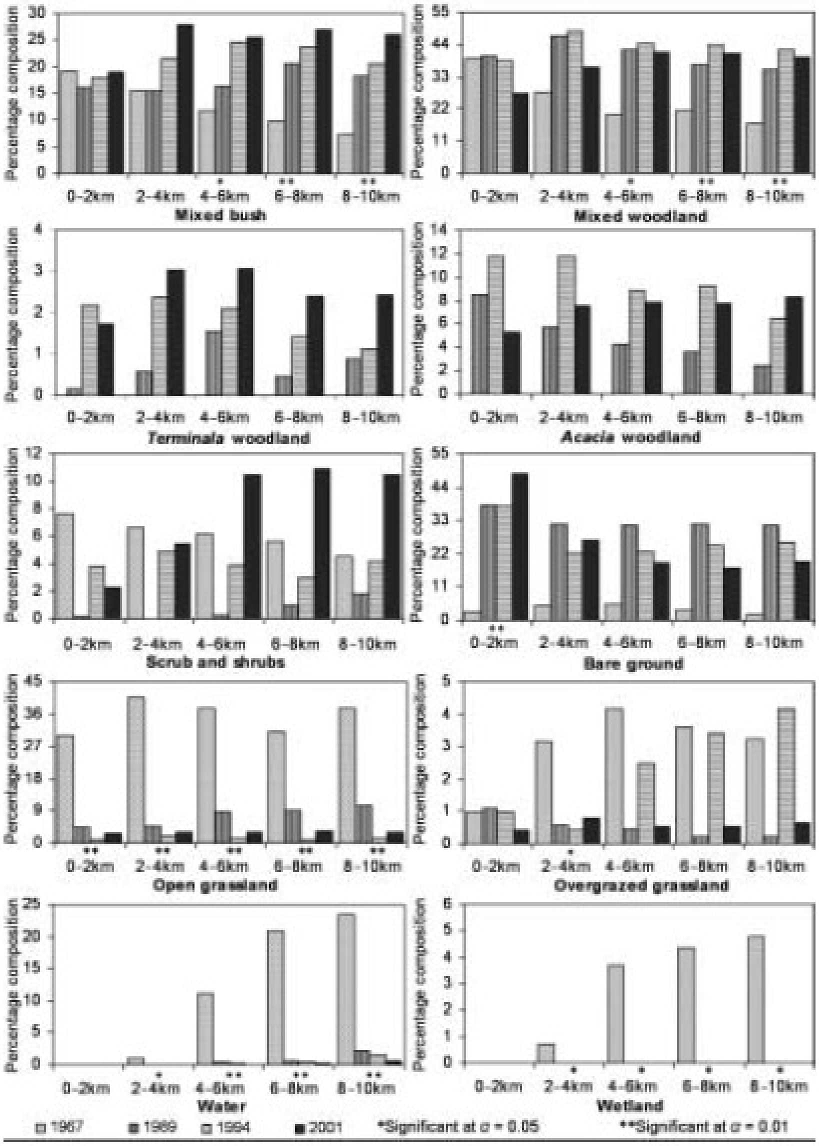

Figure 4. Temporal variations in the distribution of selected cover types by buffer zone around Gumare: 1967–2001. *Source*: [3].

zoning are captured by gradual increase in woody cover: 1.6% for the 2–4 km and 7.1% for the 8–10 km buffer zones between 1989 and 1994 (figure 4). In this instance, the positive correlation between distance from the village and woody cover distribution reflects policy-determined spatial variations in levels of resource exploitation; with other intervening factors, such as heavy browsing by elephants, explaining the decrease in outlying areas between 1994 and 2001. Although buffer analysis provided some useful insights, this technique could not capture the spatial bias in woody cover increase toward dryland, with emergent floodplains exhibiting marginal bush encroachment. This variation can be explained by the nature of floodplain emergence. Because of gradual dry-down, water tables declined in a similar manner to the extent that protracted persistence of soil water-logging delayed the successful establishment of species adapted to water-deficit conditions. Related to this constraint was a poorly developed seed-bank on account of the prolonged residence of water prior to floodplain desiccation. This retarded successful establishment of woody cover. For species such as *Acacia erioloba,* successful establishment was contingent on seed dispersal by livestock whose numbers were drastically reduced by prolonged drought between 1978 and 1987. Additional inhibitions came from establishment of a fire-prone environment that suppressed the pioneer establishment of woody seedlings [3]. While mixed bush and mixed woodland exhibited variable trends, *Terminalia* and *Acacia* woodland increased by 1% and 4%, respectively (figure 4).

Although temporal variations in the former were marginal, there was observed to be a periodic trend. Between 1989 and 1994, *Terminalia* woodland decreased by 1% after which a two-fold increase was observed. The most likely cause of this periodicity appears to be related to spatial trends in the physical growth of the village. Two observations help to explain how this phenomenon influenced trends in the distribution of *Terminalia* woodland. The first, mentioned above, relates to planning regulations that require new residential plots to be established within officially prescribed boundaries of the village. This requirement implied that although substantial ground was cleared in the initial phases of the village's rapid expansion, further clearance of areas beyond specified limits was impossible. This restriction facilitated the increase after 1994. The second observation concerns the centralized provision of piped water which appears to have encouraged homestead nucleation. The combined outcome was that although population continued to increase, there was no corresponding frontier expansion of the village potentially capable of undermining the natural increase in *Terminalia* woodland. This view is supported by results of buffer analysis that indicate progressive increase in all buffer zones, with areas beyond 4 km from the village centre exhibiting substantial increase, while inner buffer zones within the 4 km radius exhibited marginal expansion. Marginal increase in the latter category is consistent with the finding that in general, environmental pressure gradually diminishes with increasing distance from the village with significant increase in outer zones further confirming the spatial effects of land use zoning.

From the standpoint of human impact on the environment, the trends described suggest that although deforestation features frequently in the literature, there is no evidence of this phenomenon around Gumare. Instead, the opposite situation is evident, with indications suggesting that deforestation through overexploitation for firewood is an oversimplified generalization. This view is supported by the persistent increase in *Acacia* woodland, though largely confined to upland areas outside the emergent floodplain (for reasons stated above) with spatial bias toward the former indicating the combined influence of overgrazing and declining rainfall. These factors appear to have reinforced each other to induce and accelerate bush encroachment and progressive contraction of grazing resources as open grassland declined. Though *Acacia* woodland exhibited a persistent upward trend, buffer analysis revealed spatial variations that point to the possible influence of other factors apart from overgrazing and deteriorating rainfall. In the innermost 0–2 km buffer zone, trends similar to those observed for *Terminalia* woodland emerged. But the long-term upward trend in *Acacia* woodland was more prominent in the 8–10 km buffer zone where an uninterrupted 5.9% increase was observed while other zones exhibited initial increase and a terminal decline between 1989 and 2001 (figure 4). Terminal decrease in the 2–8 km buffer zones can be explained by increased elephant activity in this environment. Field observations of elephant damage to woody vegetation in these localities revealed knockdown of favoured species especially *A. erioloba*, excessive browsing and pollarding of *Acacia mellifera* and uprooting of selected species notably *Ximenia americana*. Though elephant damage to vegetation is a major cause for concern, the same damage has also provided substantial firewood to the local people. Contrary to expectation, the majority of people interviewed reported difficulties in obtaining firewood because of increasing scarcity (table 3). Absolute scarcity appears unlikely in view of the sizeable amounts regularly contributed by elephants. Instead, the major causes of the reported difficulties appear to be directly related to shortages of labour and suitable means of transport. The large specimens often favoured by elephants make head-loading and transportation by donkey carts extremely difficult. The firewood problem in Gumare has to be considered as arising mainly from lack of means to harvest what is available with reports of increasing shortages in the literature suggesting misrepresentations that fail to capture the underlying causes of the problem.

Equally important is the fact that persistent increase in woody cover was inversely related to observed trends in the distribution of open grassland which significantly (á = 0.01) contracted by nearly 44% between 1967 and 2001 (figure 3). Although deteriorating rainfall contributed to the observed decrease in open grassland, its effects on herb cover dynamics were both direct and indirect. Direct effects included wet season decrease in production as below average rainfall induced rangeland deterioration. Indirect effects included declining rainfall, which facilitated bush and scrub encroachment by conferring competitive advantages to deep-rooting species such as *Pechuel loeschea* and *Grewia flava* that are better adapted to moisture deficiency compared to shallow-rooting grasses. While mixed bush significantly increased, similar trends were also observed in the distribution of scrub and shrubs. Between 1967 and 2001, scrub and shrubs significantly (á = 0.01) increased by 6.6%. This expansion further reduced the proportion of open grassland by replacing incompetent grasses of higher nutritive value. Consequently, while open grassland declined in terms of spatial coverage, the quality of grazing also declined as less palatable species increased. Bush encroachment is unlikely to have yielded usable browse to compensate for forage losses associated with the persistent decrease in open grassland. The beneficial effect of bush encroachment often suggested on the basis of increased browse [23] is not straightforward. Dry-season *Acacia* foliage has a poisonous tannin build-up that affects fodder digestibility by causing fermentation in the rumen [24]. This countervailing factor suggests that bush encroachment does not always yield usable browse for livestock. An additional consideration often overlooked is that, not all browse irrespective of digestibility is practically accessible to livestock. Unlike the giraffe, for example, physiologically adapted to reach browse at crown level in most bushes, cattle and goats have a lower browse-line. This physiological limitation implies that the high quality browse at reachable heights for the giraffe is inaccessible to domestic stock, with high bush densities further aggravating this phenomenon by establishing impenetrable thickets where the accessibility of browse is restricted to the expansion front. This phenomenon was observed in different localities of the study area where *A. mellifera* and *Dichrostachys cinerea* tended to be dominant in abandoned arable land and overgrazed areas.

Regarding the latter, heavy grazing by zebra was observed in areas distant from the fossil floodplains, leading to extensive overgrazing spatially unrelated to the confined occurrence of perennial surface water in the permanent floodplains. Though boreholes are used country-wide to mediate the effects of surface water shortages, livestock farming in this area largely depends on hand-dug wells in the Thaoge valley. The spatial impact of these artificial water sources is broadly spread out in the form of overgrazing, although in terms of long-term trends, the area mapped as overgrazed grassland from satellite imagery actually decreased instead of increasing. This apparent contradiction can be explained by considering a grazing resource base that had declined to a point where overgrazed grassland ceased to be detectable. In a comparative investigation of trends in land use under different levels of population pressure in Zimbabwe's Gutu district of Masvingo province, Hamandawana [25] observed similar trends in communal areas (CAs), where increasing numbers of livestock between 1967 and 2000 initiated overgrazing to levels where it became meaningless to use herb cover distribution as an indicator of grazing conditions.

In a follow-up investigation, Hamandawana *et al.* [26] observed similar trends in the Serima communal area of the same district, with over-exploitation of grazing resources through increasing numbers of livestock again emerging as the major cause of downward trends in herb cover distribution. Although examples of such situations are many, the common denominator in most cases is the large number of livestock in environmental settings where forage demands exceed rangeland productivity. Extreme variations in human population densities exemplified by Botswana's national average of three people/km^2 in rural areas and Zimbabwe's 50 people/km^2 in the case of Gutu district, suggest that although demographic pressure has a bearing on common access resource use, management regimes play an equally important role. In Gumare's immediate environs, human numbers *per se* do not offer a plausible explanation of deteriorating conditions. In 2001, Gumare's population was 7478. Assuming a conservative distribution of land by restricting this population to the 900 km^2 investigated in this study area, the population density during this period was 8.3/km^2. Although this density is six times less than Zimbabwe's 50 people/km^2 in CAs, similar trends characterized by severe overgrazing were observed in both areas. This suggests that the management dimension has more to do with the downward trends observed in Gumare, since despite low population densities, negative trends at magnitudes comparable to those in areas with higher population densities were still evident.

Although careful consideration of the factors described above is necessary to enhance objective assessment of trends in land cover distribution, the major insight from the above discussion is that overall, grazing conditions substantially deteriorated; with human agency appearing to accelerate naturally induced downward trends that are likely to continue as scrub and shrubs, mixed bush and mixed woodland continue to increase. Although the expansion of woody cover should have begun a corresponding decrease in bareness, the opposite situation was observed, with bare ground increasing by 14.2% between 1967 and 2001. This anomaly can be explained by floodplain emergence and the rapid growth of infrastructure during the same period as Gumare's population increased. Though floodplain grazing occasionally improves in years of good rainfall and high floods, cover quickly disappears from heavy grazing and the high frequency of peat fires [27]. These fires suggest that floodplain emergence in this environment is a recent phenomenon, with little passage of time between now and the last regular floods that supported active *papyrus* growth. This explains why combustible peat has not yet been exhausted. It may be noted that our understanding of planetary change processes in general and global warming in particular can be enhanced by investigating the contribution of these peat accumulations to carbon sequestration.

4. Survey of the role of human factors in the degradation of natural resources

From this analysis of the different types of data, the direction of environmental change in this sub-region can be summarized as indicating: 1) progressive expansion of woody cover at the expense of open grassland; 2) contraction of grazing through the combined effects of bush encroachment, overgrazing and deteriorating rainfall; 3) noticeable decrease in the quality of grazing through the progressive increase in scrub and shrubs of low nutritional value; 4) persistent drying sequences and progressive stream shortening with surface water becoming scarcer compared to higher flood years of the recent historical past; 5) disappearance of wetland materials for homestead construction materials and associated overexploitation of substitute materials; 6) declining levels of dryland and floodplain cultivation through the combined effects of deteriorating rainfall and persistent flood failures; 7) accelerated degradation of natural rangeland caused by shifts in emphasis from arable farming to livestock production; and 8) artificially induced crowding of livestock and wildlife through habitat partitioning to facilitate tourism oriented wildlife conservation.

5. Conclusion

This paper has examined the role of human factors in the degradation of natural resources in and around the Okavango Delta. The direction of environmental change in this sub-region is to a large extent the convergent outcome of interaction between natural and human factors. Under the former category, sustained decrease in rainfall appears to have been the primary instigator of downward trends from a wide range of drivers whose adverse environmental effects have been aggravated by human agency. Regarding the latter, human interventions have accelerated adverse changes instigated by natural processes while in other instances, human agency went further to cause externalities that reinforced the former in determining the direction of environmental change. Evidence from the second half of the 19th century up to the present points to progressive deterioration of environmental conditions and limited prospects for reversal of downward trends. Mistakes of the past need to be avoided by formulating appropriately informed human response and adaptation strategies which include sustainable resource use practices. These might include planned designation of bush-encroached areas to wildlife management and the development of a number of lighter-weight papyrus cutting machines in keeping with the needs of local people and the availability of modern metallurgy.

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