Restoration and Rehabilitation of Zibadianja Lagoon in Kwando-Linyanti River System in Botswana

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Abstract

The 2003 drying of Zibadianja Lagoon (and its reserve) situated on the south of Kwando-Linyanti Rivers in Botswana had negative impacts on the tourism in the concession area operated by a commercial tour operator. Aerial surveys and extensive ground studies were undertaken to investigate the factors responsible for reduced flows into the lagoon. Fifteen years hydrometric data collected in the Kwando and Linyanti Rivers were used to substantiate the changing flood regimes into the lagoon. The inflow channels to the lagoon with extensive blockages were identified and water flow measurements in the channels were determined on monthly basis before and after the clearance of blockages. The flow measurements and monitoring indicated that the water flow reductions in the Kwando River over a time scale, the development of vegetation blockages in the supplier channels, wildlife grazing and rising of sediments facilitated the drying of the Zibadianja lagoon. The feeder channels to the lagoon had been continuously monitored and managed to restore the hydrology and to rehabilitate the ecosystem in the area, which has improved the tourism activities.

Introduction

The Cuando River (figure 1A), as it is called where it originates, rises in the central plateau of Angola, and then flows southeast, along the border with Zambia. Along this stretch it flows in a maze of channels in a swampy corridor 5-10 km wide. As with all rivers in south-central Africa, its flow varies enormously between the rainy season when it is flooded and may be several kilometers wide, and in the dry season it may convert into marshes. The Cuando continues in its marshy channel across the neck of the Caprivi Strip (figure 1B) of Namibia and then forms the border between Namibia and Botswana as it continues south-east. Several prominent changes took place in its flows since the last 10,000 years (http://en.wikepedia.org/wike/Chobe_river). Presently the Kwando River (figure 1C), as it is called in Botswana and Namibia, terminates into the Linyanti River (figure 1D) and has diverted east to connect to the seasonal lake 'Lake Liambezi' (figure 1E), and from this point the river is called Chobe (Figure 1F), which is connected to the Zambezi River at Kazungula (figure IG). The Linyanti River had been dry since the 1980s in its terminal section up to the Lake Liambezi. In years when the Okavango experiences a good flood some of the water escapes east along the normally dry channel of the Magwegqana River (Selinda Spillway) (figure 1I) of the Okavango Delta (figure 1J) into the Kwando/Linyanti Swamp, thus connecting the Zambezi basin. It did not happen for the past 30 years but the Okavango Delta and Zambezi basin were connected by floods in 2008/09 and 2009/10 hydrological years.

The Kwando-Linyanti River system, thus, further northeast of the Okavango Delta forms a prominent geological feature. The Kwando River enters Botswana at Longitude 23^0 17'.855' and Latitude 17^0 59'.942 and the inflow discharges are measured at monthly intervals at Bates gauging station (figure 2). The river flows down to Sajawa (Sajaawa) after which it becomes Linyanti River joined by several cross-flow channels and floodplains between latitudes 18^0 15' and 18^0 30' along the Kwando River in the Eastern

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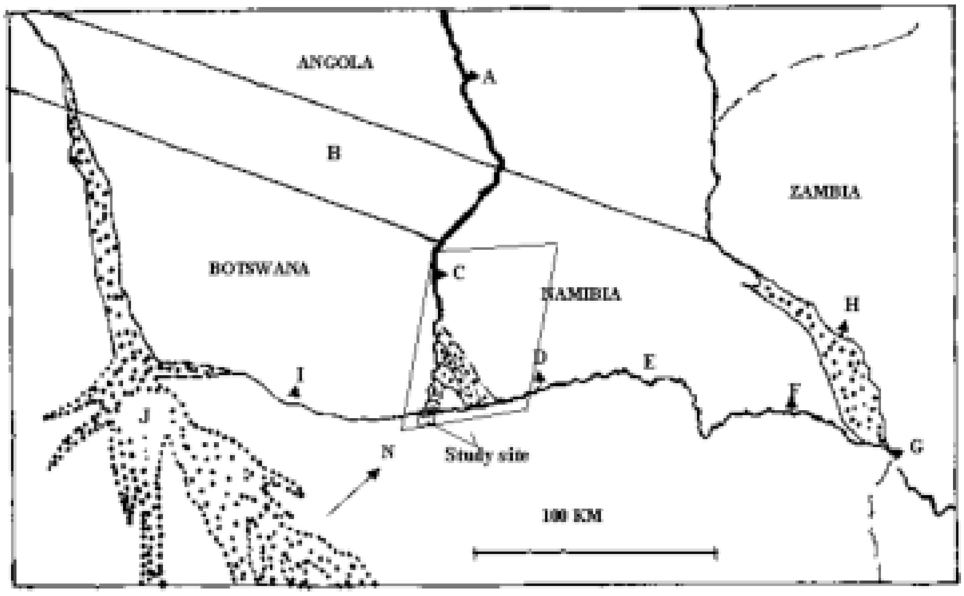


Figure 1: Okavango Delta, Kwando, Linyanti and Chobe River system. A = the Cuando River, B = Caprivi Strip, C = Kwando River, D = Linyanti River, E = Lake Liambezi, F = Chobe River, G = Confluence of Chobe and Zambezi River at Kazungula, H = Zambezi and Caprivi Swamps I = Magwegqana River, J = Okavango River Delta. Box encloses Kwando and Linyanti Rivers with the study site.

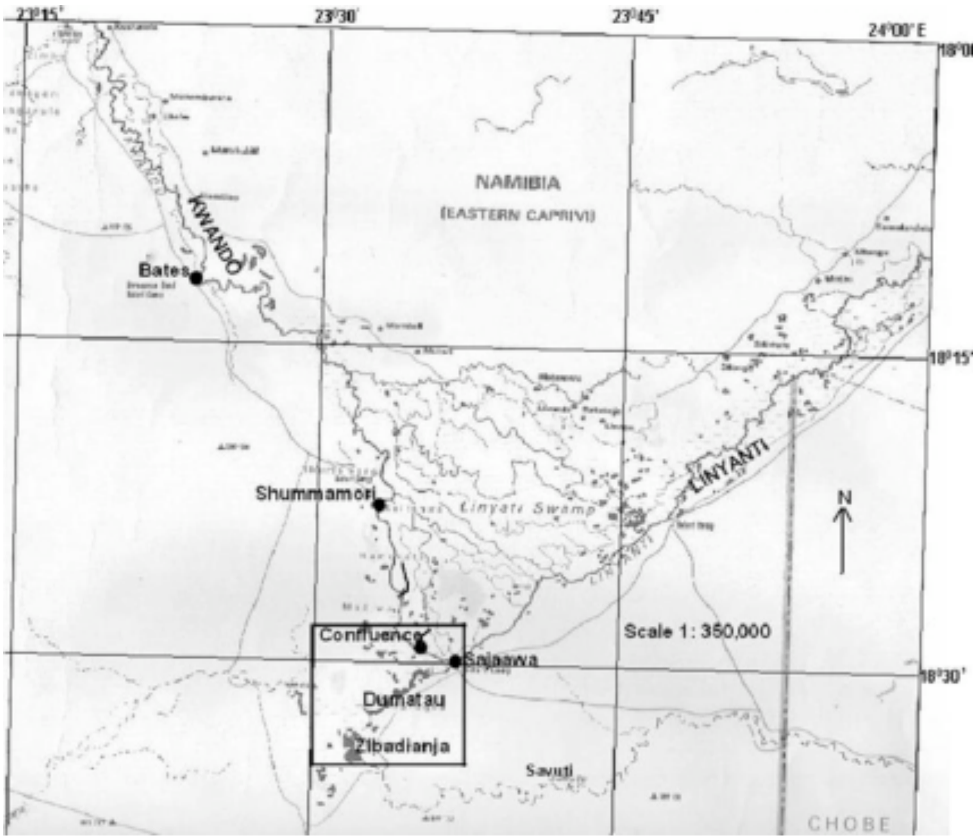


Figure 2: Kwando-Linyanti Rivers showing hydrological stations and the area of study in a square box.

Caprivi, Namibia (figure 2). The Kwando River produced 1 to 2 km wetlands along its length while Linyanti River does not have significant floodplains in Botswana except for the prominent Dumatau and Zebadianja Lagoons that have resulted to the south of the system. Significant declines in water levels in the Zibadianja Lagoon were observed in 2001 and the lagoon dried in 2003. It was against this drying phenomena that Linyanti Explorations (Pty) Ltd, a tourist company operating in the area, approached the Hydrology and Water Resources Division in the Department of Water Affairs to find out the hydrographical characteristics of the channels and the causative factors for the decline in the water levels into the lagoon. Unlike the Okavango Delta, the hydrology of the Kwando Linyanti River system is poorly studied. Therefore, this paper presents the primary attempt to monitor and study river flow characteristics in order to get a better understanding of the decline in the river flows to the Zibadianja Lagoon, especially.

Materials and Methods

This section provides a site description of the area under study. The Zibadianja Lagoon is approximately 2.67 km^2. The area of study is presented in Figure 2 in a square box with details in figure 3 showing the Dumatau channels (in a rectangular box) that supply water from the Kwando River to the Dumatau Lagoon, which in turn spill over to the Zibadianja Lagoon and Selinda Canal. The Dumatau Lagoon is connected to the Zibadianja Lagoon through the reed-blocked channel (figures 3). Being a large lagoon, the Zibadianja inhabits several hippopotami, large populations of fish and aquatic flora and fauna. The lagoon is the major tourist attraction for photography and game watching in the Kwando-Linyanti River system. The concession area belongs to Linyanti Explorations Private Limited, Botswana (Kurugundla and Mpho 2003).

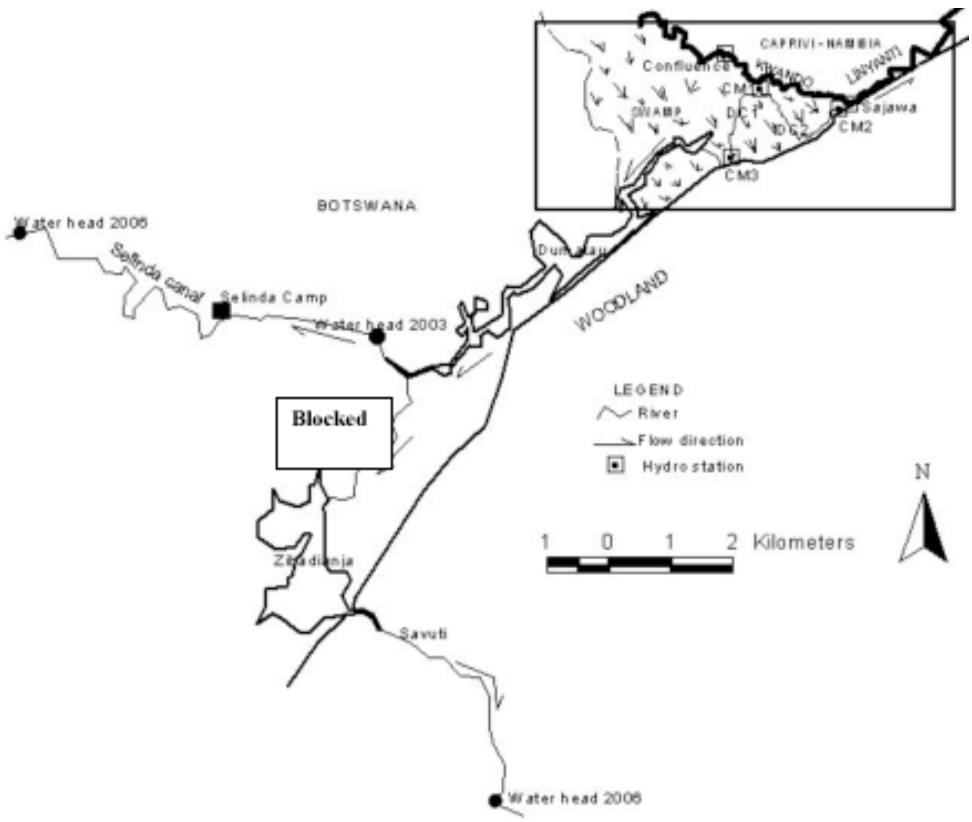


Figure 3: Network of outflow channels from Kwando River in a rectangular box flowing to Dumatau and Zibadianja Lagoons and Selinda canal. 'Water head' indicates the distances the water flows reached in 2003 and 2006. DC1 = Dumatau Channel 1, DC2 = Dumatau Channel 2 and the sites of water flow measurements: CM1, CM2 and CM3.

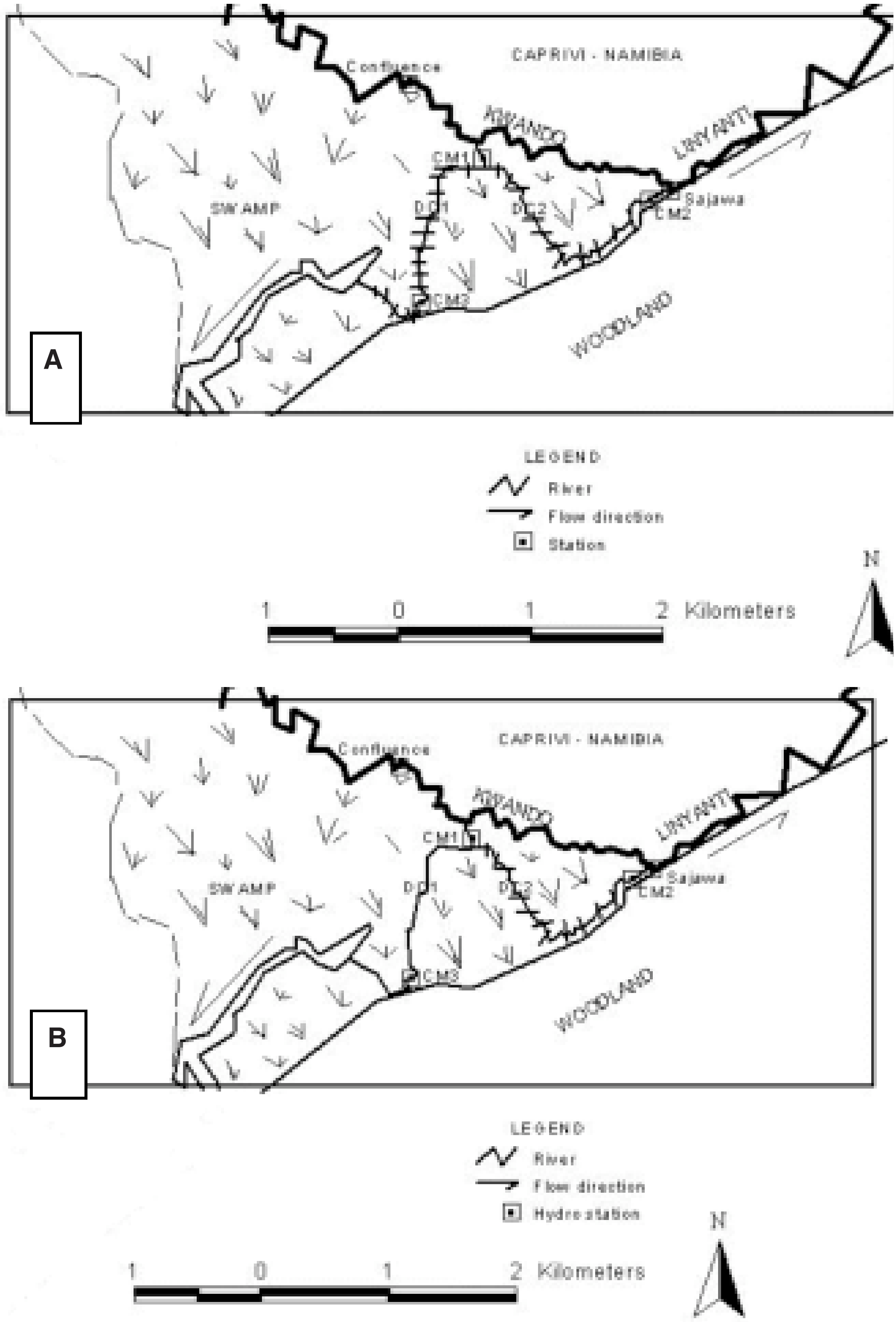


Figure 4: Details of Dumatau Channels, DC1 and DC2 and the sites of water flow measurements: CM1, CM2 and CM3. A represents channels with vegetation blockages indicated by cross lines while B is a representation of DC1 Channel after the blockage clearance.

Water Flow Data Collection and Measurements

The water flow discharge data for Bates, Shummamori, Confluence and Sajawa gauging stations (figure 2) from 1986 to 2006 used for the study was obtained from the Hydrology Division, Water Affairs, Gaborone. The monthly water discharges were computed to the annual million cubic meters (Mm^3), using Microsoft Excel. Using the annual million cubic meters at Bates, the percentage discharge flows arrived at Shummamori was determined for each year and similarly the percentage flows for Confluence and Sajawa were calculated in relation to the total annual flows of Shummamori and Confluence respectively.

It is important to provide information on surveys and description of Dumatau channels. Aerial surveys were undertaken over the Kwando River and Zibadianja Lagoon on 16 May 2003. Subsequently extensive ground surveys were carried out navigating the network of channels in the downstream wetlands on the south-west of Sajawa from 28 to 31 May 2003 (figures 3 and 4). The blocked narrow channels that flow into Dumatau Lagoon from the main Kwando River were identified and surveyed. The flow direction from Kwando River to Zibadianja Lagoon is: Kwando River→Dumatau Channels→Dumatau Lagoon. The Dumatau Lagoon bifurcates into the Zibadianja channel (blocked, figure 3) on the south and Selinda canal on the south westerly direction.

A channel originates from the Kwando River few meters in the downstream of Confluence hydrological station bifurcates into Dumatau channel 1 (DC1) and Dumatau channel 2 (DC2) (figure 4). The DC1 runs onto the south-west of Kwando River and finally flows down to Dumatau Lagoon (figure 4A). On the other hand, the DC2 runs on the south-east of the Kwando River and turns on to north-east along woodland to connect Sajawa hydrological station in the Linyanti River (figure 4A). Water flow velocities were measured at CM1 (Current Meter 1) just before the bifurcation of the two channels and at CM2 on DC2 just before it joins the Sajawa station from June 2003 to 2006. Flow discharges were also measured at the inflow point to Dumatau Lagoon at CM3 on DC1 (figure 4A). The monthly flow data measured between June 2003 to September 2006 at CM1, CM2 and CM3 were converted to annul million cubic meters. The percentage flows at CM1 was determined with respect to the Confluence discharges while the percentage flows for CM2 and CM3 were calculated by considering the total flows being shared from CM1 Point. DC1 was blocked at frequent intervals by papyrus while the DC2 was completely blocked with papyrus and reeds at the time of investigations. The blockages in Dumatau Channel 1 (DC1) alone were cleared between December 2003 and January 2004 (figure 4B). Vegetation clearances had been undertaken continuously as part of DC1 channel management since the year 2003 (Kurugundla and Mpho 2003).

Current metering measurements were conducted using two-point method, i.e., 0.2 and 0.8 m of the depth from surface at partial width across the channel. Two-point method is the most widely used method to measure the stream flows (Wisler and Brater 1978). Flow velocity measurements were taken at one or more points in the vertical at each width station by counting revolutions of the rotor during a period of not less than 50 seconds. The number of measurements was computed to obtain mean velocity. The current meter propeller formula used for the study and water flow velocity was determined using the formula Velocity = A*N+B, where A = 0.2467 and B = 0.014 or A = 0.2620 and B = 0.003 and they are constant. N = Number of revolutions = 36 counts/50 seconds = 0.72.

The current meters are calibrated and the manufacture company provides the formulae and they have different breaking points. The flow meter we used has the breaking point of 0.72 and its number is 195355. On the basis of the above formula, one can determine that the counts less than 36 fall within V1 = 0.2467*N +0.014 and the counts greater than 36 fall into V2 = 0.2620*N+0.003. Years represent the hydrological years that run from October to September. A manual gauge was installed in Dumatau Lagoon in June 2003 to record the water levels in the lagoon to determine whether the water levels in the lagoon would change before and after the clearance of the blockages in the Dumatau Lagoon.

Table 1: Blockage clearances in Kwando River in the upstream of Shummamori area.

From	To
21 March 1998	31 March 1998
22 April 1998	-
June1998	-
19 July 1998	25 July 1998
27 November 1998	30 November 1998
25 September 1998	12 October 1998
9 August 2000	12 September 2000
June 2000	December 2000
June 2001	November 2001
May 2002	September 2002
24 February 2004	25 February 2004
6 March 2004	9 March 2004
12 October 2005	17 October 2005
20 March 2006	24 March 2006

Results and Discussion

In riverine wetland systems like the Okavango Delta, within a single year vast areas of land can be flooded and then dry out leaving seasonal opportunities for various activities such as wildlife resource use, fishing, agriculture (flood recession farming), and collection of plant materials and for tourism. The above activities are absent in the Kwando-Linyanti River system even though tourism is very active in less demarcated wetlands on the Botswana side, especially in the Selinda, Zibadianja and Dumatau areas.

The annual flow discharge data from 1986 to 2006 collected at Bates, Shummamori, Confluence and Sajawa together with the flow discharge measurements of Dumatau Channels obtained between June 2003 and September 2006 are utilised for the study. Table 1 below shows the blockage clearances undertaken in the Shummamori section and does not mean that the vegetation was completely cleared in the sections. The percentage volumes arrived at Shummamori with respect to the inflow station at Bates, was higher between 1995 and 1999 compared to the flows arrived from 2000 to 2006 despite the higher inflows at Bates (figure 5). This shows that most of the volumes of water must have been diverted to the Caprivi between 2000 and 2006 apparently due to the blockages in the upstream of Shummmori (table 1). The distribution of flows to the east of the main Kwando channels as the result of aggradation due to vegetation blockages in the section of Shummamori was noticed as early as 1980s (Smith 1987). The percentage flows arrived at Confluence were higher from 1991 to 1994 (significant in 1993, +22.2%) than in the upstream at Shummamori (figure 6) and the gains in flows at Confluence (table 2) was due to the water that flowed back to the Kwando River through the narrow streams in the upstream of Confluence. The same gains in the flow pattern did not happen at Confluence (table 2) after 2002 for which the data is available apparently due to the blockage development in the upstream of the river (table 1). It should be remembered at this stage that the flows into Dumatau Channels at CM1, CM2 and CM3 increased (figure 10) as the result of channel clearance from December 2003 to January 2004. The gains in flows at Sajawa was higher between 2002 and 2006 except in 2003 (figure 7) because some of the filter flows flowed back to Sajawa not only via blocked Dumatau Channel 2 (DC2) (figure 4B) but also through the floodplain flow from Caprivi just after the Confluence station (table 2).

The distance between Confluence and Sajawa is 2.1 km and the flows were high up to 1996 implying that the sufficient flows flowed into Dumatau and Zibadianja Lagoons. Declines in flows after 1996 period at Sajawa probably resulted in insufficient flows into the lagoons (figure 7). Unless stated by Linyanti Explorations (dated 9 October 2001) that the Zibadianja Lagoon had low water levels in 2001 therefore the decline in flows into the lagoon could have been started as early as 1997 as shown in Figure 7 for Confluence station. The Zibadianja Lagoon last flowed out into the Savuti channel (figure 9) in 1992 and had more than 75% water in 1999 (Mpho 2002), mainly due to higher rainfall in Selinda area (figure 8).

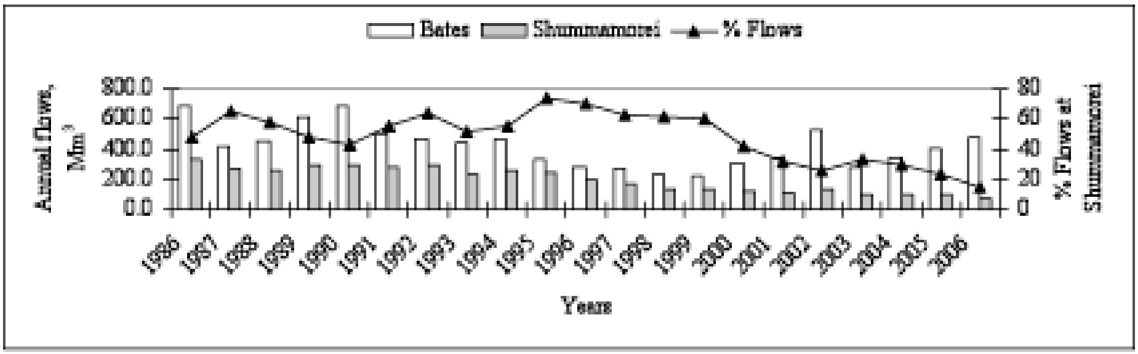


Figure 5: Annual flows at Bates and Shummamorei and percent flows arrived at Shummamorei.

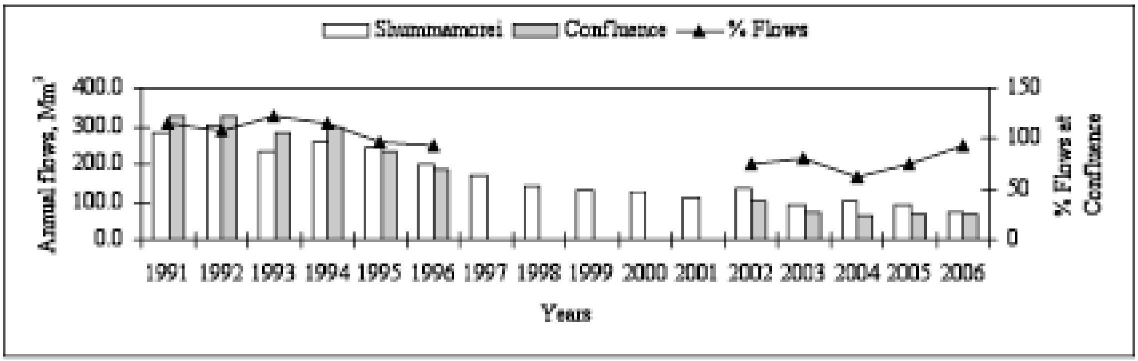


Figure 6: Annual flows at Shummamorei and Confluence and percent flows arrived at Confluence.

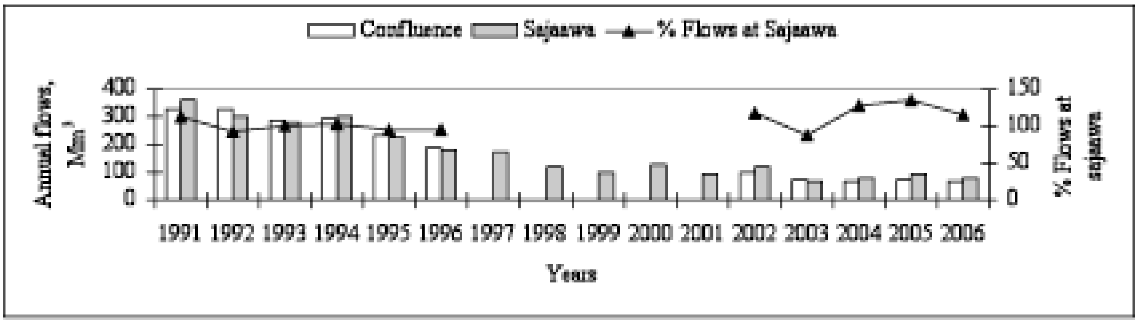


Figure 7: Annual flows at Confluence and Sajawa and percent flows arrived at Sajawa.

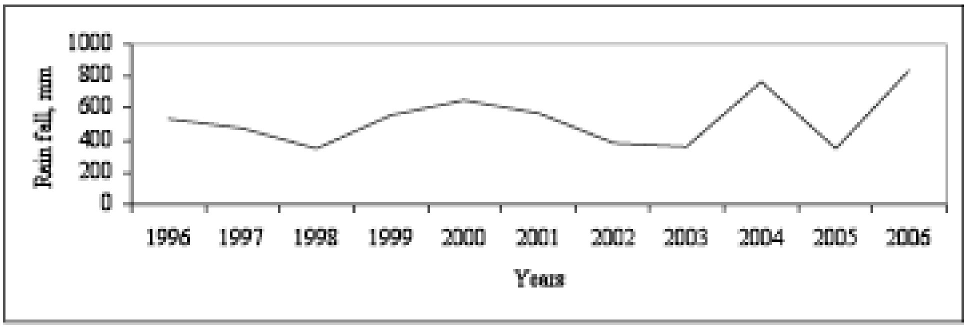


Figure 8: Rainfall at Selinda Station.

Table 2: Water flow losses and gains between Bates, Shummamori, Confluence and Sajawa hydrological stations on Kwando-Linyanti Rivers. *Loss = Evapo-transpiration, percolation and the volumes of water that would supposedly stay/flow in the section of the system; ^Gains = Water that flows back from floodplain to join the river at hydro-stations in the downstream so that the downstream discharges are higher than the upstream flows.

Hydrological years	*Loss (-) between Bates and Shummamorei	*Loss (-) and ^Gains (+) between Shummamorei and Confluence	*Loss (-) and ^Gains(+) between Confluence and Sajawa
1986	-52.5		
1987	-34.9		
1988	-42.1		
1989	-52.3		
1990	-56.8		
1991	-44.6	+15.4	+11.3
1992	-35.6	+08.3	-07.3
1993	-47.8	+22.2	-01.1
1994	-45.2	+14.9	-01.9
1995	-26.4	-02.3	-04.7
1996	-29.8	-06.1	-05.4
1997	-36.9		
1998	-38.3		
1999	-39.4		
2000	-58.4		
2001	-67.6		
2002	-74.7	-25.5	+18.1
2003	-67.1	-19.7	-02.8
2004	-69.9	-37.7	+28.3
2005	-76.8	-25.8	+33.8
2006	-84.8	-07.3	+15.1

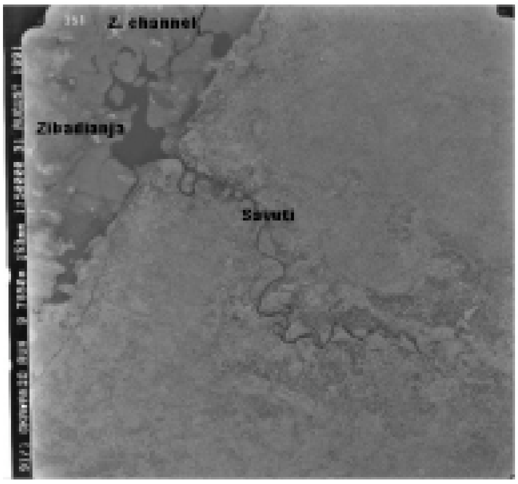


Figure 9: Aerial photograph of 1992 showing the ouitflows to the Savuti canal from Zibadianja Lagoon.

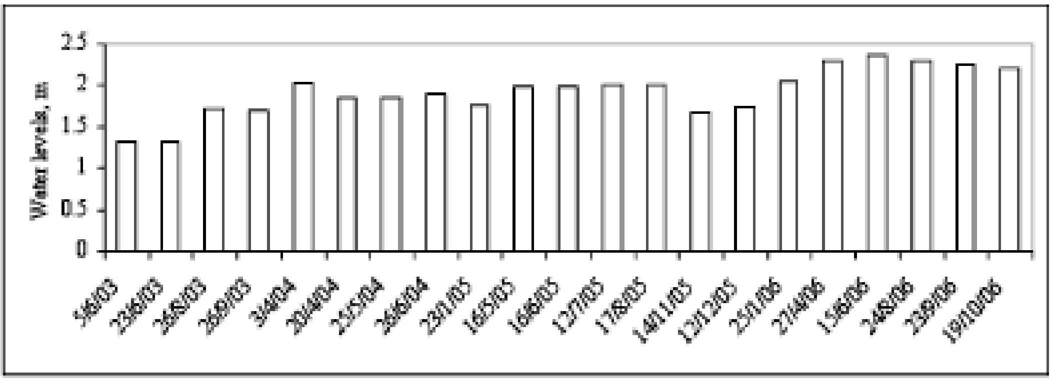
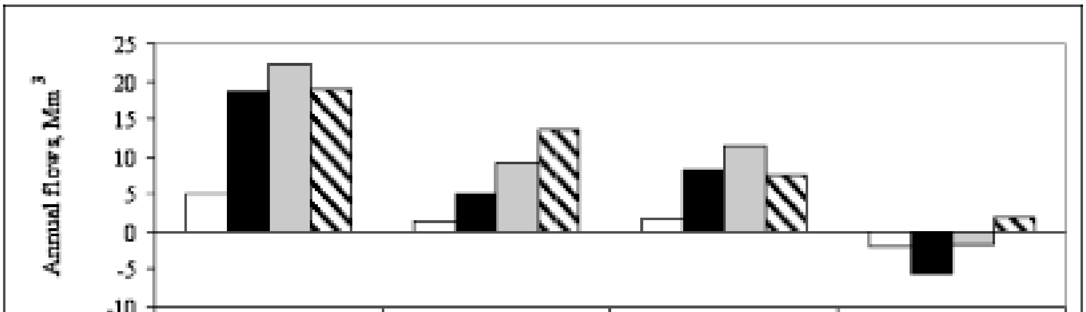


Figure 10: Annual flow discharges at CM1, CM2 and CM3. Losses and gains between CM1 and CM3 = Total Flows at CM1 – Back flows at CM2+Outflows at CM3. Flows in 2003 represent the discharges collected from June 2003 to December 2003 before the clearance of blockages.

The flow discharges recorded at CM1 and CM2 on Dumatau channel 1 and at CM3 on Dumatau channel 2 are presented in figure 10 above. Considerable volumes of water flowed to Sajaawa on Linyanti River through DC2 blocked channel at CM2 (figure 10). Outflows to Dumatau Lagoon at CM3 increased in 2005 (11.48Mm^3, figure 10), which was evident in the increase of rainfall in late 2005 and early 2006 (Figure 8). Floods arrived in Kwando River in March 2004. As a result, flows apparently increased in Dumatau channels (figure 10) after the clearance of vegetation blockages between December 2003 and January 2004 resulted in the gradual increase of water levels in Dumatau Lagoon (figure 11), which facilitated the filling of Zibadianja Lagoon with flood water even though the Zibadianja channel was blocked with reeds such as *Phragmites australis*, *Cyperus papyrus*, and tall grass (*Miscanthus junceus*).

The formation of vegetation (papyrus) blockages in the channels had been a common feature in the Okavango Delta (Wilson 1973; McCarthy & Ellery 1997; Kurugundla 2003) and such blockages are less pronounced in the Kwando-Linyanti Rivers. Bernard and Moetapele (2005) utilising the indigenous knowledge suggest that channel blockage played a part in the drying of Gomoti in the Okavango Delta. Dincer *et al* (1987) implied that the 1974 flood found new ways, increasing flow towards the Boro distributary in the Okavango Delta. The bed load and suspended sediments carried by Kwando River in the section between Confluence and Sajawa should be deposited only into the valley of Dumatau channel



	CM1-Total Flows	CM2-Back flows to Sajaawa	CM3-Outflows to Dumatau	Loss & Gain between CM1 and CM3
□ 2003	5.12	1.45	1.71	-1.96
■ 2004	18.77	4.98	8.11	-5.68
▨ 2005	22.42	9.24	11.48	-1.7
▧ 2006	18.96	13.54	7.41	1.99

Figure 11: Water levels in Dumatau Lagoon after the blockage clearance in the DC1 channel.

wetlands as the banks of the river on the north in Caprivi are solid and elevated. The potential importance of bed load sediments has been recognised in the Okavango Delta (UNDP 1977; Dincer *et al* 1981) and is associated with the aggradation of channels and the vegetation growth (McCarthy *et al* 1986; McCarthy and Ellery 1997).

The quantities of the bed load sediment and suspended material might be less important in the riverine channels as the high velocity is most unlikely to allow these sediments to deposit in the channel bed but the same have greater impact on the distal floodplains like Dumatau and Zibadianja areas that have low flood level regimes. Elephants, and other wild animals graze heavily in these areas and the impact on the vegetation is enormous. The resultant coarse material from the grazed vegetation could add to the system to increase the dissolved and suspended solids in the Dumatau channels. The blockages unless attended regularly the downstream wetlands would be on the way of extinction. Therefore continuous management of channels in the section of Dumatau is always essential on regular intervals for a long term sustainability of the biodiversity. Bernard and Moetapele (2005) suggest that the sediments and channel blockages played a part in desiccation. Indigenous management methods such as burning of vegetation in seasonal drying channels and continuous clearing of small channel blockages would sustain the regular downstream flows to protect the biodiversity and tourism.

Conclusions

The water resource use for the tourism sector has been recognised as one of the major activities to ensure the development of socio-economic conditions in the country. Hence there is a need for the sustainable utilisation and management of water resources in the tourism dominated concession areas. The plan of clearing the blockages in the channels for the communities and stakeholders utilisation, although not new in the country, the activity should be implemented on regular basis to manage the resourceful wetlands. The involvement of Linyanti Explorations in the clearance of blockages should be considered as the adoption of eco-tourism approach and the sustainable restoration of biodiversity in the Zibadianja Lagoon in the Kwando River. This would benefit the tourism and biodiversity, which does not negatively impact the ecology of the wetland system. There is a need, however, to review the hydrology of the inflow and outflow channels by the Department of Water Affairs regularly and the review process should take into account the socio-economic and environmental implications in the area. Finally, sustainable natural resource use will require concerted efforts and commitment by the stakeholders to ensure that socio-economic benefits are carried on in a sustainable manner.

Acknowledgements

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References

Bernard, T and Moetapele, N 2005, 'Desiccation of the Gomoti River: Biophysical process and indigenous resource management in Northern Botswana', Journal of Arid Environments, vol. 63, pp.256-283.

Dincer, T, Hutton, LH and Khupe, B 1981, 'Study, Using Stable Isotopes, of Flow distribution, Surface Groundwater Relations and Evapotranspiration in the Okavango swamp', Botswana IAEA Proc., Ser. ST1/PUB/493, pp.3-26.

Dincer, T, Child, S and Khupe, B 1987, 'A simple mathematical model of a Complex hydrologic system – Okavango Swamp, Botswana. Journal of Hydrology', vol. 93, pp. 41-65.

Kurugundla, CN 2003, 'Identification of Blockages in the Okavango Delta -Causes and Effects: An Interim Report, 04 February 2003', Department of Water Affairs. Gaborone: Botswana.

Kurugundla, CN and Mpho, M 2003,'Hydrological Phenomenon of Zibadianja Lagoon Kwando-Linyanti System', Botswana. 09 June 2003, Department of Water Affairs. Gaborone: Botswana.

McCarthy, TS. Ellery, WN. Rogers, KH, Cairncross, B and Ellery, KS 1986, 'The Roles of Sedimentation and Plant Growth in Changing Flow Patterns in the Okavango Delta', African Journal of Science, vol. 82, pp.579-584.

McCarthy, TS & Ellery, WN 1997, 'The fluvial dynamics of the Maunachira channel system, north-eastern Okavango swamps, Botswana', Water South Africa, vol. 23, pp.115-126.

Mpho, M 2002, 'Kwando-Savuti-Linyanti River System and its effect on Zibadianja Lagoon, 19 March 2002', Department of water Affairs. Gaborone: Botswana.

Smith, PA 1987, 'Salvinia in the Kwando-Linyanti River System, 3 July 1987', Department of Water Affairs, Gaborone: Botswana.

UNDP 1977, 'Investigations of the Okavango Delta as a primary water resource for Botswana', United Nations Development Programme: Food and Agriculture Organisation. AG DP/Bot/71/506.

Wilson, BH 1973, 'Some natural and Man-made Changes in the Channels of the Okavango Delta', Botswana Notes and Records, vol.5, pp.132-153

Wisler, C O and Brater, EF 1978, Hydrology: Stream Flow Records. New York: John Wiley and Sons.