ENTRO
EASTERN NILE TECHNICAL REGIONAL OFFICE

BARO-AKOBO-SOBAT MULTIPURPOSE WATER RESOURCES DEVELOPMENT PROJECT STUDY

BASELINE, DEVELOPMENT POTENTIALS, KEY ISSUES AND OBJECTIVES REPORT

Annex 5: Water balance

V.1 March 2016

BRL Ingénierie

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CONTENT OF ANNEX 5

Annex 5-a: Flow data

FLOW DATA CHRONOGRAM

	FLOW STATION NAME	SOURCE	CALENDER YEAR 1903-09	1910-19	1920-29	1930-39	1940-49	1950-59	1960-69	1970-79	1980-89	1990-99	2000-09	2010-2015
To be used for calibration	Alwero at Abobo	EMP												
	Baro at Burebeiy	NBRP												
	Baro at Gambela	NBI												
	Baro at Gambela	NBRP												
	Baro at Gambella	EMP												
	Baro at Itang	NBI												
	Baro at Kella	NP												
	Baro at Masha	NP												
	BirBir at Yubdo	NBI												
	Geba at Suppi	NBI												
	Pibor at Pibor Post	NBE												
	Pibor at Pibor Post	NBI												
	Pibor upstream of Khor Gila mouth	NBE												
	Pibor upstream of Khor Gila mouth	NBI												
	Sobat at its mouth into White Nile (at Hillet Doleib)	NBE												
	Sobat at Nasser	NBE												
	Sor at Metu	EMP												
	Sor at Metu	EMWE												
Auxiliary Stations	Abu Tong cut at its mouth into White Nile	NBE-NBI												
	Adura at its head downstream of Baro-Adura bifurcation	NBE-NBI												
	Adura downstream of Khor Makwai mouth	NBE-NBI												
	Agwei at its mouth into Pibor	NBE-NBI												
	Akobo at its mouth into Pibor	NBE-NBI												
	Assua at its mouth into Bahr el Jebel	NBE-NBI												
	Baro at its mouth into Sobat	NBE-NBI												
	Baro downstream of Baro-Adura bifurcation	NBE-NBI												
	Baro downstream of Baro-Adura junction	NBE-NBI												
	Baro downstream of Khor Jakau mouth	NBE-NBI												
	Baro downstream of Khor Machar head	NBE-NBI												
	Baro downstream of Khor Makeir head	NBE-NBI												
	Baro upstream of Baro-Adura bifurcation	NBE-NBI												
	Baro upstream of Baro-Adura junction	NBE-NBI												
	Baro upstream of Khor Jakau mouth	NBE-NBI												
	Baro upstream of Khor Makwai head	NBE-NBI												
	Khor 18 kms upstream of Machar head at head	NBE-NBI												
	Khor 18.5 kms upstream of Machar head at head	NBE-NBI												
	Khor 3.5 kms upstream of Machar head at head	NBE-NBI												
	Khor 4.3 kms downstream of Machar head at head	NBE-NBI												
	Khor 4.8 kms upstreamof Machar head at head	NBE-NBI												
	Khor 6.5 kms upstream of Khor Jakau mouth at its head	NBE-NBI												
	Khor Atar at its tail into White Nile	NBE-NBI												
	Khor Barakwich at its mouth into Baro, 7 kms downstream of Machar head	NBE-NBI												
	Khor Fullus at its mouth into Sobat	NBE-NBI												
	Khor Geni at its mouth into Pibor	NBE-NBI												
	Khor Gila at its mouth into Pibor	NBE-NBI												
	Khor Jakau at its mouth into Baro	NBE-NBI												
	Khor Lolle at its mouth into White Nile	NBE-NBI												
	Khor Macap at its mouth into Pibor	NBE-NBI												
	Khor Machar at its head (offtake from Baro)	NBE-NBI												
	Khor Makeir at its head	NBE-NBI												
	Khor Makwai at its mouth into Adura	NBE-NBI												
	Khor Mokwai at its mouth into Pibor	NBE-NBI												
	Khor Nyanding at its mouth into Sobat	NBE-NBI												
	Khor Twalor at its mouth into Sobat	NBE-NBI												
	Khor Wakau at its mouth into Sobat	NBE-NBI												
	Pibor at its mouth into Sobat	NBE-NBI												
	Pibor downstream of Akobo mouth	NBE-NBI												
	Pibor downstream of Khor Gila mouth	NBE-NBI												
	Pibor downstream of Khor Makwai mouth	NBE-NBI												
	Pibor upstream of Akobo mouth	NBE-NBI												
	Pibor upstream of Khor Makwai mouth	NBE-NBI												
	Sobat at 2 kms downstream of Nyandig mouth	NBE-NBI												
	Sobat at its head	NBE-NBI												
	Sobat downstream of Khor Twalar mouth	NBE-NBI												
	Sobat upstream of Khor Twalar mouth	NBE-NBI												
	White Nile At Kosti	NBE-NBI												
	White Nile at Malakal	NBE-NBI												
	White Nile at Melut	NBE-NBI												
	White Nile at Mogren (Khartoum)	NBE-NBI												
	White Nile at Renk	NBE-NBI												
	White Nile downstream of Jebel Aulia Dam	NBE-NBI												
	White Nile downstream of Lake No	NBE-NBI												
	White Nile upstream of Maya Berboi head	NBE-NBI												
	White Nile upstream of Maya Sinyora Gauge	NBE-NBI												

LEGEND	
	All Months Data Availab
	6 Months Data Available
	1 Months Data Available
	No Data Available

Locations of selected flow gauging stations

No	Name
1	Akobo at mouth into Pibor
2	Alwero at Abobo
3	Baro u/s Pibor
4	Baro at Gambela
5	Baro at Itang
6	Baro at Kella
7	Baro at Masha
8	Birbir at Yubdo
9	Geba at Suppi
10	Gilo at mouth into Pibor
11	Pibor at Pibor Post
12	Pibor d/s Gilo
13	Pibor u/s Akobo
14	Pibor u/s Baro
15	Pibor u/s Gilo
16	Sobat at Hillet Doleib
17	Sobat at Nassir
18	Sor at Metu
19	Agwei u/s Pibor
20	Fullus u/s Sobat
21	Khor Machar at its head
22	Khor Mokwai u/s Adura
23	Khor Mokwai u/s Pibor
24	Nyanding u/s Sobat
25	Pibor d/s Akobo
26	Pibor d/s Mokwai
27	Pibor u/s Mokwai
28	Twalor u/s Sobat

INITIAL SELECTION OF FLOW GAUGES

Flow Gauging Station	Source	Catchment area (km^2)	Lat	Long	Record Period (Unpatched)	Analysis period
Agwei at its mouth into Pibor	NBI	13 727	7.64	33.02	1934-1939, 1942-1944	
Alwero at Abobo	EMP	2 859	7.84	34.55	1976-1990	1976-1990
Baro at Burebeiy	NBRP	38 602	8.42	33.23	1929-1932	1929-1932
Baro at Gambela	NBI	23 541	8.25	34.58	1904-1910, 1929-1932, 1990-2009	1904-1957, 1967-2009
	NBRP	23 541	8.25	34.58	1906-1928	
	EMP	23 541	8.25	34.58	1906-1957, 1967-1989	
Baro at Itang	NBI	24 692	8.18	34.27	1974-1982	
Baro at its mouth into Sobat	NBI	38 602			1929-1933, 1941-1963, 1967-1970, 1972-1981	1929-1932
Baro at Kella	NP	4 737	8.23	34.97	1987	
Baro at Masha	NP	1 729	7.57	35.48	1990, 1995, 1997, 1999-2003	
BirBir at Yubdo	NBI	1 858	8.95	35.48	1985-1990	
Fullus at its mouth into Sobat	NBI	17 492	9.31	31.60	1929-1931, 1933-1934, 1938-1939	
Geba at Suppi	NBI	3 735	8.48	35.65	1986-1991, 1993-2005	1986-1991, 1993-2005
Gilo at its mouth into Pibor	NBI	12 081	8.14	33.20	1929-1939, 1941-1944, 1946-1960, 1962-1963, 1973-1977	1929-1933
Khor Machar at its head	NBI	-	8.47	33.52	1928-1939, 1941-1963, 1968-1970, 1972, 1974-1978	
Khor Mokwai at its mouth into the Adura	NBI	7 572	8.34	33.54	1946-1956	
Khor Mokwai at its mouth into Pibor	NBI	1 814	8.33	33.22	1929-1933, 1943-1963, 1974-1977	
Nyanding at its mouth into Sobat	NBI	7 197	8.67	32.68	1934, 1938-1939, 1941-1962, 1969-1970, 1978-1980	
Pibor at mouth into Sobat	NBI	132 041	8.14	33.20	1929-1933	
Pibor at Pibor Post	NBE	71 426	6.80	33.13	1928-1932	
Pibor d/s of Akobob mouth	NBI	117 179	7.81	33.05	1929-1933	
Pibor d/s of Gilo mouth	NBI	129 260	8.15	33.19	1929-1933	
Pibor d/s of Mokwai mouth	NBI	132 041	8.35	33.22	1929-1933	
Pibor u/s of Akobo mouth	NBI	89 266	7.80	33.03	1929-1939, 1941-1945	
Pibor u/s of Khor Gila mouth	NBE	117 179	8.13	33.19	1929-1939, 1941-1944, 1946-1963, 1973-1977	
Pibor u/s of Mokwai mouth	NBI	129 260	8.34	33.21	1929-1933, 1945-1963, 1973-1977	

Flow Gauging Station	Source	Catchment area (km^2)	Lat	Long	Record Period (Unpatched)	Analysis period
Sobat at mouth into White Nile (at Hillet Doleib)	NBE	207 308	9.36	31.59	1905-1983	1905-1983
Sobat at Nasir	NBE	170 991	8.61	33.06	1929-1963, 1968-1972, 1978-1981	1929-1963, 1968-1972
Sor at Metu	EMP	1 712	8.30	35.60	1967-1993	1967-2006
	EMWIE		8.30	35.60	1985-2006	
Twalor at mouth into Sobat	NBI	1 346	8.55	32.96	1934-1939, 1941-1962, 1970	1945-1950

Sources: NBRP: Nile Basin Research Programme; NBE: Nile Basin Encyclopaedia; EMP: Ethiopian Master Plan Studies; NBI: Nile Basin Initiative; NP: Baro 1 and 2 Feasibility Studies (Norplan, 2006); EMWIE: Ethiopian Ministry of Water, Irrigation and Energy

FLOW DATA QUALITY CONTROL

Data quality checks were conducted on the flow records at the selected stations including tests for stationarity, an assessment of the period of data availability and the extent of data gaps, and correlation analyses.

Stationarity

Cumulative flow graphs (single mass plots) were used to evaluate the stationarity and extent of missing data of the flow records.

Baro at Masha is missing a significant amount of data over its record period. Geba at Suppi is missing a significant amount of data between 1991 and 1995, and the gradient of the cumulative flow plot changes at 2001. The flow at Gambela is stationary, however, there is a gap in the flow record between 1958 and 1967. The record at Baro at its mouth into Sobat contains several gaps, however there is a complete record between 1929 and 1933 which is stationary.

The record at Gilo at its mouth into Pibor contains missing years, however, the period from 1929 to 1933 is complete and stationary. The cumulative flow plot for Agwei at its mouth into Pibor shows that the record is not stationary and contains missing data, which suggests that this gauge should be excluded from this study.

The record at Pibor at its mouth into the Sobat, as well as Pibor d/s of Gilo mouth, has a complete and stationary record from 1929 to 1933. Pibor Post, Pibor d/s of Akobo mouth, Pibor u/s of Akobo mouth, Pibor u/s of Gilo mouth, contain missing data and are not stationary records.

The gauge at Sobat at Nasir gives a good quality, stationary flow record between 1929 and 1963. Similarly, the gauge at Sobat at Hillet Doleib provides a good record from 1919 to 1963.

The gauges at Fullus at its mouth into Sobat and Nyanding at its mouth into Sobat contain missing data, and do not have stationary flow. The gauge at Twalor at its mouth into Sobat also contains missing data and is non-stationary for most of its record, however, there are a few years of good, stationary flow data between 1945 and 1950.

Missing data

The gauge on the Baro River at Gambela is the most complete of all the stream flow gauges and has a long record from 1904 to 2009 with a few years of missing data between 1958 and 1967 and some missing data after 2007.

In the upper Baro catchment, there are flow records at four gauges on the Baro, Birbir and Geba rivers (between 1986 and 2005, with missing data) and at one gauge on the Sor River (1966 to 2005). The Baro at Masha gauge has missing peak flow as well as missing low flow data. The Baro at Kella gauge has only one year of flow data. The Geba at Suppi gauge has missing data, with only a few years of complete records. The flow record on the Birbir River at Yubdo is mostly complete. The Sor at Metu has an almost complete record from 1967 to 2006.

The gauge at Baro at its mouth into the Sobat provides five years of complete flow data between 1929 and 1933, while the remainder of the record period has missing base flow readings in the dry months.

The Alwero River at Abobo has a record from 1976 to 1990. However, it is characterised by missing data.

The gauge on the Pibor River, at Pibor Post has significant missing data during its short record period of 1928 to 1933. The gauge at Pibor mouth into the Sobat gives four full years of flow data from 1929 to 1932, with some additional flow peaks measured in 1933. The other gauges along the

Pibor River (upstream and downstream of the Gilo, Akobo and Mokwai mouths) give fairly complete flow records between 1929 and 1933, however, many of the years are missing base flow records in the dry months.

The gauge at Khor Gilo mouth into the Pibor gives a complete record between 1931 and 1933, with the remainder of the dataset missing base flows in the dry months. Similarly, the gauge at Agwei mouth into the Pibor gives base flow values for 1935, but is missing base flows for the remainder of the record period.

The Nyanding at its mouth into Sobat and Twalor at its mouth into Sobat gauges are characterised by missing data. While the gauges record peak flows for over 20 years, there are no complete years (mostly missing base flow values). Khor Fullus only has six years of data, however, 1930 and 1933 give a full year of flow data.

The stations on the Sobat River downstream of the Baro-Pibor junction at Nasir (1929 to 1963) and Hillet Doleib (1905 to 1983) have long flow records with almost no missing data.

Correlation analysis

Upper Baro sub-basin

The flow records at gauges in the upper Baro sub-catchments were expected to be more or less similar as these gauged catchments are similar in size and location. On this premise, the flows for Birbir at Yubdo, Geba at Suppi, Sor at Metu, Baro at Masha and Baro at Kella were compared for an overlapping time period (see Fig 1). The catchment areas for Birbir at Yubdo, Sor at Metu and Baro at Masha are comparable at 1858, 1712 and 1729 km^2 respectively. The gauges at Baro at Kella and Geba at Suppi measure flow from larger catchments of 4737 and 3735 km^2 respectively. The plot in Fig 1 highlights inconsistencies in the Masha data with regard to apparent missing peaks, while wet season flows at Yubdo appear to be too low compared to the peak flows of the surrounding sub-catchments of similar size.

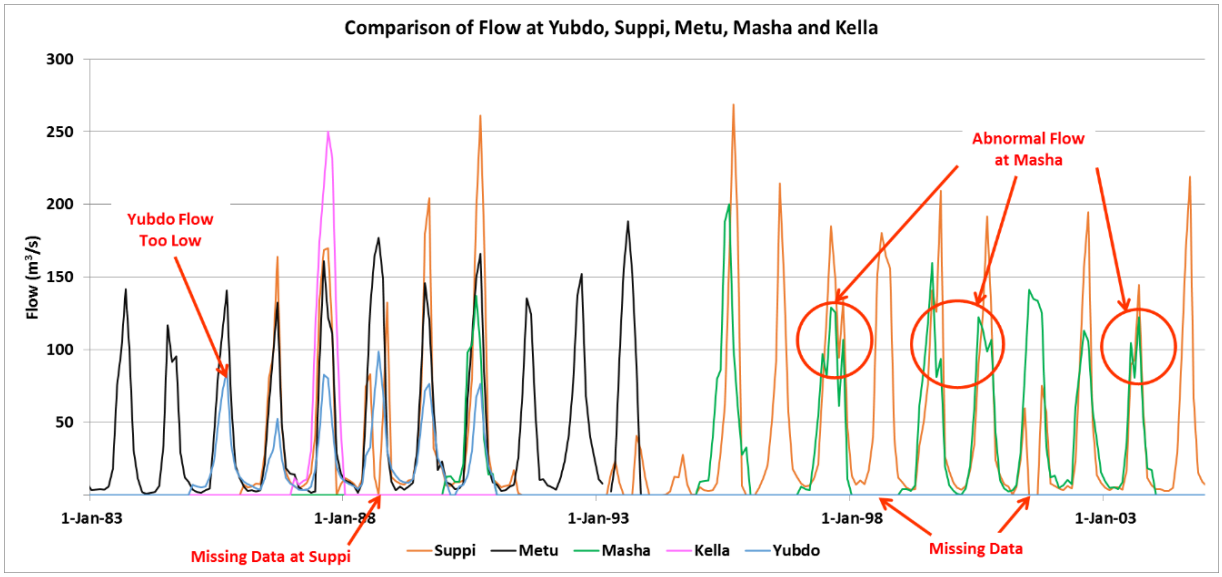


Figure 1: Comparison of flow records at Suppi, Metu, Masha, Kella and Yubdo

The unit runoff was calculated for each of the upper Baro sub-catchments and plotted against the corresponding Mean Annual Precipitation values for each catchment, as shown in Figure 2. The unit runoff for Birbir at Yubdo appears too low compared to similar sub-catchments.

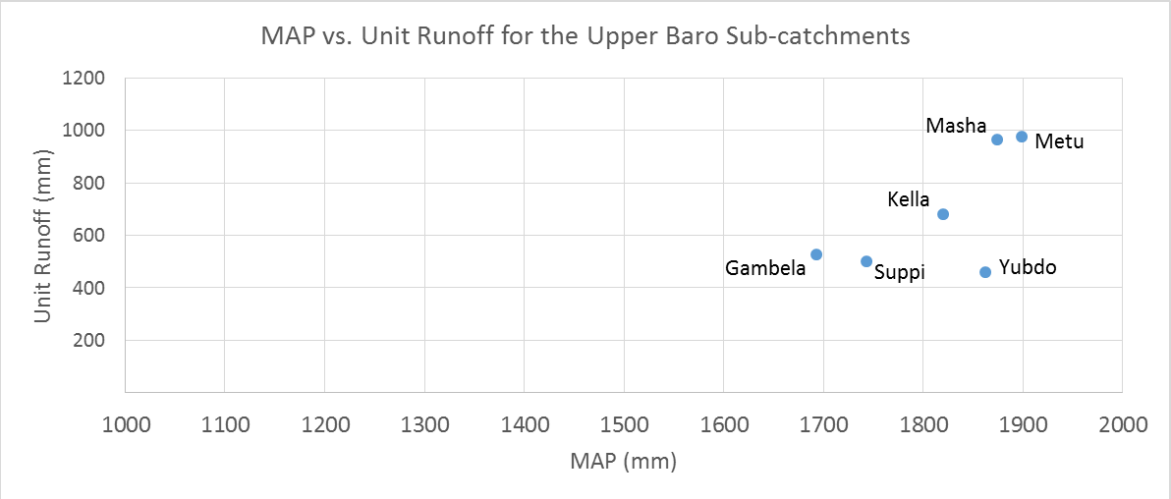


Figure 2: Comparison of MAP and unit runoff for the upper Baro sub-catchments

Lower Baro River

The flow records at Gambela and Itang were expected to be similar as Itang is located directly downstream of Gambela. A comparison plot of these two records is shown in Figure 3. The flow records show good agreement for the overlapping record period, with the exception of two or three apparent anomalies as indicated.

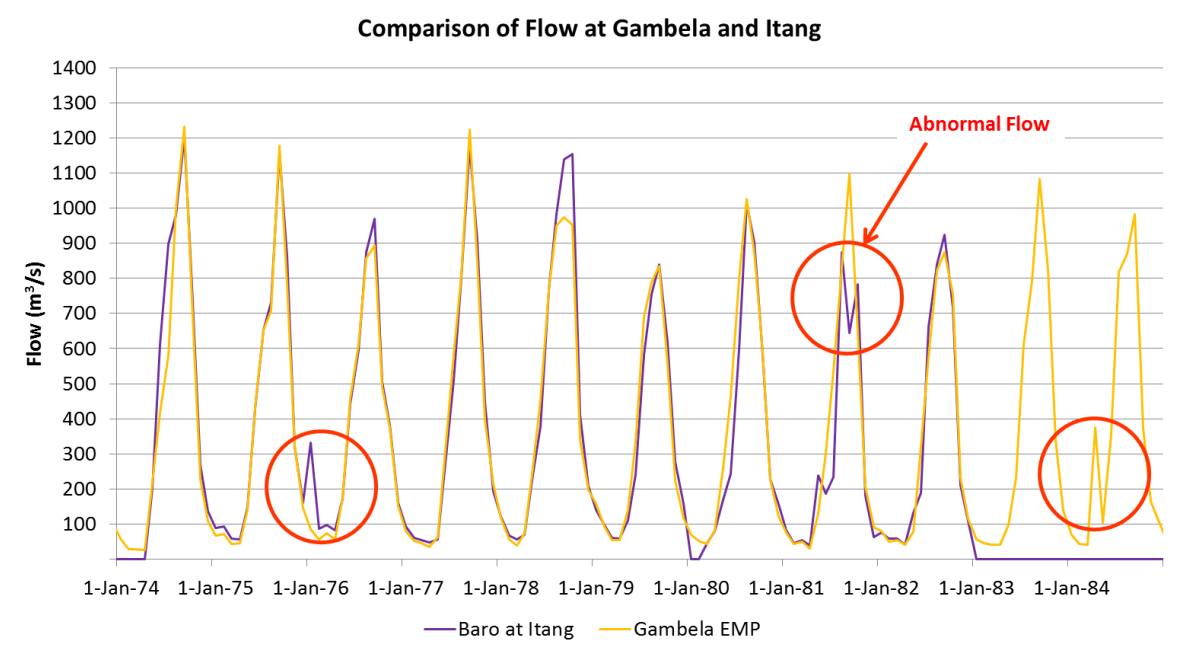


Figure 3: Comparison of flow records at Gambela and Itang

Lower Sobat

The flow records at Nasir and Hillet Doleib on the Sobat were expected to be similar as most of the flow at Hillet Doleib comes from the contribution from Nasir. The Sobat tributaries (Twalor, Nyanding, Beguyang and Fullus Rivers) also contribute to the total flow recorded at Hillet Doleib, and water may be spilled from the Sobat upstream of Nyanding to the Wal River. A comparison plot of Hillet Doleib and Nasir is shown in Figure 4. The flow records show good agreement for the overlapping record period. The flow record at Nasir has missing values from 1964 onwards. The plot also highlights possible missing peak flows at Hillet Doleib where the shape of the hydrograph appears abnormal. The years which indicate greater flow peaks at Hillet Doleib could be due to high flows from the Sobat tributaries.

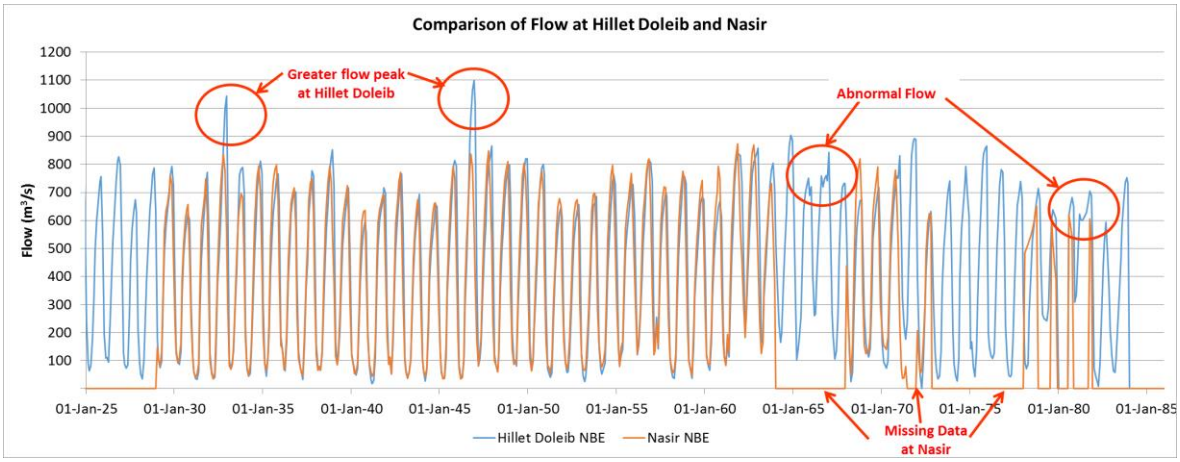


Figure 4: Comparison of flow records at Nasir and Hillet Doleib

Lower Pibor

The flow records at key gauging stations along the Pibor River were plotted for an overlapping period and compared, as shown in Figure 5. The flows downstream of the Akobo mouth and the flows upstream of the Gilo mouth show a good match, as expected. The flows upstream of the Akobo mouth are lower than the flows downstream of the Akobo mouth, and the two flow records have similar shaped hydrographs, as expected. The flow record at Pibor Post is short and contains missing data for the later years.

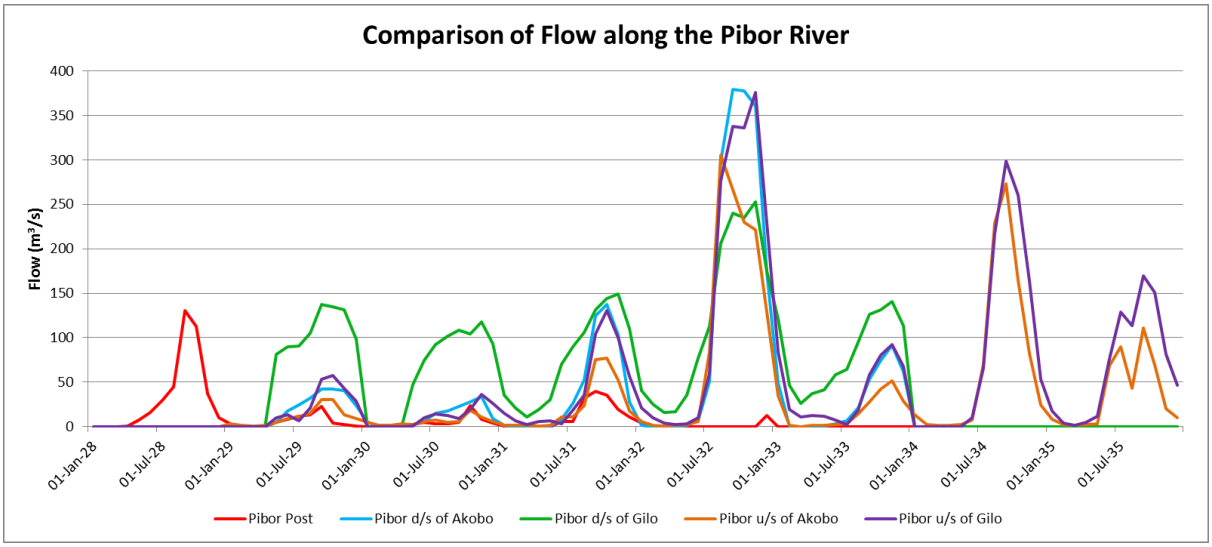
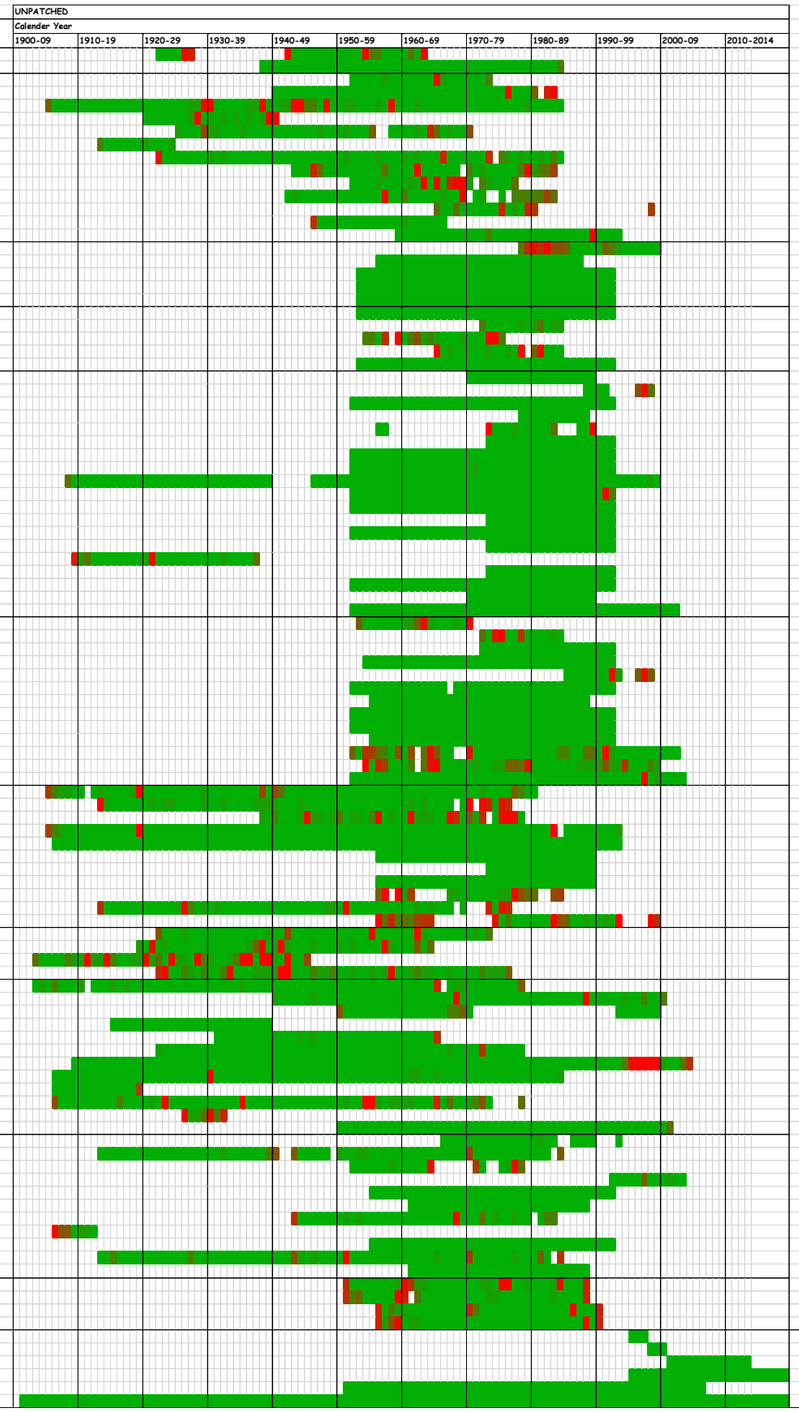


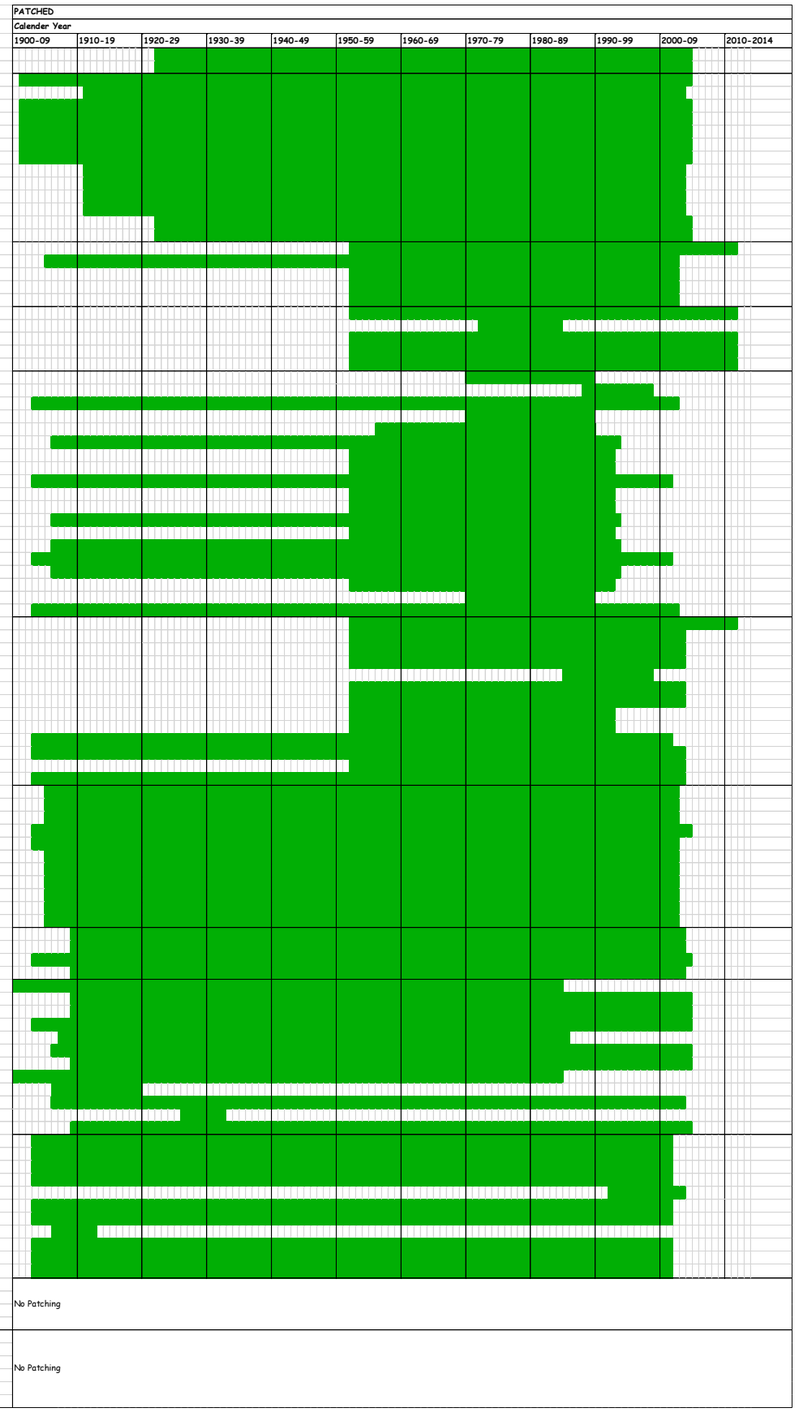
Figure 5: Comparison of flow records along the Pibor River

Annex 5-b: Rainfall data

RAINFALL DATA CHRONOGRAM

GROUP	RAINFALL STATION NAME	SOURCE	PATCHED MAP
Upstream of Pibor Post	1224Nagi_Shot	DST	1094
	1937Kapoeta	FAO	766
Adjacent to Upstream of Pibor Post	1220Mongalla	DST	895
	1490Agaro	GHCN	918
	1580Bor	NBE	889
	2123Malek	NBE	862
	2439Terakeka	NBE	922
	2447Tombe	NBE	849
	2454Torit	NBE	1016
	2584Orom	MWE	944
	2585Karenga	MWE	970
	2586Naam	MWE	994
	2588Madi_Opei	MWE	977
	2591Kaabong	MWE	723
	3312Lokichokio	NBRP	501
Abobo, Gilo, Akobo Headwaters	730Mizan_Teferi	DST	2293
	1448Abobo	EMP	1137
	2180Mizan_Teferi_School	EMP	2164
	2438Tepi	EMP	1592
	2535Yeki	EMP	1581
Adjacent to Abobo, Gilo, Akobo Headwaters	1577Bonga	EMP	1786
	1797Gojeb	GHCN	1336
	2112Maji	GHCN	1650
	2376Shebe	GHCN	1587
	2525Wush-Wush	EMP	1803
Upstream of Gambela	1496Alem_Teferi_School	EMP	1634
	1498Alge	FAO	1037
	1610Bure	EMP	1279
	1642Chanka	EMP	1480
	1676Dembi_Dollo	GHCN	544
	1677Dembi_Dolo	EMP	1234
	1691Dongoro	EMP	2122
	1791Gimbi_HS	EMP	1844
	1806Gore	GHCN	2115
	1847Hurumu	EMP	2037
	2172Metu_Hospital	EMP	1839
	2191Mugi	EMP	1723
	2267Nolekaba	EMP	1960
	2324Rob_Gebeya	EMP	1417
	2352Saiyo	NBE	1258
	2377Shebele	EMP	1513
	2530Yayu	EMP	1602
	2539Youbdo	EMP	1583
	3611Gore	NBRP	2163
Adjacent to Upstream of Gambela	1488Agaro	GHCN	1657
	1507Anger_Gutin	GHCN	1380
	1508Anger_Gutin	EMP	1559
	1512Arjo	EMP	2138
	1560Bedele	FAO	1386
	1649Chora_Kumbabe	EMP	1765
	1781Getema	EMP	1412
	1837Henna	EMP	1963
	1867Jarso	EMP	1735
	2163Mendi	EMP	1608
	3233Nekemtewelega	NBRP	2009
	3238Sibusirewellega	NBRP	1363
	3673Nedjo	NBRP	1634
Lowlands Upstream of Nasir	11926ambela	DST	1238
	1198Pibor	DST	889
	1494Akobo	NBE	938
	1764Gambela	FAO	1219
	1766Gambella	EMP	1262
	1864Itang	EMP	883
	1874Jikawo	EMP	798
	2290Pakwo	EMP	1037
	2291Pakwo	GHCN	1047
	2294Pibor_Post	NBE	914
	3542Ganbella	NBRP	1059
Lowlands Upstream of Hillet Doleib	1197Nasir	DST	765
	1462Abwong	NBE	754
	1839Hillet_Doleib	NBE	795
	2242Nasser	NBE	778
Adjacent to Lowlands Upstream of Hillet Doleib	1193Kodok	DST	758
	1194Malakal	DST	754
	1195Malakal_MofA	DST	789
	1196Malakal_Town	DST	796
	1207Shambe	DST	708
	1211Fangak	DST	900
	2118Malakal_Aero	GHCN	778
	2162Melut	NBE	629
	2432Taufikia	NBE	733
	2448Tonga	NBE	868
	2546Zeraf_Cut	NBE	572
	3441Malakal	NBRP	778
Machar Marshes	1177J_Maiak	DST	716
	1178El-Kurmuk	DST	922
	1201Yabus_Bridge	DST	927
	1261J_Dinduro	DST	485
	1523Asosa	EMP	1155
	1562Begi_School	EMP	1387
	1641Chali	GHCN	744
	1705El_Keili	NBE	843
	2005Kiltukara	EMP	1596
	2060Kurmuk	NBE	936
	2061Kurumuk	EMP	831
Daily	GHCND_ET000063403_Gore_Prec	GHCN	
	GHCND:ET000063402_JIMMA_Prec	GHCN	
	GHCND:SU000062941_Jua_Prec	GHCN	
	GHCND:SU000062840_Malkal_Prec	GHCN	
Satellite Rainfall	RFE1.0 Decadal		
	RFE1.0 Daily		
	RFE2.0 Daily		
	SimCLIM		
	Swedish Meteorological and Hydrological Institute		
	Climatic Research Unit		





No Patching

No Patching

List of patched rainfall stations in the vicinity of the Baro-Akobo-Sobat Basin

ID	Station name	Lat	Long	Source[1]	StartDate	EndDate	Accuracy[2]
1	Gojeb	7.250	36.230	DST	3/31/1972	3/31/1994	1
2	Mizan Teferi	6.560	35.200	DST	1/31/1978	12/31/1999	3
3	GAMBELA	8.250	34.583	DST	8/31/2005	12/31/1980	2
4	KODOK	9.883	32.117	DST	1/31/2003	7/31/1978	3
5	MALAKAL	9.550	31.650	DST	1/31/1940	9/30/2000	2
6	MALAKAL (M. OF A.)	9.500	31.667	DST	7/31/1950	12/31/1999	2
7	MALAKAL TOWN	9.533	31.650	DST	1/31/2015	12/31/1939	3
8	NASIR	8.617	33.067	DST	6/30/2022	9/30/1973	2
9	PIBOR	7.333	33.222	DST	12/31/2013	11/30/1976	2
10	YABUS BRIDGE	9.933	34.167	DST	1/31/1952	12/31/1978	3
11	JUBA	4.867	31.600	DST	1/31/1949	9/30/2000	3
12	JUBA TOWN	4.850	31.617	DST	6/30/2024	12/31/1949	4
13	LOA	3.800	31.950	DST	1/31/1945	12/31/1963	2
14	MONGALLA	5.250	31.833	DST	1/31/1952	9/30/1973	3
15	NAGI SHOT	4.267	33.567	DST	1/31/2022	11/30/1963	3
16	OPARI	3.917	32.050	DST	1/31/2029	4/30/1973	2
17	TORIT	4.417	32.550	DST	1/31/2023	12/31/1984	3
18	Abobo	7.850	34.550	EMP	1/31/1956	12/31/1987	2
19	Abwong	9.117	32.200	NBE	1/31/2019	12/31/1964	2
20	AGARO	7.900	36.900	GHCN	4/30/1953	10/31/1970	3
21	AGORO	3.800	33.000	GHCN	1/31/1940	7/31/1984	2
22	Akobo	7.800	33.050	NBE	1/31/1938	12/31/1978	2
23	Alem Teferi School	8.900	35.233	EMP	1/31/1970	12/31/1989	1
24	ANGER GUTIN	9.400	36.400	GHCN	5/31/1972	12/31/1984	3
25	Anger Gutin	9.367	36.367	EMP	1/31/1972	12/31/1992	3
26	Arjo	8.750	36.500	EMP	1/31/1954	12/31/1992	1
27	Bambessi	9.750	34.733	EMP	1/31/1955	12/31/1997	2
28	Bedele	8.450	36.333	EMP	1/31/1952	12/31/1992	1
29	Begi School	9.350	34.533	EMP	1/31/1961	12/31/1988	2
30	Bonga	7.217	36.233	EMP	1/31/1953	12/31/1992	1
31	Bor	6.200	31.550	NBE	6/30/2005	12/31/1992	2
32	Bure	8.283	35.100	EMP	1/31/1952	12/31/1992	2
33	Chanka	8.833	35.133	EMP	1/31/1978	12/31/1988	1
34	Chora Kumbabe	8.417	36.133	EMP	1/31/1952	12/31/1992	1
35	Dembi Dolo	8.533	34.800	EMP	1/31/1973	12/31/1992	3
36	Dongoro	9.267	35.683	EMP	1/31/1952	12/31/2000	2
37	GAMBELA	8.250	34.580	FAO	8/31/2005	11/30/1993	2
38	Gambella	8.250	34.583	EMP	8/31/2005	12/31/1993	2
39	Getema	8.900	36.467	EMP	1/31/1955	12/31/1988	1
40	Gimbi H S	9.167	35.783	EMP	1/31/1952	12/31/2003	2
41	GORE	8.150	35.530	GHCN	5/31/2008	5/31/2004	2
42	HARO	9.900	36.500	GHCN	4/30/1970	12/31/1984	3
43	Henna	9.417	35.583	EMP	1/31/1952	12/31/1992	2

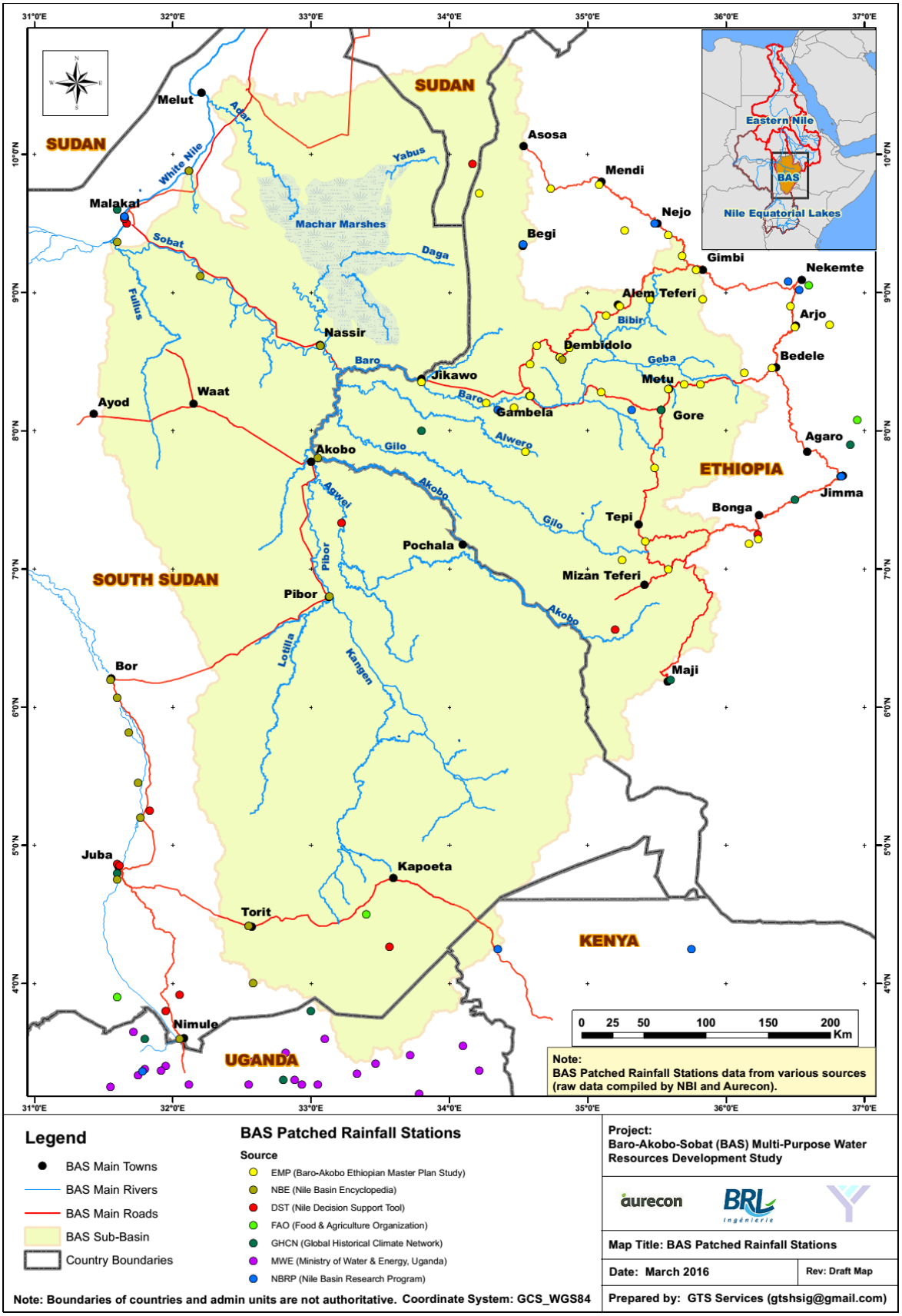
ID	Station name	Lat	Long	Source[1]	StartDate	EndDate	Accuracy[2]
44	Hillet Doleib	9.367	31.600	NBE	5/31/2003	5/31/1945	3
45	Hurumu	8.333	35.700	EMP	1/31/1952	12/31/1992	1
46	Itang	8.200	34.267	EMP	1/31/1956	12/31/1989	2
47	Jarso	9.450	35.267	EMP	1/31/1952	12/31/1992	2
48	Jikawo	8.350	33.800	EMP	1/31/1973	12/31/1989	2
49	JIMMA	7.670	36.830	FAO	6/30/1952	12/31/1998	2
50	JIMMA	7.670	36.830	GHCN	6/30/1952	10/31/2011	1
51	JUBA	4.800	31.600	GHCN	1/31/2001	12/31/2004	2
52	KAJO-KAJI	3.900	31.600	FAO	1/31/2016	12/31/1982	1
53	KAPOETA	4.500	33.400	FAO	1/31/1938	8/31/1985	2
54	Kiltukara	9.717	34.217	EMP	1/31/1955	12/31/1992	3
55	KITGUM V.T.C	3.300	32.800	GHCN	1/31/2014	12/31/1995	1
56	Kodok	9.883	32.117	NBE	8/31/2000	2/29/1980	3
57	LEKEMTI	9.050	36.600	FAO	1/31/1971	12/31/1998	2
58	Lerua Mission (Palataka)	4.000	32.583	NBE	2/28/2027	3/31/1938	4
59	LIMUGENET	8.080	36.950	FAO	1/31/1969	12/31/1991	3
60	MAJI	6.200	35.600	GHCN	4/30/1954	9/30/1975	3
61	MALAKAL (AERO)	9.600	31.600	GHCN	1/31/2009	5/31/2004	2
62	Malek	6.067	31.600	NBE	12/31/2019	2/29/1940	3
63	Masha	7.733	35.483	EMP	1/31/1952	12/31/1992	2
64	Mendi	9.783	35.083	EMP	1/31/1955	12/31/2000	2
65	Metu Hospital	8.300	35.583	EMP	1/31/1952	12/31/1992	1
66	Mizan Teferi School	7.000	35.583	EMP	1/31/1953	12/31/1992	2
67	Mongalla	5.200	31.767	NBE	4/30/2003	8/31/1939	2
68	MOYO	3.600	31.800	GHCN	1/31/1939	7/31/1980	3
69	Mugi	8.617	34.633	EMP	1/31/1973	12/31/1992	3
70	Nasser	8.617	33.067	NBE	6/30/2022	3/31/1981	2
71	Nimule	3.600	32.050	NBE	1/31/2004	12/31/1965	2
72	Nolekaba	8.950	35.833	EMP	1/31/1952	12/31/1992	2
73	Pakwo	8.167	34.467	EMP	1/31/1956	12/31/1989	2
74	PAKWO	8.000	33.800	GHCN	6/30/1956	5/31/1984	3
75	Pibor Post	6.800	33.133	NBE	9/30/2013	11/30/1976	1
76	Rejaf	4.750	31.600	NBE	1/31/2014	8/31/1939	2
77	Rob Gebeya	8.600	34.867	EMP	1/31/1973	12/31/1992	3
78	Saiyo	8.517	34.817	NBE	10/31/2009	8/31/1937	2
79	SHEBE	7.500	36.500	GHCN	3/31/1965	12/31/1984	3
80	Shebele	8.483	34.583	EMP	1/31/1973	12/31/1992	3
81	Tepi	7.200	35.417	EMP	1/31/1953	12/31/1992	2
82	Terakeka	5.450	31.750	NBE	1/31/2025	12/31/1972	3
83	Tombe	5.817	31.683	NBE	1/31/2013	11/30/2024	3
84	Torit	4.417	32.550	NBE	11/30/2022	12/31/1992	2
85	Wama	8.767	36.750	EMP	1/31/1975	12/31/1987	2
86	Wush-Wush	7.183	36.167	EMP	1/31/1953	12/31/1992	1
87	Yayu	8.333	35.817	EMP	1/31/1952	12/31/1992	1
88	Yeki	7.067	35.250	EMP	1/31/1953	12/31/1992	2

ID	Station name	Lat	Long	Source[1]	StartDate	EndDate	Accuracy[2]
89	Youbdo	8.950	35.450	EMP	1/31/1970	12/31/1989	1
90	Adjumani Dispensary	3.383	31.800	MWE	1/31/1942	11/30/2002	4
91	Moyo Boma	3.650	31.717	MWE	1/31/1938	12/31/1998	3
92	Obongi Dispensary	3.250	31.550	MWE	6/30/1939	2/28/1979	2
93	Zaipi Dispensary	3.400	31.950	MWE	1/31/1942	6/30/1980	2
94	Pakelli Dispensary	3.367	31.917	MWE	1/31/1943	6/30/1980	3
95	Adjumani Prisons Farm	3.333	31.750	MWE	10/31/1968	2/28/1982	3
96	Kitgum Centre VT	3.300	32.883	MWE	4/30/2014	9/30/2003	1
97	Atiak Dispensary.	3.267	32.117	MWE	1/31/1942	5/31/1977	2
98	Palabek Divisional Hqs	3.433	32.583	MWE	6/30/1939	2/28/1981	1
99	Padibe	3.500	32.817	MWE	1/31/1942	12/31/1983	1
100	Patiko	3.017	32.317	MWE	1/31/1965	1/31/1985	3
101	Aringa Valley Coffee	3.267	32.933	MWE	7/31/1967	4/30/1983	3
102	Acholi Ranch	3.267	32.550	MWE	7/31/1970	8/31/1985	3
103	Kitgum Matidi	3.267	33.050	MWE	2/28/1943	12/31/1982	2
104	Kalongo Hospital	3.050	33.367	MWE	1/31/1956	12/31/1981	3
105	Paimol	3.067	33.417	MWE	1/31/1942	4/30/1980	2
106	Orom	3.417	33.467	MWE	1/31/1943	5/31/1983	1
107	Karenga	3.483	33.717	MWE	1/31/1952	11/30/1977	2
108	Naam	3.350	33.333	MWE	1/31/1942	9/30/1983	1
109	Madi Opei	3.600	33.100	MWE	5/31/1965	9/30/1998	3
110	Kacheri	3.200	33.783	MWE	3/31/1964	12/31/1991	3
111	Kaabong	3.550	34.100	MWE	9/30/1946	12/31/1966	3
112	Kotido	3.017	34.100	MWE	2/28/1947	10/31/2003	2
113	Loyoro [County Dodoth]	3.367	34.217	MWE	4/30/1947	11/30/1963	3
114	JIMMA	7.667	36.833	NBRP	6/30/1952	12/31/2002	2
115	NEKEMTEWELEGA	9.080	36.450	NBRP	6/30/1952	12/31/2002	1
116	SIBUSIREWELLEGA	9.020	36.530	NBRP	3/31/1954	12/31/1999	1
117	LODWAR	3.117	35.617	NBRP	1/31/1950	12/31/2004	3
118	LOKICHOKIO	4.250	34.350	NBRP	1/31/1959	12/31/1993	3
119	LOKITAUNG	4.250	35.750	NBRP	1/31/1957	11/30/1993	3
120	MALAKAL	9.550	31.650	NBRP	1/31/1950	8/31/2001	2
121	ADJUMANI	3.367	31.783	NBRP	1/31/1961	12/31/2000	3
122	GANBELLA	8.150	34.350	NBRP	11/30/1956	4/30/1999	4
123	BEGIE	9.350	34.533	NBRP	2/28/1967	12/31/2003	2
124	GORE	8.150	35.320	NBRP	1/31/1952	8/31/2002	2
125	NEDJO	9.500	35.483	NBRP	1/31/1952	12/31/2003	1

(1) **Sources:** DST: NB-DSS Work Package 2 stage 2; GHCN: Global Historical Climate Network; NBRP: Nile Basin Research Programme; MWE: Ministry of Water and Energy Uganda; NBE: Nile Basin Encyclopedia; FAO: Food and Agricultural Organisation; EMP: Ethiopian Master Plan Studies.

(2) **Patching correlation Accuracy** 1 – Excellent; 2 – Good; 3 – Acceptable; 4 – Non-compliant

Locations of rainfall stations

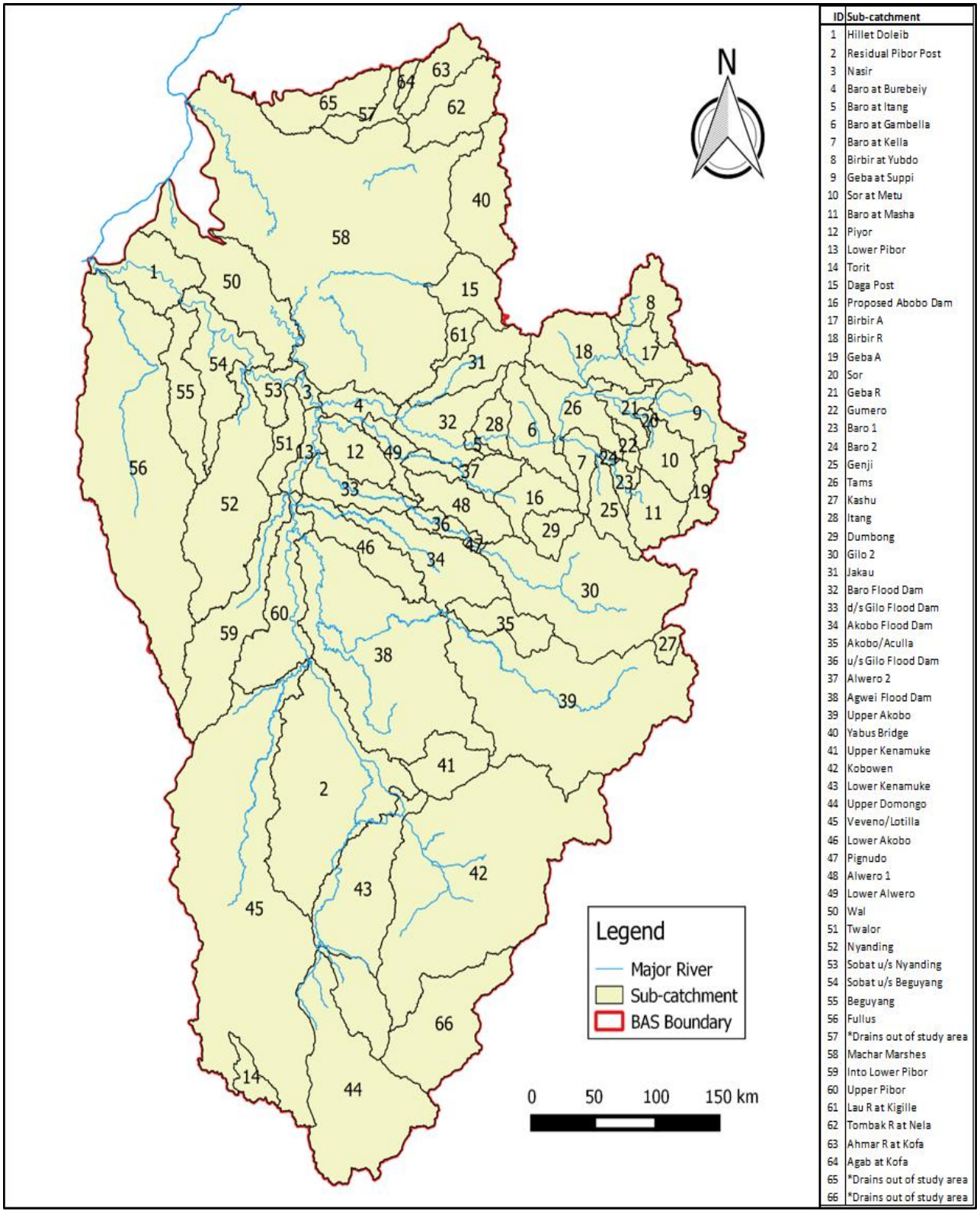


Annex 5-c: Evaporation data

Average monthly evaporation values at various stations in the Baro-Akobo-Sobat

Station Name	Source	Type	Record Period	Lat	Long	Average Monthly Evaporation (mm)												MAE (mm)
						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Abobo	EMP	Penman	1956-1987*	7.51	34.33	119	132	161	153	129	114	108	114	117	123	114	116	1500
Bedelle	EMP	Penman	1985-1998*	8.27	36.20	124	137	143	139	141	141	117	96	100	116	136	140	1530
Gambella	EMP	Penman	1906-1993*	8.15	34.35	136	140	176	161	130	113	107	113	116	124	120	125	1561
Pokwo	EMP	Penman	1956-1989*	8.10	34.28	127	138	172	162	134	113	109	107	118	127	118	123	1548
Gore	EMP	Penman	1952-2002*	8.09	35.32	145	130	152	138	121	97	96	97	103	125	125	131	1460
Jikawo	EMP	Penman	1973-1989*	8.21	33.48	112	109	149	152	115	88	88	97	110	108	107	99	1334
Metu	EMP	Penman	1952-1992*	8.20	35.35	116	133	156	159	123	102	93	98	101	121	108	111	1421
Mizan	EMP	Penman	1953-1992*	7.00	35.35	114	118	134	130	123	109	100	103	107	118	110	109	1375
Wush	EMP	Penman	1953-1992*	7.11	36.10	111	116	134	131	126	111	100	103	107	119	107	108	1373
Anger	EMP	Penman	1954-1992*	9.22	36.22	110	121	143	150	127	109	100	103	103	116	104	105	1391
Arjo	EMP	Penman	1954-1992*	8.45	36.30	106	114	138	131	119	100	89	94	100	112	105	105	1313
Bambessi	EMP	Penman	1955-1992*	9.45	34.44	128	145	169	161	122	99	91	92	93	98	101	121	1420
Dembi	EMP	Penman	1973-1992*	8.32	34.48	111	119	139	135	112	97	91	95	98	115	102	108	1322
Gimbi	EMP	Penman	1952-1992*	9.10	35.47	118	131	152	154	124	102	93	96	100	112	114	115	1411
Kurmuk	EMP	Penman	1961-1988*	10.26	34.28	163	181	205	199	151	125	114	118	116	127	130	152	1781
Mendi	EMP	Penman	1955-1992*	9.47	35.05	116	131	144	144	125	104	99	92	95	109	99	107	1365
Nedjo	EMP	Penman	1952-2003*	9.30	35.29	106	130	142	141	122	101	96	91	93	108	98	106	1334
Dongoro	EMP	Penman	1952-1992*	9.16	35.41	117	128	150	151	114	93	84	87	92	102	103	106	1327
Wama	EMP	Penman	1975-1987*	8.46	36.45	116	126	162	145	133	112	91	95	101	114	111	110	1416
Bonga	EMP	Penman	1953-1992*	7.13	36.14	114	118	131	127	119	106	99	101	104	114	112	109	1354
Gambela	FAO	Penman-Monteith	1985-1986	8.25	34.58	-	-	-	-	144	117	119	109	126	139	131	143	-
Burre	FAO	Penman-Monteith	1989-1991	8.27	35.08	155	130	165	142	122	101	101	101	113	155	142	146	1570
Gore	FAO	Penman-Monteith	1982-1991	8.17	35.55	120	121	138	135	116	92	96	95	102	128	110	113	1365
Alge	FAO	Penman-Monteith	1990-1991	8.53	35.67	147	132	-	135	133	104	103	-	-	130	136	153	-
Nejo	FAO	Penman-Monteith	1989-1990	9.50	35.48	217	-	-	243	156	172	150	107	124	175	216	251	-
Bedele	FAO	Penman-Monteith	1986-1991	8.45	36.38	-	120	136	129	126	116	97	102	105	130	128	115	-
Gambela	Shahin, 1985	Open Water	1950-1957	8.25	34.58	205	216	248	180	109	75	65	65	66	87	108	155	1578
Akobo	Shahin, 1985	Open Water	1950-1957	7.78	33.02	270	277	285	222	136	135	102	74	60	81	117	202	1961
Gore	Norplan, 2006	Open Water	1974-2003	8.15	35.53	112	116	134	128	111	88	81	85	91	102	100	103	1251
Baro-1	Norplan, 2006	Open Water	1974-2004	8.07	35.33	116	120	138	132	115	91	84	87	94	106	104	106	1293
Baro-2	Norplan, 2006	Open Water	1974-2005	8.15	8.15	119	123	142	135	118	93	86	90	96	108	106	109	1325
Genji	Norplan, 2006	Open Water	1974-2006	8.12	35.22	120	125	144	137	120	95	87	91	98	110	108	110	1345
Malakal	FAO Calculator	Penman-Monteith	1951-2005	9.53	31.65	186	190	229	186	152	144	133	121	120	149	174	180	1965
Torit	FAO Calculator	Penman-Monteith	1951-2005	4.42	32.55	180	179	198	150	105	99	105	105	99	112	123	158	1614
Pibor Post	FAO Calculator	Penman-Monteith	1951-2005	6.80	33.13	195	193	220	168	127	120	124	121	111	124	144	180	1827
*Record period estimated based on corresponding rainfall station record period																		

Annex 5-d: Model subcatchment information



ID	Sub-catchment
1	Hillet Doleib
2	Residual Pibor Post
3	Nasir
4	Baro at Burebeiy
5	Baro at Itang
6	Baro at Gambella
7	Baro at Kella
8	Birbir at Yubdo
9	Geba at Suppi
10	Sor at Metu
11	Baro at Masha
12	Piyor
13	Lower Pibor
14	Torit
15	Daga Post
16	Proposed Abobo Dam
17	Birbir A
18	Birbir R
19	Geba A
20	Sor
21	Geba R
22	Gumero
23	Baro 1
24	Baro 2
25	Genji
26	Tams
27	Kashu
28	Itang
29	Dumbong
30	Gilo 2
31	Jakau
32	Baro Flood Dam
33	d/s Gilo Flood Dam
34	Akobo Flood Dam
35	Akobo/Aculla
36	u/s Gilo Flood Dam
37	Alwero 2
38	Agwei Flood Dam
39	Upper Akobo
40	Yabus Bridge
41	Upper Kenamuke
42	Kobowen
43	Lower Kenamuke
44	Upper Domongo
45	Veveno/Lotilla
46	Lower Akobo
47	Pignudo
48	Alwero 1
49	Lower Alwero
50	Wal
51	Twalor
52	Nyanding
53	Sobat u/s Nyanding
54	Sobat u/s Beguyang
55	Beguyang
56	Fullus
57	*Drains out of study area
58	Machar Marshes
59	Into Lower Pibor
60	Upper Pibor
61	Lau R at Kigille
62	Tombak R at Nela
63	Ahmar R at Kofa
64	Agab at Kofa
65	*Drains out of study area
66	*Drains out of study area

Delineation of model subcatchments

MODEL SUBCATCHMENT INFORMATION

Sub-catchment	Catchment Area (km2)	MAP (mm)	Rainfall stations used for catchment rainfall file (monthly)	Rainfall stations used for catchment rainfall file (daily)	MAE (mm)	Evaporation stations used for catchment monthly evaporation	NAM parameters used	MAR (million m3/a)	Runoff Coefficient
Hillet Doleib	3,015	769	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,916	Malakal (FAO calculator)	Alwero	7	0.003
Residual Pibor Post	10,975	886	1937Kapoeta, 3312Lokichokio, 2112Maji, 2294Pibor_Post	Pibor Post	1,731	Pibor Post (FAO calculator)	Alwero	16	0.002
Nasir	348	788	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,738	Malakal (FAO calculator)	Alwero	2	0.007
Baro at Burebeiy	1,203	825	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,673	Gambella (Observed)	Alwero	2	0.002
Baro at Itang	221	1,013	2191Mugi, 2377Shebele, 1192Gambela, 1764Gambela	Gore	1,550	Gambella (Observed)	u/s Gambella	5	0.022
Baro at Gambella	2,269	1,363	2191Mugi, 2377Shebele, 1192Gambela, 1764Gambela	Gore	1,484	Gambella (Observed)	u/s Gambella	630	0.204
Baro at Kella	1,016	1,611	1610Bure, 3611Gore	Gore	1,445	Metu (Observed)	u/s Gambella	455	0.278
Birbir at Yubdo	1,858	1,863	1691Dongoro, 1791Gimbi_HS, 2267Nolekaba, 2539Youbdo, 1837Henna, 3673Nedjo	Gore	1,389	Dongoro (Observed)	u/s Gambella	1,431	0.413
Geba at Suppi	2,740	1,750	1806Gore, 1847Hurumu, 2530Yayu, 1649Chora_Kumbabe	Gore	1,358	Arjo (Observed)	u/s Gambella	1,597	0.333
Sor at Metu	1,712	1,899	1806Gore, 2172Metu_Hospital, 2530Yayu	Gore	1,375	Arjo (Observed)	u/s Gambella	1,179	0.363
Baro at Masha	1,729	1,875	2438Tepi, 1806Gore, 3611Gore	Gore	1,385	Arjo (Observed)	u/s Gambella	1,159	0.357
Alwero at Abobo	710	1,311	1764Gambela, 2290Pakwo, 2291Pakwo, 2141Masha	Gore	1,491	Metu (Observed)	Alwero	108	0.116
Piyor	1,814	907	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,687	Gambella (Observed)	Alwero	8	0.005
Torit	822	967	1490Agoro, 2454Torit	Torit	1,609	Torit (FAO calculator)	Alwero	10	0.013
Upper Daga	3,124	1,401	1562Begi_School, 2005Kiltukara	Gore	1,501	Bambessi (Observed)	u/s Gambella	641	0.146
Proposed Abobo Dam	1,071	1,333	1764Gambela, 2290Pakwo, 2291Pakwo, 2141Masha	Gore	1,486	Metu (Observed)	Alwero	177	0.124
Birbir A	1,634	1,733	1691Dongoro, 1791Gimbi_HS, 2267Nolekaba, 2539Youbdo, 1837Henna, 3673Nedjo	Gore	1,393	Dongoro (Observed)	u/s Gambella	1,081	0.382
Birbir R	3,377	1,556	1496Alem_Teferi_School, 1610Bure, 1642Chanka, 2324Rob_Gebeya	Gore	1,403	Metu (Observed)	u/s Gambella	1,482	0.282
Geba A	995	1,731	1806Gore, 1847Hurumu, 2530Yayu, 1649Chora_Kumbabe	Gore	1,356	Arjo (Observed)	u/s Gambella	582	0.338
Sor	152	1,865	1806Gore, 2172Metu_Hospital, 2530Yayu	Gore	1,393	Arjo (Observed)	u/s Gambella	99	0.349
Geba R	1,053	1,783	1806Gore, 1847Hurumu, 2530Yayu, 1649Chora_Kumbabe	Gore	1,405	Arjo (Observed)	u/s Gambella	615	0.328
Gumero	424	2,040	1610Bure, 3611Gore	Gore	1,409	Metu (Observed)	u/s Gambella	345	0.398
Baro 1	492	2,022	1610Bure, 3611Gore	Gore	1,409	Metu (Observed)	u/s Gambella	393	0.395
Baro 2	115	2,085	1610Bure, 3611Gore	Gore	1,424	Metu (Observed)	u/s Gambella	97	0.406
Genji	1,385	1,816	1610Bure, 3611Gore	Gore	1,417	Metu (Observed)	u/s Gambella	861	0.342
Tams	2,590	1,466	1610Bure, 3611Gore	Gore	1,444	Metu (Observed)	u/s Gambella	890	0.234
Kashu	456	2,032	1448Abobo, 2535Yeki, 2112Maji	Gore	1,373	Mizan (Observed)	u/s Gambella	376	0.406
Itang	930	1,227	2191Mugi, 2377Shebele, 1192Gambela, 1764Gambela	Gore	1,522	Gambella (Observed)	u/s Gambella	99	0.087
Dumbong	1,079	1,441	1764Gambela, 2290Pakwo, 2291Pakwo, 2141Masha	Gore	1,463	Metu (Observed)	Alwero	258	0.166
Gilo 2	9,364	1,600	1448Abobo, 2180Mizan_Teferi, 2438Tepi, 2535Yeki	Gore	1,427	Mizan (Observed)	u/s Gambella	3,858	0.257
Jakau	2,337	1,391	2191Mugi, 2377Shebele, 1192Gambela, 1764Gambela	Gore	1,488	Gambella (Observed)	u/s Gambella	485	0.149
Baro Flood Dam	2,798	1,024	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Gore	1,557	Gambella (Observed)	Alwero	89	0.031
d/s Gilo Flood Dam	1,867	959	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,698	Gambella (Observed)	Alwero	15	0.008
Akobo Flood Dam	3,882	1,094	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,609	Gambella (Observed)	Alwero	161	0.038
Akobo/Aculla	1,737	1,331	1448Abobo, 2535Yeki, 2112Maji	Gore	1,533	Mizan (Observed)	Alwero	109	0.047
u/s Gilo Flood Dam	746	1,047	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,593	Gambella (Observed)	Alwero	25	0.032
Alwero 2	1,611	1,043	1764Gambela, 2290Pakwo, 2291Pakwo, 2141Masha	Gore	1,554	Metu (Observed)	Alwero	47	0.028
Agwei Flood Dam	13,727	1,037	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,701	Gambella (Observed)	Alwero	246	0.017
Upper Akobo	14,281	1,546	1448Abobo, 2535Yeki, 2112Maji	Gore	1,481	Mizan (Observed)	u/s Gambella	4,698	0.213
Upper Yabus	6,321	1,219	1177J_Maiak, 1178El-Kurmuk, 1201Yabus_Bridge, 1523Asosa, 1641Chali, 2005Kiltukara, 2060Kurmuk, 2061	Gore	1,605	Kurmuk (Observed)	u/s Gambella	907	0.118
Upper Kenamuke	1,982	1,098	1937Kapoeta, 3312Lokichokio, 2112Maji, 2294Pibor_Post	Pibor Post	1,609	Pibor Post (FAO calculator)	Alwero	50	0.023
Kobowen	18,758	1,006	1937Kapoeta, 3312Lokichokio, 2112Maji, 2294Pibor_Post	Pibor Post	1,560	Pibor Post (FAO calculator)	Alwero	253	0.013
Lower Kenamuke	5,412	816	1937Kapoeta, 3312Lokichokio, 2112Maji, 2294Pibor_Post	Pibor Post	1,646	Pibor Post (FAO calculator)	Alwero	4	0.001
Upper Domongo	8,712	934	1937Kapoeta, 3312Lokichokio, 2112Maji, 2294Pibor_Post	Torit	1,585	Torit (FAO calculator)	Alwero	46	0.006
Veveno/Lotilla	24,765	896	1220Mongalla, 2439Terakeka, 2447Tombe, 2454Torit, 2294Pibor_Post	Pibor Post	1,712	Pibor Post (FAO calculator)	Alwero	43	0.002
Lower Akobo	2,431	974	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,695	Gambella (Observed)	Alwero	23	0.010
Pignudo	104	1,167	1448Abobo, 2180Mizan_Teferi, 2438Tepi, 2535Yeki	Gore	1,563	Mizan (Observed)	Alwero	3	0.025
Alwero 1	2,076	1,071	1764Gambela, 2290Pakwo, 2291Pakwo, 2141Masha	Gore	1,566	Metu (Observed)	Alwero	72	0.032
Lower Alwero	1,026	930	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Gore	1,632	Gambella (Observed)	Alwero	8	0.008
Wal	5,403	762	1197Nasir, 1462Abwong, 1193Kodok, 2162Melut	Malakal	1,839	Malakal (FAO calculator)	Alwero	30	0.007
Twalor	1,346	849	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,769	Malakal (FAO calculator)	Alwero	15	0.013
Nyanding	7,197	865	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,831	Malakal (FAO calculator)	Alwero	78	0.013
Sobat u/s Nyanding	1,099	789	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,778	Malakal (FAO calculator)	Alwero	6	0.007
Sobat u/s Beguyang	3,576	783	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,837	Malakal (FAO calculator)	Alwero	15	0.005
Beguyang	2,592	806	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,862	Malakal (FAO calculator)	Alwero	13	0.006
Fullus	17,492	844	1494Akobo, 1197Nasir, 1462Abwong, 1839Hillet_Doleib, 2242Nasser, 1195Malakal_MofA, 1207Shambe	Malakal	1,894	Malakal (FAO calculator)	Alwero	122	0.008
Machar Marshes	29,362	897	1197Nasir, 1462Abwong, 1193Kodok, 2162Melut	Malakal	1,732	Malakal (FAO calculator)	Alwero	1,167	0.044
Into Lower Pibor	5,126	894	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,846	Gambella (Observed)	Alwero	9	0.002
Upper Pibor	4,113	903	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,821	Gambella (Observed)	Alwero	9	0.002
Lower Pibor	957	798	1198Pibor, 1494Akobo, 1864Itang, 1874Jikawo, 2291Pakwo, 2294Pibor_Post, 3542Ganbella	Pibor Post	1,705	Gambella (Observed)	Alwero	1	0.001

Annex 5-e: Information sources – Floodplains, wetlands and marshes in the Baro-Akobo-Sobat basin

The following sources were used to conceptualise and model the floodplains of the BAS Basin, and are discussed in more detail below:

- GIEMS - Global Inundation Extent from Multi-satellites Dataset (Prigent et al., 2007; Fluet-Chouinard et al., 2015; Miolane et al., in print)
- GLWD - Global Lakes and Wetlands Database (Lehner and Doll, 2004).
- TTI spatial mapping of wetlands and marshes in the BAS Basin (Baro-Akobo-Sobat Multipurpose Water Resources Development Project: Scoping Report: Annex2, Dec 2015)
- The Hydrology of the Nile (Sutcliffe and Parks, 1999)
- Baro-Akobo basin master plan study of water and land resources of the Gambela Plain (Selkhozpromexport, 1990)
- 2012 Field Report on visit to Machar Marshes
- Baro-Akobo-Sobat Wetlands Knowledge Base Consultancy (Ssebuliba, 2012)
- A Directory of African Wetlands (Hughes and Hughes, 1992)

GIEMS

The Global Inundation Extent from Multi-Satellites (GIEMS) is a monthly-mean water surface extent derived at a low spatial resolution of 0.25°equal-area grid for the period between 1993 and 2007. The derivation included combining satellite observations in the visible, near-infrared, and passive/active microwaves. It expresses the fractional inundation within each 773 km^2 grid box (resolution at the equator) attributed to lakes, rivers, wetlands and irrigated agriculture.

GIEMS-D15 was derived from the GIEMS data at a pixel size of 15 arc-seconds. The downscaling procedure predicted the location of surface water cover with an inundation probability map that was generated by bagged decision trees using globally available topographic and hydrographic information from the SRTM-derived HydroSHEDS database and trained on the wetland extent of the GLC2000 global land cover map. GIEMS-D15 represents three states of land surface inundation extents: mean annual minimum, mean annual maximum, and long-term maximum (the largest surface water area of any global map to date).

The GIEMS data was also downscaled to a 3 arc second (90 m) dataset (GIEMS-D3) using topographical information from the HydroSHED database and a new floodability index procedure. The resulting GIEMS-D3 database is the only long-term (1993-2007), dynamic (monthly time-scale), and high spatial resolution inundation database that is available at the global scale.

GLWD

The Global Lakes and Wetlands Database (GLWD) represents a comprehensive dataset of global surface water area, including small and large lakes, reservoirs, smaller water bodies, rivers, and a good representation of the maximum global wetland extent. GLWD is a static database.

TTI

Using landsat and radar images, TTI prepared an inundation map for the study basin. (refer

The Hydrology of the Nile (Sutcliffe and Parks, 1999)

Sutcliffe and Parks (1999) reported that the streamflow in the Baro River below the Machar Marshes does not exceed 1.5 km^3 per month (560 m^3/s), even though the inflow upstream of the Marshes at Gambella exceeds that value. Hurst (1950) estimated that 78% of the lost water is diverted into the Machar Marshes, and the remaining 22% spills over to the left bank.

Baro-Akobo basin master plan study of water and land resources of the Gambela Plain (Selkhozpromexport, 1990)

A study by Selkhozpromexport (1990) reported on the flooding of areas along the Baro, Alwero, Gilo and Akobo Rivers due to limited conveyance capacities as follows:

- Baro River: 860 – 1000 m^3/s
- Gilo River: 150 – 300 m^3/s
- Alwero River: 60 - 70 m^3/s.

These capacity ranges were used in the model in order to simulate spills when the river capacities were exceeded. Selkhozpromexport (1990) also reported on the 1988 flood at Gambella and presented maps of inundated areas for one in 10 year and one in 2 year floods – these were digitised for this project.

2012 Field Report on visit to Machar Marshes

This report describes a field mission to the Baro River at the locations of major spills to the Machar and provides information about the locations and elevations of spill channels

Baro-Akobo-Sobat Wetlands Knowledge Base Consultancy (Ssebuliba, 2012)

This report provided useful information on the river system and wetlands in the basin.

A Directory of African Wetlands (Hughes and Hughes, 1992)

This report provides very useful information regarding the location and extent of wetlands in the study area, including the Pibor catchment. It also describes the main rivers draining into and out of the wetlands.