Technical Note: Hydrology of the Bahi wetland, Tanzania

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Description

The Bahi wetland is a shallow ephemeral lake located in central Tanzania, approximately 60 km north-east of the city of Dodoma. Several studies have highlighted the importance of the lake and the surrounding wetland to local communities, who utilize it for cultivation, livestock keeping and fishing (Department of Irrigation and Technical Services, 2004; Yanda *et al.*, 2007). Located within the Bahi depression, a downwarped section of the Eastern Rift Valley, between latitudes 05°51' and 06°20' south and longitudes 34°59' and 35°21' east, the lake has a surface area of approximately 974 km^2 (Figure 1) and lies at an altitude of 830 masl. There is no outflow from the lake, which consequently varies considerably in size depending on precipitation in the catchment area. In some years the lake dries completely. The Bahi wetland receives water from various seasonal rivers, mainly draining from the north. Of these the Bubu and Mponde are the largest. Other rivers flowing into the lake are the Lawila, Nkojigwe, Msemembo, Maduma and Zuboro. The total catchment area of the lake is 23,447 km^2. All the rivers are ephemeral, usually ceasing to flow during the dry season (i.e. May to December).

Climate

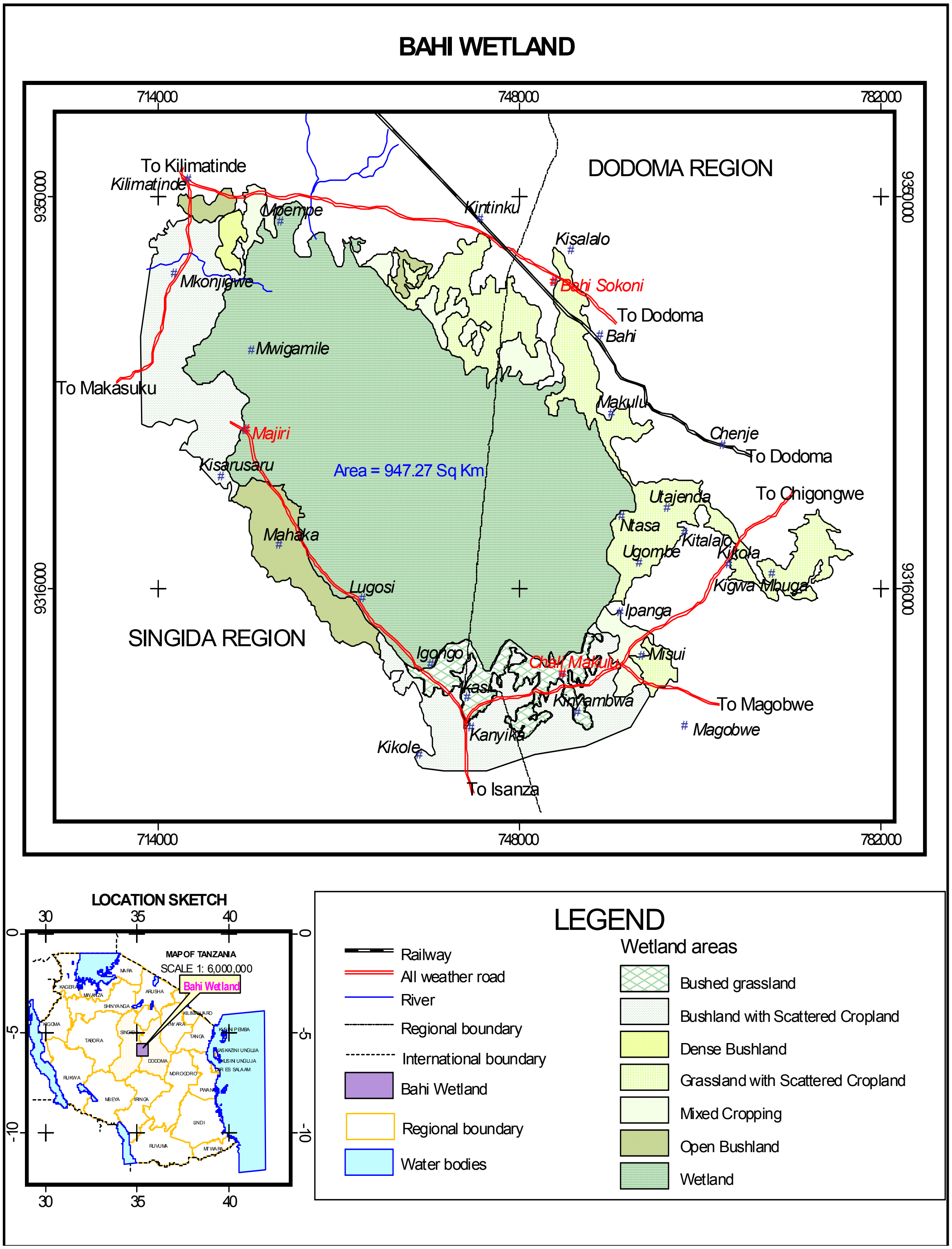
The climate of the region, largely controlled by the movement of air masses associated with the inter-tropical convergence zone (ITCZ), is semi-arid with a short rainy season extending from December to March. Mean annual rainfall across the catchment is approximately 600 mm with slightly higher rainfall at the higher altitudes in the north of the catchment (Figure 2). However, the rainfall pattern is irregular with significant variation from one year to the next and often several concurrent years with below average rainfall (Figure 3). Potential evapotranspiration (determined by the method of Penman-Monteith) is approximately 1620 mm and mean monthly values exceed mean monthly rainfall throughout the year (Figure 2). Table 1 lists the climate stations for which data were obtained for this study. Table 2 summarizes mean monthly rainfall, temperature and potential evaotranspiration for the Bahi meteorological station, which is the closest monitoring site to the wetland.

Table 1: *Climate stations for which data obtained*

Nos.	Name	Latitude	Longitude	Altitude (masl)	Distance from wetland (km)	Rainfall data	Temperature data	Potential Evaporation
	Bahi met station	N/A	N/A	N/A	<10 km	Daily 1980-2007*	Mean monthly+	Mean monthly+
TZ55BHMS	Bahi Mission	5.93 °S	35.30 °E	854	24.3	Monthly average only	Monthly average only	N/A
TZ54KLMT	Kilimatinde – C.M.	5.85 °S	34.91 °E	1,158	37.7	Monthly average only	Monthly average only	N/A
TZ64DMM	Dodoma Met station	6.03 °S	34.81 °E	1,372	38.2	Monthly average only	Monthly average only	N/A
TZ65LNGL	Ilangali	6.78 °S	35.06 °E	762	77.4	Monthly average only	Monthly average only	N/A
TZ55FRKW	Farkwa	5.38 °S	35.58 °E	1,219	92.2	Monthly average only	Monthly average only	N/A

Sources: * Daily rainfall data (1980 to 2006) obtained from Wami-Ruvu River Basin Office

+ Obtained from Department of Irrigation and Technical Services (2004)
All others from FAO databases FAOClim and LocClim.



Source: Department of Irrigation and Technical Services (2003).

Figure 1: Map of the Bahi Wetland

Table 2: *Mean monthly climate data from the Bahi meteorological station*

Month	Rainfall (mm)	Mean daily temperature (°C)	Potential evapotranspiration (mm) (Penman-Monteith)
Jan	124.7	26.0	130
Feb	116.4	26.3	125
Mar	116.8	26.9	127
Apr	61.3	25.0	120
May	11.4	24.2	115
Jun	0.0	22.3	111
Jul	0.0	22.2	121
Aug	0.0	23.5	136
Sep	0.5	25.3	159
Oct	0.7	27.1	180
Nov	38.9	28.0	165
Dec	119.5	27.6	133
Annual	590.1		1622

(source: + data supplied by Wami-Ruvu River Basin Office
* from Department of Irrigation and technical Services, 2004)

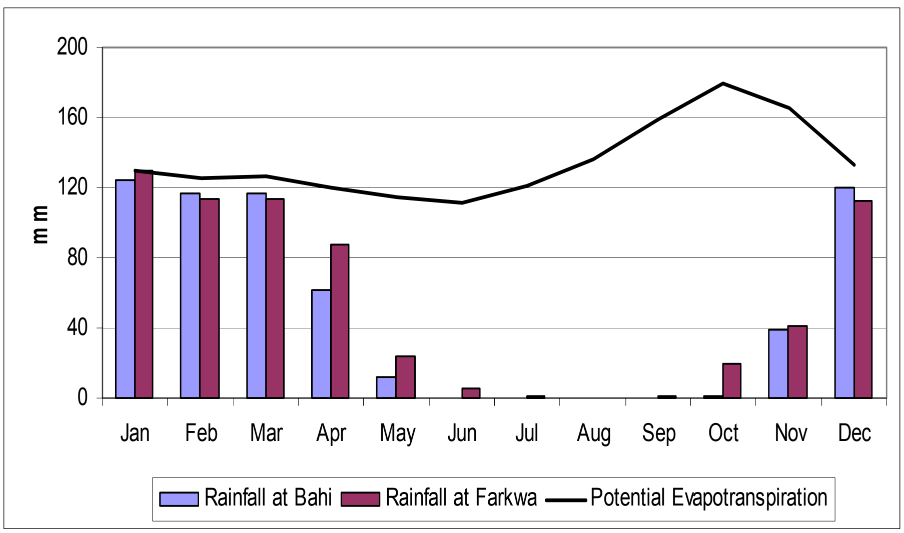


Figure 2: *Mean Monthly rainfall and Potential Evapotranspiration (Penman-Monteith)*

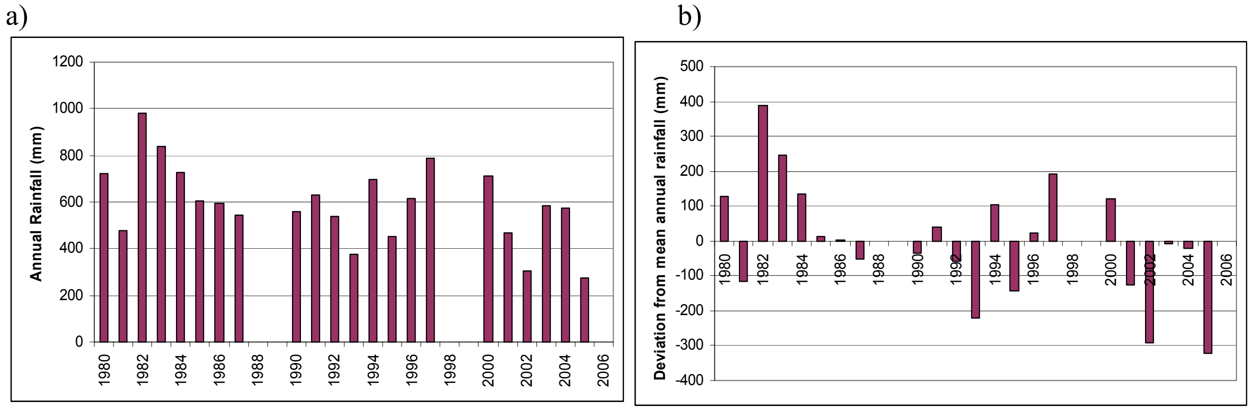


Figure 3: *Rainfall measured at Bahi met station: a) annual time series b) deviation from the annual mean*

River flows

All the major rivers flowing into the Bahi wetland originate from the northern part of the catchment in the Mbulu and Babati highlands. The catchment area of the Bubu river, the primary inflow, is 12,661 km^2 (i.e., 54% of the total). With the exception of the grassy floodplain extending around the edge of the lake (locally know as *mbuga*), the dominant vegetation is thorn scrub and thicket (Government of Tanzania, 1967). The drainage system to the south of the swamp comprises several small ephemeral rivers, which drain directly into the lake.

In the past several flow gauges were installed on the Bubu River and some flow monitoring of the other rivers was also undertaken. However, largely as a consequence of flood damage or vandalism, as well as lack of funds for operation and repair, most of the gauges are no longer operational. Table 2 provides a summary of data obtained from the Ministry of Water Resources for the current study. There are no data available after 1983 and for most stations the records available are sparse and incomplete. By far the best data available are for the Bubu at Bahi (gauge 2R4), but even this station (Figure 4) has only twenty years of complete data between 1957 and 1981 and nothing after this date.

Table 2: *Flow gauging stations for which data were obtained*

Station No.	**River**	**Location**	**Latitude**	**Longitude**	**Catchment Area (km^2)**	**Record**	**Nos. of complete years***
2R4	Bubu	Bahi	5°38' S	35°18'E	11,470	1957-1981	20
2R24	Bubu	Kinyika	5°49' S	35°18'E	12,700	1969-1974	2
2R1A	Bubu	Farkwa	5°19' S	35°38'E	7,360	1957-1983	11
2R7	Bubu	Gwandi	N/A	N/A	N/A	1956-1961	1
2R29	Bubu	Thawi	4°38' S	35°41'E	N/A	1971-1982	3
2R23	Mponde	Mponde	5°28' S	35°12'E	1,922	1969-1973	2
2R26	Maduma	Mahuru	5°25' S	34°59'E	933	1970-1978	6

* Short periods (i.e. < 3 days) of missing data were infilled by interpolation

Source: Ministry of Water Resources

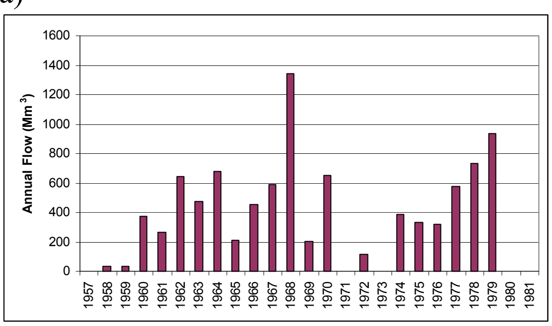
Figure 4: *Photograph of the Bubu River at Bahi (location of gauge 2R4) in the dry season*

Monthly river flows are seasonal, reflecting the variation in rainfall in the catchment. Table 3 presents mean monthly flows for the three stations for which more than 6 years of complete data are available. On average 95% the discharge occurs between December and April. Figure 4 shows the annual flow series and mean monthly flow for the same 3 stations. There is considerable year to year variation in flow, most likely reflecting the high rainfall variability. Annual flows in the Bubu at Bahi range from 30.5 Mm^3 (1958) to 1,343 Mm^3 (1968).

Table 3: *Mean monthly flow (Mm^3) at three gauges*

Gauge	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2R4	67.0	72.9	88.9	104.9	42.8	11.8	3.6	1.4	0.04	0	1.5	48.6	443.6
2R1A	18.4	21.5	29.5	25.2	12.3	2.9	0.6	0.9	0.01	0	0.44	14.5	126.2
2R26	3.0	2.9	1.8	0.5	0.03	0	0	0	0	0.01	0.02	2.29	10.5

a)



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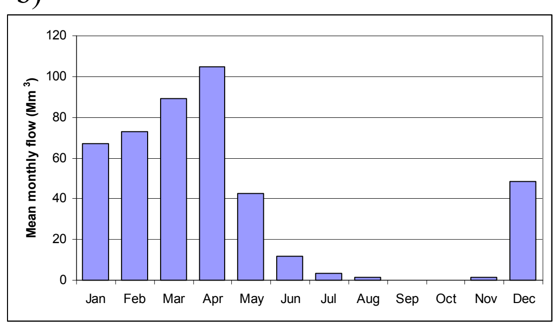

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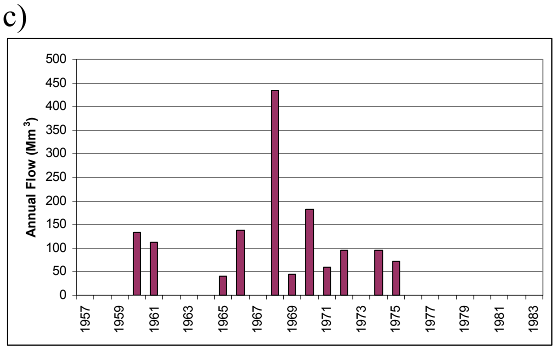

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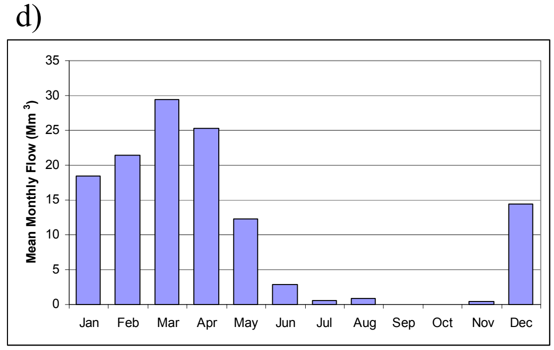

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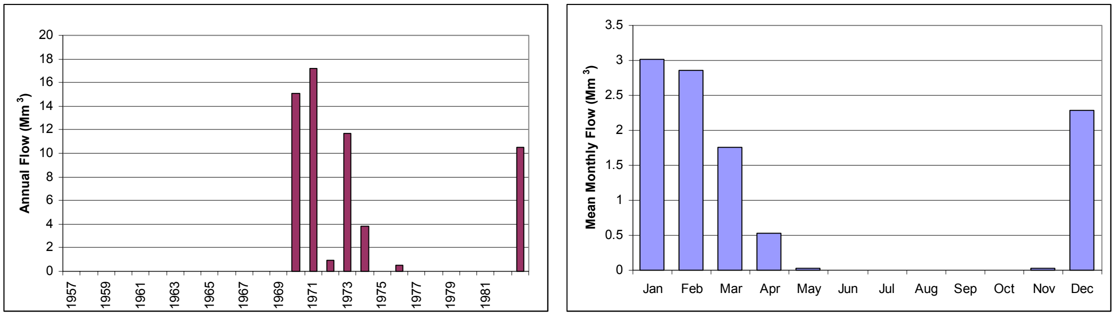

Figure 4: *Annual flow and mean monthly flow for three stations: a) 2R4 b) 2R1A and c) 2R26*

The three gauges for which there are more than 6 years of data indicate a clear relationship between catchment area and mean annual flow. Analyses of data from these three stations, indicates mean annual runoff across the catchment is in the range 11 - 41 mm (Table 4). This indicates a coefficient of runoff in the range 2 – 6 %. The mean annual runoff estimated for the Bubu at Bahi (i.e., 443.6 Mm^3) is significantly greater than that derived by the Department of Irrigation (i.e., 183 Mm^3) (Department of Irrigation and Technical Services, 2003). However, the Department of Irrigation estimate was based on just 4 years of data, while that in the current study has been determined using a much longer flow record (Table 3).

Table 4: *Runoff characteristics at three locations within the catchment*

Gauge	Catchment area (km)	Mean Annual Flow (Mm^3)	Runoff (mm)
2R4	11,470	443.6	38.7
2R1A	7,360	126.2	17.1
2R26	933	10.5	11.3

Wetland water budget

A crude (back of the envelope) estimate of the annual water budget of the wetland was determined. The water budget of the wetland is approximated by the equation:

$$P + Q_i = E + Q_o \quad \text{(equation 1)}$$

Where:
- P = precipitation onto the wetland
- Q_i = inflow into the wetland
- E = evapotranspiration from the wetland (a combination of open water evaporation and evapotranspiration from the surrounding grassland, as the lake recedes)
- Q_o = outflow

This assumes that groundwater fluxes to and from the wetland are negligible. Table 5 presents a summary of the mean annual water fluxes, with evapotranspiration computed from equation 1. The estimate indicates that on average approximately 60% of the water in the wetland originates as direct rainfall onto the wetland with 40% originating as inflow from the surrounding catchment. The estimated evapotranspiration of 1,415 Mm^3 equates to 1,494 mm (i.e., 92% of the annual potential estimated using the Penman-Monteith equation (Table 2).

Table 5: *Estimate of the average annual water fluxes (Mm^3) into and out of the Bahi wetland*

	Annual
Direct rainfall onto the wetland⁺	852
Evapotranspiration from the wetland	1,415
Inflow from catchment*	563
Outflow from the wetland	0

⁺ Estimated to be 600 mm over an area of 947 km^2

* Assumed coefficient of runoff of 4%, (i.e. 24 mm) and catchment area of 23,447 km^2

The Possible Impact of Irrigation

In recent years there has been an increase in irrigation in the area, primarily for rice cultivation. Since the early 1980s IFAD have assisted with the establishment of many small-scale rice irrigation schemes through programs such as the Freedom from Hunger Campaign, the Integrated Rural Development Program and the Rift Valley Rice Production program. These are mostly based around traditional methods of irrigation (locally known as *vinyungu*) that comprises the construction of large bunds into which rainwater and some river flows are diverted (i.e., effectively spate irrigation). Table 6 provides an estimate of the current irrigated area located close to rivers flowing into the lake. Currently the total area remains small, but many of the schemes have been reasonably successful and farmers are expanding them on their own initiative.

Table 6: *Estimated area of rice irrigation close to the wetland.*

Village/scheme	**Estimated Area (ha)**
Bahi	1,200-1,500
Chikuyu	300
Weselleila	100
Walelya	200
Chipanga	250 (currently only 40 ha producing)
Chikepelo	120
Charli	106 (currently only 20-40 ha producing)
Uhaleya	134
TOTAL	2,110 – 2,710

Source: personal communication with Mr. Laurent Gallet (IFAD Program Coordinator) and Nicholas Lupindu (Irrigation Technician at the District Agriculture and Development Office)

For 2,500 ha, assuming 1,000 mm of the total evaporative demand (i.e. 1,622 mm) is met through diverted water and irrigation efficiencies are of the order of 50%[1], diversions of approximately 50 Mm^3 are required. This represents approximately 9% of the estimated mean annual inflow into the lake. However, in very dry years diversions to rice irrigation schemes could potentially abstract a significant proportion of the inflow to the lake. For example, in 1938 the total inflow is estimated to have been only about 60 Mm^3 (i.e., derived by scaling the flow measured on the Bubu at Bahi) and clearly current irrigation areas could have diverted a significant proportion of this flow.

[1] Research in the Usangu catchment in Tanzania has shown that field application efficiency of smallholder farmers is typically in the range 56% to 69% (Machibya and Mdemu, 2005)

Although the irrigation schemes are bringing benefits to many people, care is required to ensure that future development of water resources is sustainable. Consideration should be given to the other natural resources that the lake and surrounding wetlands provide. To this end a water resource management plan should be developed for the lake and surrounding catchment. Clearly this needs to take into account the high variability in rainfall and runoff.

Data requirements to improve the analyses

i) time series of water levels measured in the lake
ii) any additional data on inflows into the lake – in particular the data record for the Bubu at Bahi
iii) a water-level volume relationship for the lake
iv) estimates of variation in the areal coverage of open water as the lake fills and dries and differences between years - from image analysis

References

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