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Full Length Research Paper

Water balance of the Juba and Shabelle Rivers in Ethiopia-Somalia

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Abstract

The Juba and Shabelle Rivers are the only perennial and transboundary rivers in Somalia but two-thirds of the river basins are located outside Somalia, mostly in Ethiopia, with a part of the Juba basin in Kenya. The two rivers originate from the Bale mountain ranges at an altitude of about 4230 m in the Ethiopian highlands flowing towards the Indian Ocean crossing the border between Ethiopia and Somalia. The study area was delineated using a 30 m resolution Shuttle Radar Topography Mission (SRTM) digital elevation model. To fulfill the research objectives, the rainfall and daily runoff data were collected from the FAO SWALIM project office and database, the LocClim v.1.10 database and the TRMM satellite product. The daily runoff data was stored and analyzed using the HEC-DSSVue 2.0.1 system for the basic statistical analysis and a correlation testing of TRMM data and measured rainfall data. The areal rainfall was calculated using the Thiessen polygon method with the ArcGIS software and the actual evaporation was determined using the water balance method. The Juba and Shabelle Rivers have two peak flows during the Deyr and Gu flood seasons. The Shabelle River flow is decreased at the downstream runoff stations during the two peak flow seasons but there is only a very small flow reduction in the Juba River. The annual daily peak flows were observed for the Juba River at the Luuq runoff station and for the Shabelle River at the Belet Weyne runoff station, but during the Hagaa and Jilaal seasons the daily flow for the two rivers are very low and even close to zero. The actual evapotranspiration was determined as a remaining part of the water balance equation and it is mainly depended on the rainfall in each sub basin.

Keywords: Juba River, Shabelle River, Water balance

INTRODUCTION

Somalia is located at the Horn of Africa and bordered by Ethiopia to the west, Djibouti to the northwest, the Gulf of Aden to the north, the Indian Ocean to the east and Kenya to the Southwest. Somalia's total land area is 637,600 km^2, of which 45% is classified as rangelands suitable for livestock grazing, 30% is classified as desert land, 14% is covered by forest and 11% is arable land (Houghton-Carr et al., 2011). The Juba and Shabelle River basins are international river basins at the Horn of Africa drained through Ethiopia, Kenya and Somalia and the only perennial rivers flowing through Somalia.

A basin water balance assessment includes the analysis in the interactions among various types of water uses and users, and in the process, it helps in better understanding the physical, environmental, social and economic influences that impinge on the water use and management activities (Bhawan, 2001; Ufoegbune et al., 2011). These facts are clearly revealed by analyzing and comparing the specific water availability for a specify period of time for different regions. Similarly, a more comprehensive analysis requires knowing the adverse effects of a rapid degradation of the environment and other ecological problems arising from severe competition for water to be practiced between different users in riparian countries (Tadesse and Mohammed, 2009; Tafesse et al., 2010).

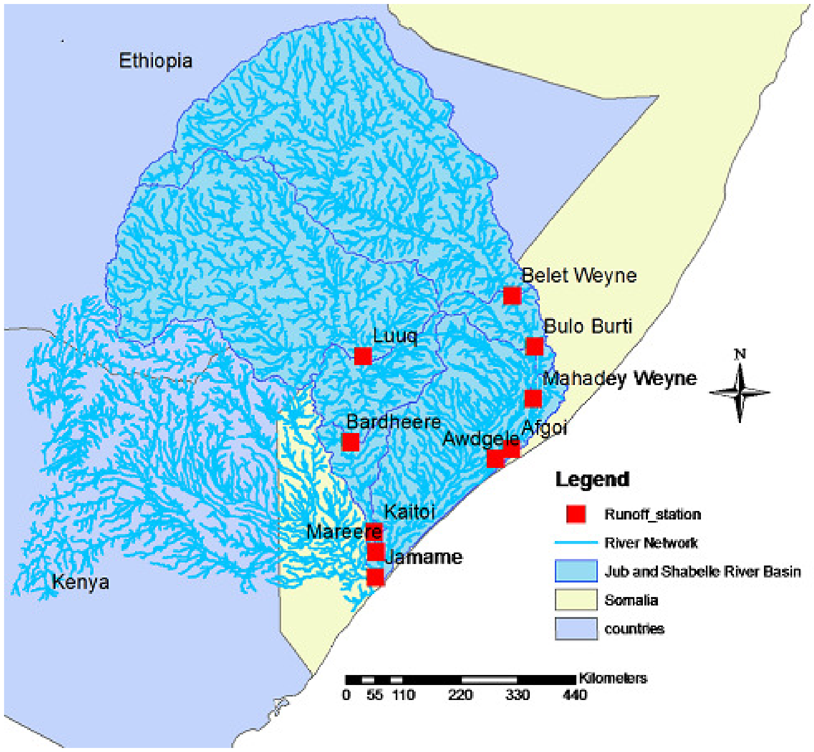

Figure 1. Juba and Shabelle River Stations

In a river basin water balance view, consistent issues of quantity and quality of surface water and groundwater water resources can be more comprehensively analyzed (Dung, 2011; Fanta et al, 2001). The water balance of the Shabelle and Juba River basins can be determined by calculating the input, output, and storage changes of water in the basins. This water balance assessment is important for an efficient water resources use and management (Hussain, 2011; Johnson and Curtis, 1994). It can provide basic information for planning of energy production, irrigation use, water supply and prevention against floods.

Almost all the Somalia's surface water resources exist in these rivers, whereas runoff contribution in Somalia is normally minimal or almost insignificant. The Shabelle River basin is larger in size and the Shabelle River is longer than the Juba River, but Shabelle River is low in annual runoff compared with Juba River due to climatic and geological conditions in the catchment (Basnyat, 2009). The total catchment area for the Shabelle River basin is 216,243 km^2 at Awdgele and for the Juba River basin 298,654 km^2 at Jamame.

About two-thirds of these areas are outside Somalia, mainly in Ethiopia. The two rivers originate from the Bale mountain ranges at an altitude of about 4230 m in the Ethiopian highlands flowing towards the Indian Ocean crossing the border between Somalia and Ethiopia (FAO SWALIM, 2010).

MATERIALS AND METHODS

Area Description

The Juba and Shabelle River basins are located between the longitudes 41°53' and 46°09' east and between the latitudes 0°16' south and 5°04' north inside Somalia. The area of the Juba and Shabelle Rivers basins are 218,114 km^2 (to Jamame, excluding Shabelle basin) and 296,972 km^2 (to the Juba confluence), respectively (Basnyat and Gadain, 2009).

The climate conditions for the Juba and Shabelle River basins can be described as mainly arid and semi-arid, and the climate is influenced by the north and south-easterly air flows of the Intertropical Convergence Zone (ITCZ). The north and south-easterly air masses meet at the Intertropical Front (ITF) and raise air upwards to form rain (Muchiri P.W., 2007a). Somalia has a bimodal rainfall distribution, with two rainy seasons (Gu and Deyr). The Gu season dominates over the Deyr in quantity and reliability of rainfall and as such it is treated as the primary rainy season. The Gu rains start as early as the second half of March and then increase in April all over the basins. Temperatures vary both across location and seasons. The mean annual temperatures ranging between 25°-30°C, with a maximum temperature of 41.3°C in March and a minimum temperature of 17°C in January. In areas near the rivers the relative humidity is high; ranging from about 75-80%, but further inland away from the rivers the air is much drier. Relative humidity is higher in the coastal areas, where it usually exceeds 80% (FAO SWALIM, 2010). Evapotranspiration is high throughout the study area. The highest potential evapotranspiration occurs in the northern areas of Gedo, Bakool and Hiraan regions where it exceeds 2100 mm/yr; in the rest of the area it is between 1500 and 2000 mm/yr (Houghton-Carr, et al., 2011).

The geology of two river basins has been developed due to the outcropping of the metamorphic basement complex, made up of migmatite and granite. Sedimentary rocks such as limestone, sandstone, and gypsiferous limestone are present, as well as an extensive, wide system of coastal sand dunes (Paron and Vargas, 2007). The river basins are characterized by three morphologic regions. The upper region can be described as high mountains, steep slopes and rugged features, mountain peaks and high plateaus with monsoon winds and rainfall, whereas in the middle region, gentle slopes and reliefs occur and transport and deposition is dominating (FAO SWALIM, 2010). The land covers in the basins consist mostly of natural vegetation and crop fields, urban areas, dunes and bare lands, and natural water bodies. The vegetation consists of bush lands, grasslands and riparian forest. In the headwaters of the Juba and Shabelle River basins, where rainfall is generally high and losses are relatively low, surface water resources are abundant. However, in the middle sections, the rainfall becomes less frequent and decreases, losses increase and runoff is highly localized and seasonal, the rivers carry considerable volumes of water during most of the year (Basnyat, 2007). The high floods in the Juba and Shabelle Rivers both cause advantages and destructions for the people living in the riverine areas (Houghton-Carr, et al., 2011). The area of the Juba and Shabelle rivers has different hydro-geological structures for exploring groundwater in alluvial deposits and weathered basements (Paron and Vargas, 2007; and Basnyat, 2007).

METHODOLOGY

The general steps followed in the study of the water on the two rivers of the study area are described below:

Data screening is the primary step to process data. Collected meteorological and hydrological data can contain errors due to anthropogenic and natural factors. As a consequence before using the data, the quality of the data has to be checked and filling the missing data in time series using suitable methods is necessary (Laat, 2010). Data screening was carried out before the progress of data analysis and further use. Missing gaps were filled based on linear regression methods.

Linear regression analysis was used for data filling and completion. This method is based on finding a significant correlation between closed by or adjacent stations and fitting the best straight line through the recorded values.

$$Y = C + C1X1 + C2X2 + C3X3 + \ldots CnXn \quad (1.1)$$

Where: Y is a series of values of the base station (dependent variable), Xn is a series of values of neighboring station i (independent variable), C is the equation's constant, Cn is the equation's coefficients

Meteorological parameters such as rainfall, temperature, relative humidity and potential evaporation were collected from the NewLocClim (http://www.fao.org/nr/climpag/pub/en3_051002_en.asp) and FAO SWALIM (http://www.faoswalim.org/) database. The meteorological variables such as temperature, relative humidity and potential evaporation for the study area were collected from the New_LocClim_V1.10 (FAO) database.

Among different types of TRMM products, this study has used TRMM-3B42 data. The product is a standard 3h time steep product with a spacing of 0.5 degree spatial resolution. TRMM Microwave Imager (TMI), Visible Infrared Radiometer Scanner (VIRS) and Precipitation Radar (PR) are some of the instruments used in TRMM for the estimation of rainfall (Kidd et al., 2003)

TRMM can accesses all available rainfall information and the accessibility of data with the website; http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM_3-Hourly

Hydrological and statistical data analyses are necessary to check the consistency or the homogeneity of the data set (Dung, 2011). Time series analysis is used for the detection of inconsistencies or non-homogeneities in the observation series (Patra, 2008). The measured daily time series runoff data were analyzed using the HEC-DSSVue 2.0.1 software for basic statistical analysis. The basic statistical characteristics of the time series such as mean, variance, maximum and minimum values and skewness are determined. The Gumbel probability distribution method applied as estimation for the flood frequency analysis.

HEC-DSSVue 2.0.1 Data storage

The HEC-DSSVue 2.0.1 software was used as a database, and for the hydrologic and statistical analysis for daily and monthly river flow measurements. This program was developed by the Hydrologic Engineering Centre's (US Army Corps of Engineers) to store, calculate, plot and edit time series and paired data retrieving serial data for application and utility programs. It is a Java-based graphical user interface program for graphing, tabulating, editing and manipulating HEC-DSS river flow data (USACE-HEC-DSS, 2010).

Flow Duration Curve

The flow duration curve (FDC) is expressing the hydrological characteristics of river flow and provides a graphical view of the variability of river flow and a cumulative distribution function of the daily flow. The flow duration curve describes the relationship between the flow and the percentage of time that the flow is equalled or exceeded (Mohamoud, 2008). It is derived by portioning the flow hydrograph, ranking the flows in descending order and sorting by the probability of a given flow being exceeded. The exceedence probability is usually expresses as the percentage of time that a flow is exceed. Therefore, e.g. the Q95 value is the flow exceeded 95% of the time.

The slope of the flow duration curve indicates the relative flow variability (climatic or anthropogenic factors) and the amount rainfall in the basins. The FDC equation for the available time series can be formulated as:

$$P = 100 * \left[\frac{M}{n+1}\right] \qquad (1.2)$$

Where: P = the probability indicates flow will be equalled or exceeded (% of time), M = the ranked position (dimensionless), n = the number of events for period of observe (dimensionless)

GIS data system

The Juba and Shabelle River basins were delineated at basins and sub-basins scale using the ArcGIS 9.3.1 software tool. A GIS database was created by the use of all available spatial information provided by the SWALIM project and other open resources. Different climatic and meteorological data sources and free available data from the SWALIM metadata source like administrative map, irrigation information, land, water and other shape files were used. These files were available from the FAO SWALIM project database (http://www.faoswalim.org/).

All spatial GIS input data files were projected to a Lambert Azimuthal equal-area projection system using ArcGIS 9.3.1. The Digital Elevation Model (DEM) used to delineate the Juba and Shabelle River basins was the 30m spatial resolution Shuttle Radar Topography Mission (SRTM) digital elevation model. Also raster files like slope, drainage network, flow accumulation, flow direction and sub basins processing units were available.

Thiessen Polygon Method

In most hydrologic analyses precipitation is the input for the basins and the average depth of precipitation over the area is computed by different methods. For this work, the estimation of the basins areal rainfall distribution is based on the Thiessen polygon method. In this method, lines were constructed using the ArcGIS tool by connecting all rainfall stations inside and near to the basins. The connecting lines are bisected perpendicularly to form a polygon around each station (Tatalovich et al., 2006). The perpendicular bisectors for each triangle edge are generated, forming the edges of the Thiessen polygons. The locations at which the bisectors intersect determine the locations of the Thiessen polygon vertices.

Thiessen polygon interpolation was used with the GIS package. It is a relatively easy procedure that needs point coverage for input and is executed using the ArcGIS toolbox command (Gold, 1991). The Thiessen polygon method considers all the measuring stations in a catchment on the basis of their aerial coverage and linear variation in the precipitation between two gauge stations is assumed (Patra, 2008).

The Thiessen polygon average precipitation (P_{av}) in the basins is computed as;

$$Pav = \frac{A1P1 + A2P2 + A3P3 + \ \ldots + AnPn}{A1 + A2 + A3 + \cdots + An} \qquad (1.3)$$

Where P_1, P_2... P_n represents precipitation at stations 1, 2, 3,..., n, A1, A2... An represents the area of gauge stations 1, 2, 3,..., n. representing the corresponding polygons.

Water balance calculation

The water balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle (Sokolov, 1974). The main inputs for a basin water balance are river flow and precipitation and the outputs will be evaporation and water abstraction (Wang et al., 2011; Wilk et al., 2006). The water balance of each sub basin depends on natural factors as its, climate, relief, geological situation, soil type and vegetation (Legesse et al., 2003). It also can be affected by human activities (Tate and Sutcliffe, 2001).

The water balance equations can be formulated for any area and period of time as:

$$I - O = \Delta S/\Delta t \qquad (1.4)$$

(De Laat and Savenije, 1999)

Where I = inflow per unit time (L/T), O = outflow per unit time (L/T) , $\Delta S / \Delta t$ = the change in storage within the system per unit of time (L/T)

The water balance of the basin for any time period of length Δt, can be expressed in detail as:

$$P + Gin - (Q + ET + Gout) = \Delta S \qquad (1.5$$

Dingman, 2002

Where: (P)precipitation, (G_{in})groundwater inflow, (Q)stream outflow, (ET)evapotranspiration, (G_{out})groundwater outflow, (Q_{go})groundwater outflow, (ΔS)change in storage,

RESULTS AND DISCUSSION

There is no rainfall data available from 1990 to 2001 in

Table 1. Correlation between measured and satellite data at Juba River Basin

		Bardheere		Kaitol		Mareere		Jamame	
		TRMM	Ground	TRMM	Ground	TRMM	Ground	TRMM	Ground
Bardheere	TRMM	1.00							
	Ground	0.74	1.00						
Kaitol	TRMM	0.96	0.62	1.00					
	Ground	0.89	0.47	0.88	1.00				
Mareere	TRMM	0.81	0.35	0.93	0.82	1.00			
	Ground	0.92	0.76	0.90	0.73	0.80	1.00		
Jamame	TRMM	0.97	0.71	0.89	0.90	0.71	0.83	1.00	
	Ground	0.95	0.87	0.88	0.75	0.70	0.96	0.91	1.00

Table 2. Correlation between measured and satellite data at Shabelle River Basin

		Bulo Burti		Mahadey Weyne		Afogi		Awdgele	
		TRMM	Ground	TRMM	Ground	TRMM	Ground	TRMM	Ground
Bulo Burti	TRMM	1							
	Ground	0.93	1.00						
Mahadey Weyne	TRMM	0.99	0.90	1.00					
	Ground	0.94	0.99	0.91	1.00				
Afogi	TRMM	1.00	0.92	0.98	0.93	1.00			
	Ground	0.94	0.95	0.92	0.97	0.94	1.00		
Awdgele	TRMM	0.99	0.88	0.99	0.90	0.99	0.92	1.00	
	Ground	0.69	0.72	0.71	0.76	0.68	0.82	0.70	1.00

almost all meteorological stations in Somalia. These gaps were filled using the TRMM data but the available data from TRMM are not covering all the missing rainfall data. Before using the remote sensed rainfall the data was checked with the ground available rainfall data. This was done by a correlation analysis.

Table 1 and 2 above show all sub basins in the Juba and Shabelle Rivers inside Somalia. It can be observed that the ground rainfall data have high correlations with the TRMM satellite data. In general, it is realistic to use these data to fill the rainfall gaps.

Hydrological Networks

There are four operational runoff stations and six stations with historic data available in the Juba and Shabelle River basins until 2011. Daily flows data are available for ten locations in each of the two rivers. These stations assist to analysis and characterizing the hydrology that would be needed for the design of water resources planning including flood management, irrigation infrastructure and hydropower development in the river basins.

Monthly Flows

The long-term monthly flow data are available from 1963 for ten stations in the Juba and Shabelle Rivers used for characterizing basins. The monthly flow data in the Shabelle River (Belet Weyne and Bulo Burti runoff stations) and Juba River (Luuq and Bardheere runoff stations) have long term daily flow data and functional runoff stations still to present. Both are in the upstream border to Ethiopia-Somalia and basins of the two rivers within Somalia less influenced by abstractions (irrigation and domestic demand) and diversions (hydropower development) (Basnyat (2007). Long-term monthly flow statistics are considered using data from 1963-1990 and 2001-2011 for Juba River and 2002-2011 for Shabelle River. During high flow season the two rivers flow contributes more than 15% of the total annual flow, while the dry month discharges nearly 2-5%.

Both rivers have two peak flow seasons during Deyr and Gu flood seasons. The rivers peak flow reaches in October and September on the Juba and Shabelle Rivers, respectively. These indicate that during Deyr season the peak flow attain at Shabelle River runoff

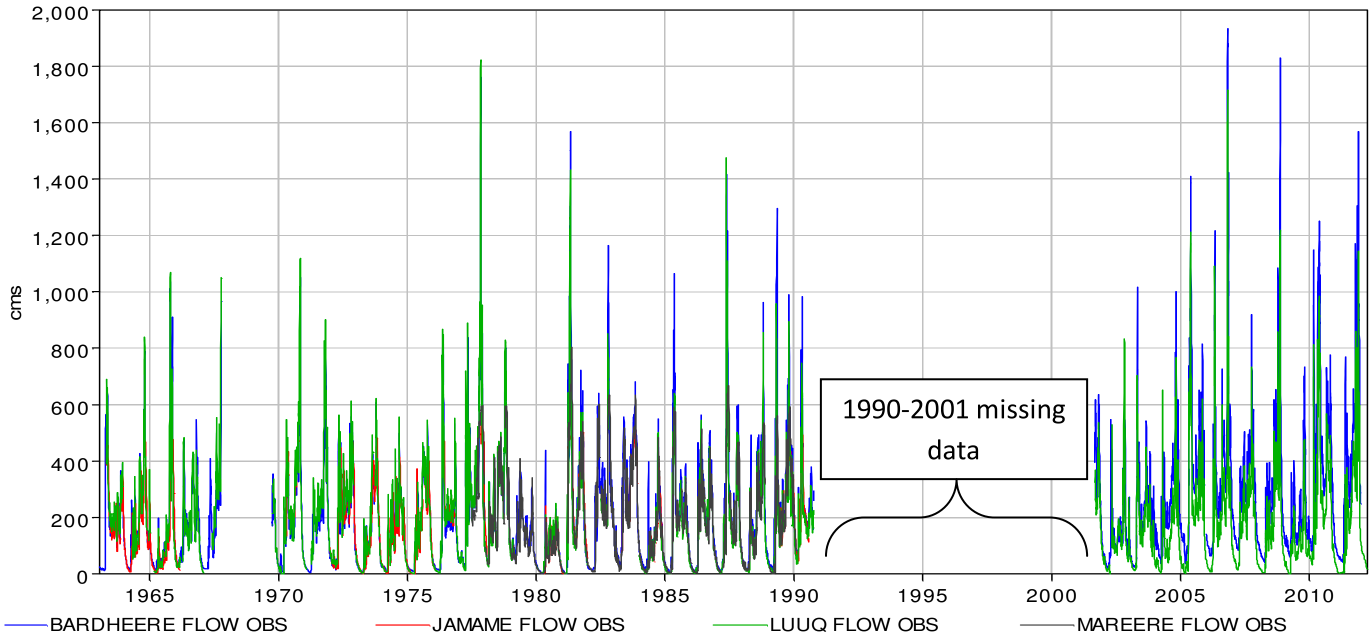

Figure 2. Juba River daily flow

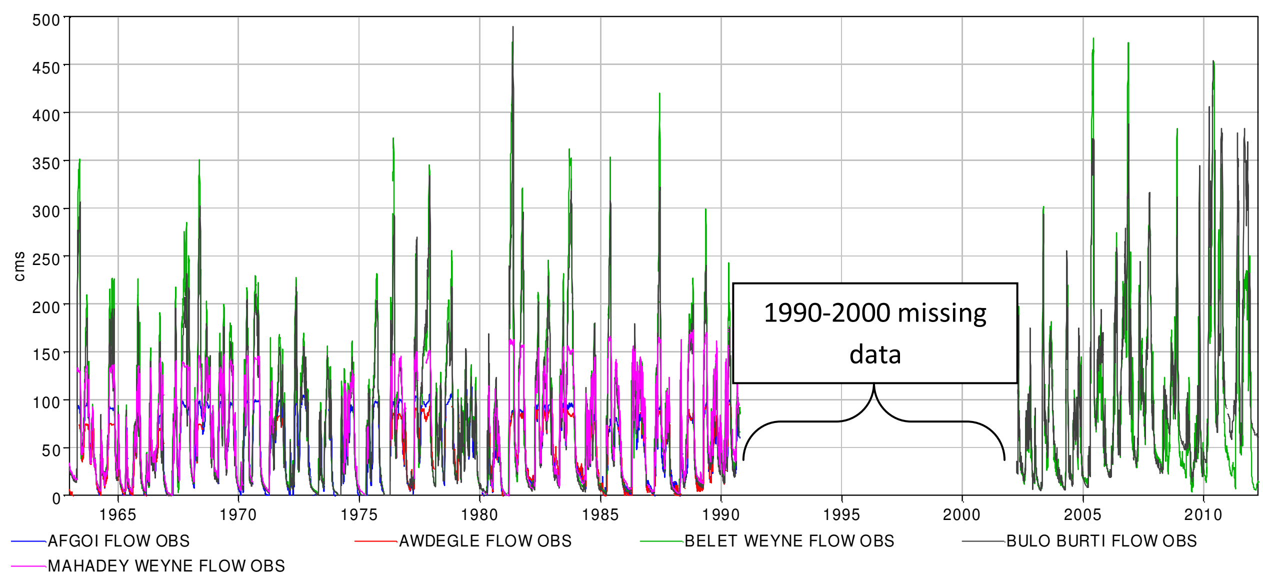

Figure 3. Shabelle River daily flow

station at a month before Juba River.

The Shabelle River has bigger catchment area than the Juba, whereas the flow in the Juba River is more than Shabelle River. This is because of the different geological formations and the higher average annual rainfall in the Ethiopian Highlands of its source contributes much runoff for the two river basins (Basnyat, 2007). The runoff contribution in Somalia is nearly negligible because the region has arid climatic condition, undefined drainage network and densities.

The long-term mean monthly and annual flows along the two rivers are presented in Table 3 and 4 below. The long-term mean annual flow at Luuq and Jamame are 185.7 and 168.1 m^3/s and Belet Weyne and Awdgele are 81.1 and 44.8 m^3/s at Juba and Shabelle Rivers, respectively. The mean annual flow volume at Luuq and Belet Weyne stations are 5.64 and 3.50 billion m^3 (bcm) in the Juba and Shabelle Rivers, respectively.

Table 3. Long-term mean annual runoff in Juba River (m^3/s)

Station	Area (km^2)	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Luuq	168,599	Mean	45	26	35	135	280	199	176	231	274	396	315	116	186
		Std.Dv.	28	20	63	145	189	113	65	70	96	143	199	80	58
		C.V.(%)	64	78	177	107	68	57	37	30	35	36	63	69	31
Berdere	200,301	Mean	69	48	55	156	336	249	204	259	311	440	395	156	223
		Std.Dv.	45	36	79	150	234	152	74	85	120	163	241	123	82
		C.V.(%)	65	74	144	96	69	61	36	33	39	37	61	79	37
Kaitoi	214,582	Mean	65	44	41	98	196	195	179	236	248	306	329	140	173
		Std.Dv.	39	31	51	87	104	95	65	75	80	127	168	115	62
		C.V.(%)	60	71	125	89	53	49	37	32	32	42	51	82	36
Mareere	215,479	Mean	45	26	30	137	290	253	189	212	236	340	326	146	186
		Std.Dv.	32	23	40	140	175	159	72	82	92	122	166	124	64
		C.V.(%)	71	89	133	102	60	63	38	39	39	36	51	85	34
Jamaame	298,654	Mean	51	24	22	96	222	205	169	214	249	316	315	134	168
		Std.Dv.	38	19	32	104	125	118	67	74	82	92	108	96	46
		C.V.(%)	75	79	144	108	56	58	39	35	33	29	34	72	27

Table 4. Long-term mean annual runoff in Shabelle River (m^3/s)

Station	Area (km^2)	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Belet Weyne	193,288	Mean	19	16	28	75	155	85	55	115	156	136	93	41	81
		Std.Dv.	16	14	37	62	97	70	25	37	62	61	78	39	29
		C.V.(%)	85	86	133	83	63	83	45	32	40	45	84	96	36
Bulo Burti	207,651	Mean	20	16	29	71	138	84	52	107	147	136	92	43	78
		Std.Dv.	18	17	44	59	87	69	23	37	62	67	72	44	30
		C.V.(%)	92	104	149	83	63	82	45	34	42	49	78	103	39
Mahadey Weyne	209,928	Mean	17	13	21	54	105	75	52	98	123	112	77	38	65
		Std.Dv.	13	12	25	38	39	41	26	28	27	28	37	33	15
		C.V.(%)	75	92	121	71	37	54	49	28	22	25	48	87	23
Afgoi	215,195	Mean	14	10	15	35	71	57	40	73	85	79	60	32	48
		Std.Dv.	14	12	20	27	23	26	20	22	16	15	25	27	12
		C.V.(%)	98	121	133	78	32	45	50	31	18	18	41	84	26
Awdgele	216,243	Mean	14	10	15	32	66	57	41	68	75	72	57	32	45
		Std.Dv.	15	13	18	25	20	23	20	20	10	9	20	26	11
		C.V.(%)	104	129	125	77	30	40	48	29	14	13	35	81	24

Flow Duration Curve

Whereas at Awdgele and Jamame the flow curves indicates flow variations within each curve of the season. The flows exceeding 50% and 90% of the time in the Juba River at Luuq station were 156.3 and 15 m^3/s, respectively but in the Shabelle River at Belet Weyne station is 58.5 and 9.3 m^3/s, respectively. At the first quarter, the flow curve (Jan-March) observed that the flow at each station shows low as compare to other quarters. During Jilaal season, the flow at Awdgele station observes too low as compared to other seasons.

Figure 6 and 7 indicates overview of the occurrences of annual daily peak flow. The upstream runoff stations (Luuq and Bardheere) at Juba River, and (Belet Weyne and Bulo Burti) at Shabelle River shows the daily peak flow but others downstream runoff stations at both rivers have low flow. The peak flow at Luuq and Bardheere, and Belet

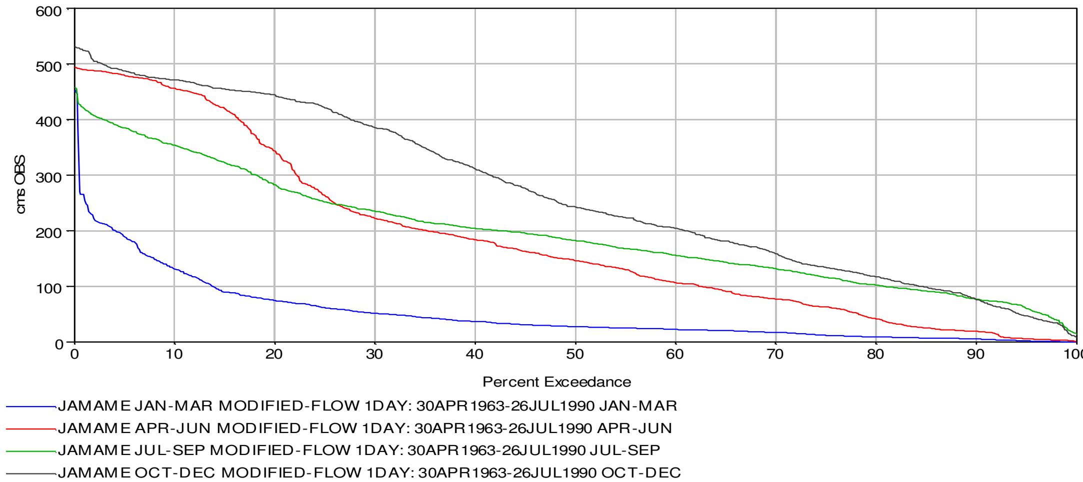

Figure 4. Quarterly flow duration Curves at Juba River (Luuq runoff station)

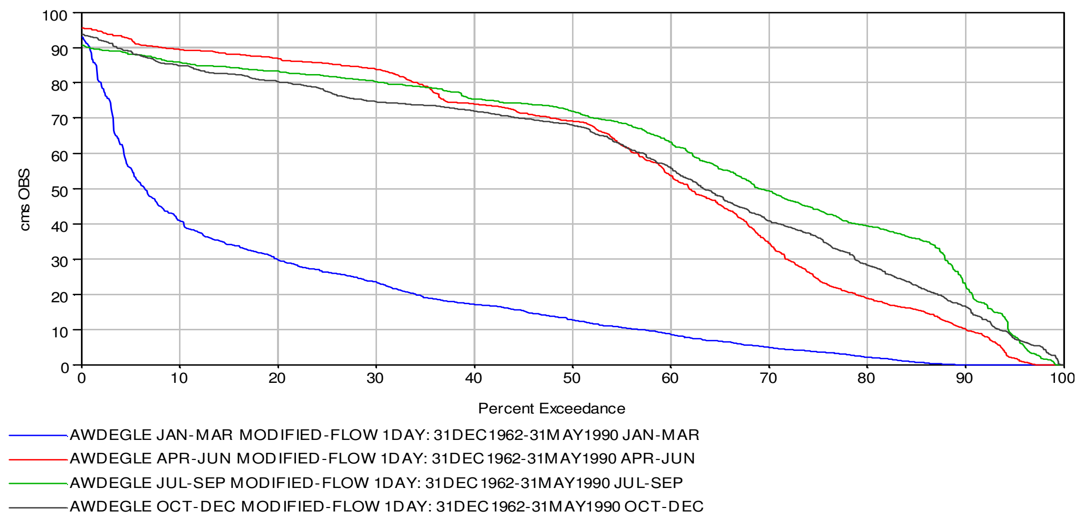

Figure 5. Quarterly flow duration Curves at Shabelle River (Awdgele runoff station)

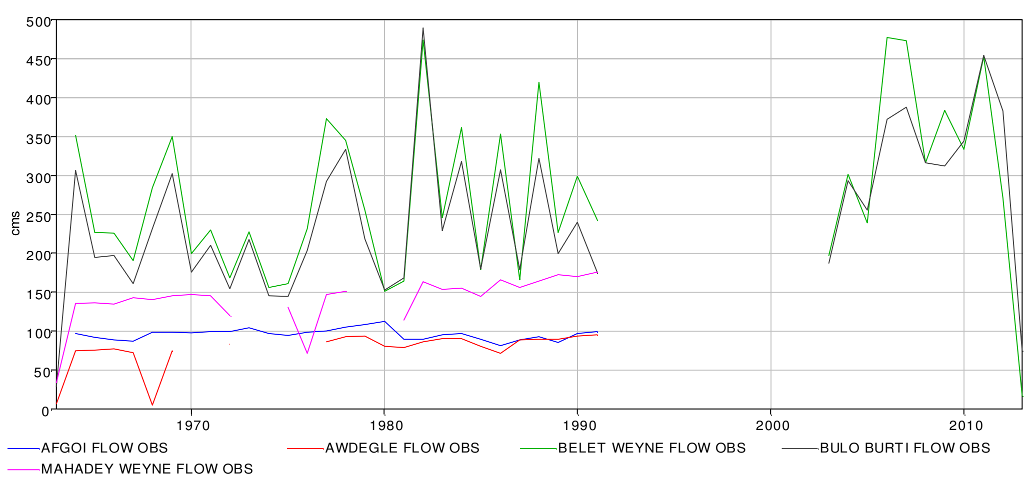

Figure 6. Shabelle River runoff stations annual daily maximum flow

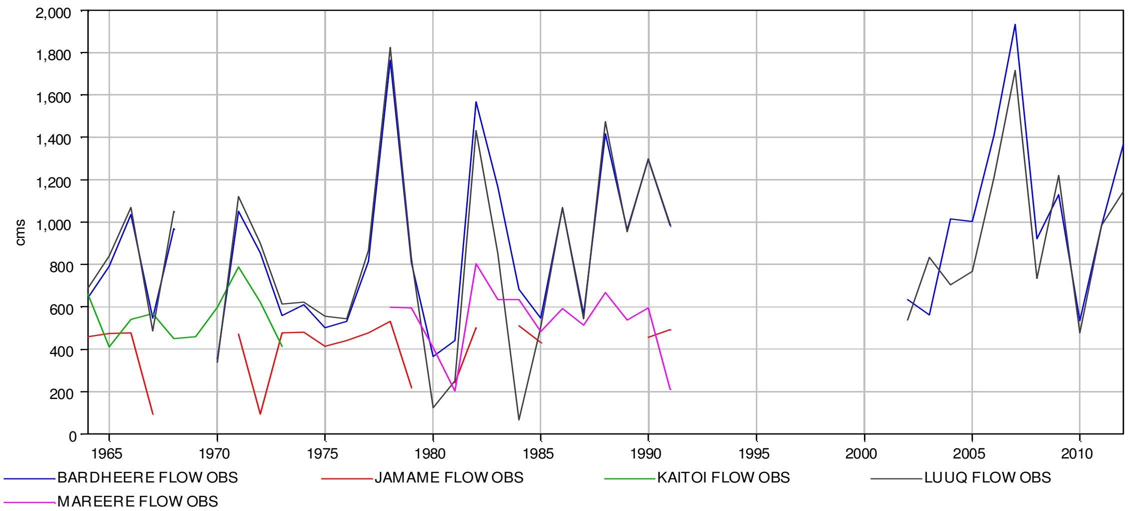

Figure 7. Juba River runoff stations annual daily maximum flow

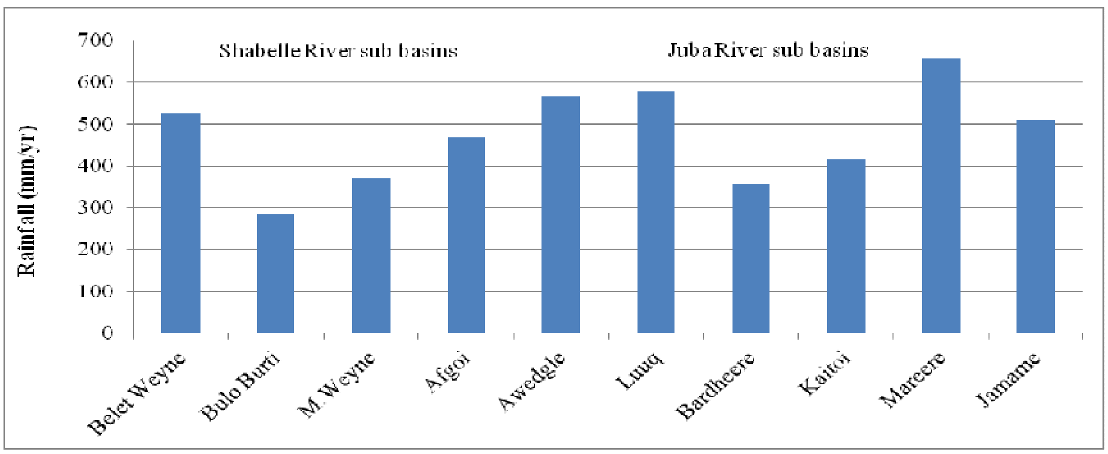

Figure 8. Long-term annual areal rainfall in the Juba and Shabelle River sub basins

Table 5. Flood Frequency Analysis (m^3/s) for Belet Weyne and Luuq runoff stations

Station	Area (Km^2)	Return periods (years)					
		2	**5**	**10**	**25**	**50**	**100**
Belet Weyne	193,288	266	352	409	481	534	587
Luuq	168,599	829	1145	1,353	1,617	1,812	2,006

Weyne and Bulo Burti have nearly equal daily peak flow and similar with time in occurrence.

Water balance calculations

Precipitation

The annual rainfall near to the Ethiopia-Somalia border (Luuq, Belet Weyne and Ceel Berde) is significantly low (200-260mm/yr), while the rainfall values in the downstream areas (Mareere, Jilib, Kismayo and Jamame) near to the coast are higher (400-760mm/yr). The annual rainfall in the Belet Weyne and Luuq sub basins have a small increase over actual evapotranspiration since the area includes high annual rainfall areas in Ethiopia, while Jamame, Awdgele and Afgoi sub basins have higher actual evaporation than rainfall. This additional increase in evaporation may appear from the swampy areas near to Shabelle and Juba Rivers. Bulo Burti, Mahadey Weyne, Awdgele and

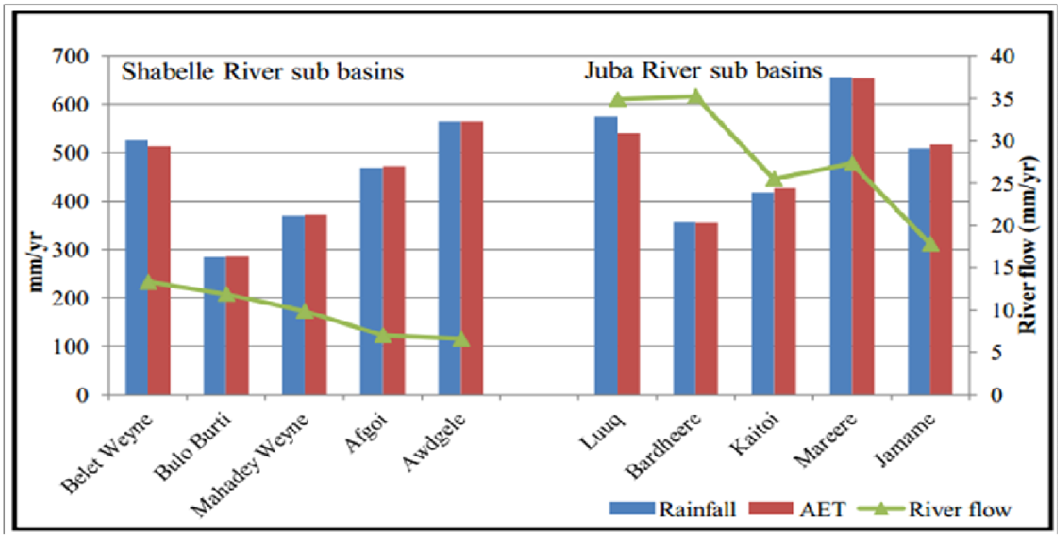

Figure 9. Water balance components in the Juba and Shabelle River sub basins

Bardheere sub basins have nearly equal amount of annual actual evaporation and rainfall. This indicates that the two rivers and other water bodies have less contribution to evaporation on these sub basins. Figure 8 shows the overview of water balance for all sub basins in Juba and Shabelle Rivers.

In general, it can conclude that the role of Juba and Shabelle Rivers in all sub basins have less impact on long-term annual water balance. This may happen due to less or nearly negligible surface runoff contribution from each sub basins in Somalia and sub basins areas are so big compare to the river cross section that contribute for evaporation.

CONCLUSIONS

Juba and Shabelle Rivers have two peak flows during the Deyr and Gu flood seasons. The river peak flows occur in October and September in the Juba and Shabelle Rivers, respectively. The Shabelle River flow decreases at the downstream runoff stations during the two peak flow seasons due to anthropogenic and natural factors, but there is less flow reduction during two peak flow seasons at the Juba River. The upstream runoff stations (Luuq and Belet Weyne) at Juba and Shabelle rivers are less influenced by abstractions. These two upstream stations are important for getting actual river flow amounts from the source and planning activities such as water resource planning, estimating peak flow and develop flood warning strategies in southern Somalia. High flows from the two rivers causes floods in the lower basins due to over-topping to the plain areas in the surrounding but during the Hagaa and Jilaal seasons the two river daily flows are low and even close to zero. The Shabelle River has a bigger catchment area than the Juba River, whereas the flow in the Juba River is higher than in the Shabelle River. The long-term mean annual flow at Luuq and Jamame runoff stations were 185.7 and 168.1 m3/s and Belet Weyne and Awdgele were 81.1 and 44.8 m3/s at Juba and Shabelle Rivers, respectively. Long-term water balance in the sub basins indicates that the Juba and Shabelle Rivers have less impact on the evaporation in all sub basins. The actual evaporation mainly depends on sub basins rainfall. This is due to less or close to zero values of the surface runoff contribution from each sub basins in Somalia. The sub basins areas are large compared to the rivers cross section that contribute to evaporation. The long-term mean annual flow volume at Luuq and Belet Weyne runoff stations was 5,638 and 3,499 mcm in the Juba and Shabelle Rivers, respectively. If the existing irrigation infrastructure can be maintained along the rivers, irrigation water demand for the year 2035 will be 3% and 63% of the annual flow volume at Juba and Shabelle Rivers, respectively. However, during low flows, the irrigation water demand for the year 2035 will be 14% and 2% of annual flow volume at Juba and Shabelle Rivers, respectively.

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