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Assessing Water Availability Using the WEAP Model in the Semi-Arid Juba Catchment of Somalia

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Abstract

Somalia is where the Juba River Catchment is located. The economic, social, and environmental implications of water stress has increased due to recent severe water scarcity, necessitating optimal water resource planning for long-term socioeconomic growth. Water is increasingly needed for a variety of uses, including livestock, irrigation, and domestic use. By examining the significant hydrological components and computing the catchment water balance using the Water Evaluation and Planning (WEAP) model, the study's goal was to evaluate the available water resources. Current agricultural water demands are 230.13 MCM while domestic water demand is 120.14MCM. For the short term plan

(2030) the agricultural water demand will be 594.1 MCM while domestic water demand is 362.79 MCM.

It is feasible to meet the water needs of the catchments' expanding population and related socioeconomic development activities. However, this necessitates the implementation of effective water resource management and monitoring measures. The WEAP model performance attained R2 of 0.6 during calibration and 0.95 and an NSE of 0.9 for calibration.

The hydrology of the Juba-catchment as predicted by the WEAP model provides sufficient confidence for future prediction, according to the values of objective functions.

Keywords

Water Availability, Water demand, WEAP Model, River Catchment, Streamflow, Semi-Arid Catchment Hydrology

Introduction

Water and development conditions in Somalia are problematic (Mourad, 2020) . The water sector is fragmented and needs coordination to establish a functioning water governance system to solve most of the water problems, especially floods and droughts (Schmidt, 2019).

Approximately 30% of the world's total land resources consist of arid and semi-arid regions, and water scarcity is a major barrier to social and economic development in these areas (Farrokhzadeh et al., 2020) .Water is an important resource that drives economies and social well-being of human societies. Understanding the processes that control the existence of water resource, its variability in time and space, and the ability to quantify its availability is important for its sustainable management and efficient allocation among competing users (Ngo et al., 2018). Water availability and scarcity are a concern not only for future but they are now a reality in the developed world (Tidwell et al., 2018). Non-availability of water has the potential to retard desirable economic and social development in a given society. Conflicts over future water allocations for various purposes have been reported both in advanced countries (Tidwell et al., 2018) and the developing countries. Therefore analysis and quantification of water availability, water use and water management are key issues. Water availability is simply the supply of water in excess of that currently allocated for consumptive use in a particular basin; that is, the amount of water available for new development. It is one of the most important indicators of sustainable development in modern society.

The Juba Basin has recently been hit with limited water availability or total lack of it in some cases. The specific catchments affected by limited water availability with strategic significance to the socio-economic development.

This study applies the Water Evaluation and Planning (WEAP) Model to assess the available water resources and simulate the unmet water demand under different future scenarios in the Juba Basin.

Study Area

The Juba and 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.

About two-thirds of these areas are outside Somalia, mainly in Ethiopia. The Juba River 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 (Basnyat & Gadain, 2009) . In terms of use of the rivers, (Abdullahi Elmi M, LicEng, 2002) assessed the significant impact in two transboundary rivers on the survival of the Somali national economy, social, environmental well-being and security of the nation. 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 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 % (Basnyat & Gadain, 2009) . The average annual rainfall is about 123 mm and 75% of this annual rainfall is recorded during the Gu season (Mourad, 2020).

Problem Statement and Objectives

Water quantity has declined as a result of excessive water consumption for domestic and agricultural purposes in areas of the Juba River Basin due to a lack of hydrological understanding, unenforced water rights, and ignorance of environmental water demands. The lack of equity in the method of allocation and the permit system has also led to conflicts as a result of the necessity to meet the water demands for both economic and social growth in the basin.

As a result, the primary objective of this article is to evaluate and simulate water demands in the Juba basin in order to give an in-depth understanding of water demand, which will be essential for implementing water distribution policies by Somalia's Water Resources Management Authority.

Data and Methods

The Water Evaluation and Planning (WEAP) tool, developed and supported by the Stockholm Environment Institute (SEI), is a microcomputer tool for integrated water resource planning. It provides a comprehensive, flexible, and user-friendly framework for water and environment policy analysis. A growing number of water specialists and environmentalists are finding WEAP to be an important addition to their toolbox of models, databases, spreadsheets, and other software (SEI., 2016).

WEAP can give water planners a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future uses (George et al., 2018). WEAP aims to incorporate these values into a practical tool for water resources planning. WEAP is distinguished by its combined approach to simulating water systems and by its policy orientation. Data linked to land use, slope, soils, and vegetation are needed to simulate these hydrological processes. WEAP is a well-known and widely used decision support system employing a priority-based water allocation scheme. Therefore, it is sufficiently general, easy to use and reliable because there are several features in WEAP that can be tweaked depending on the problem under consideration (Farrokhzadeh et al., 2020). WEAP is a laboratory for examining alternative water development and management strategies (SEI., 2016).

WEAP Model Data Inputs

Climate and Physical Data

The climatic data inputs used in the WEAP model were precipitation, air temperature, relative humidity (RH), wind speed.

Table 1: Averaged Monthly Climatic Data of Juba River Catchment (1985 to 2017)

	Months											
Average Precipitation (mm)	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
	150	180	57	7	28	52	98	105	7	0	0	0
Average Minimum Air Temperature (°C)	22.6	21.7	20.2	19.5	19.5	19.5	21	21.5	19.5	21.5	21.7	22.5
Average RH (%)	62	62	59	60	58	55	58	60	53	51	47	50
Average Wind Speed (m/s)	35.3	52.4	41	83.7	82.4	80.1	69.2	63.9	58	48.2	39.5	

Data inputs were obtained from SWE, for a period from 1985to 2017

Hydrologic Data

The hydrologic parameters used were stream flow. Stream flow Data for Juba River were collected from the Somali Water ministry of water and energy and SWLIM. The data were used for calibration of the WEAP model.

Table 2: Averaged Monthly Stream flow Data of Juba River at Bardere (2002 to 2019)

		Juba River Discharge (Mm3) at Bardhere Station										
	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years												
2002	169.5636	85.52278	74.189	530.1609	464.0458	284.3847	273.1796	403.6508	358.9606	624.2332	745.1726	212.6737
2003	319.0936	104.0939	73.28172	380.4674	1133.169	486.5862	464.8771	657.5295	889.7297	823.8068	539.6395	527.2384
2004	304.0711	259.227	159.4308	293.0677	812.8587	496.2292	496.1782	706.4547	946.5365	1331.825	1265.378	710.3597
2005	399.8377	298.9337	159.8389	275.9008	2365.707	1529.185	830.0111	1001.581	1107.181	1224.287	1383.276	1019.089
2006	310.6807	199.8868	190.2827	919.6201	1555.014	591.9803	705.4053	1102.508	1101.646	1832.171	2510.733	1132.558
2007	519.4761	318.6875	261.0843	461.765	769.6435	962.2899	748.1074	985.4181	1172.01	1598.498	883.1089	454.1813
2008	271.7733	183.2477	142.2484	237.4146	641.6794	705.1297	639.6974	989.9093	1305.057	1628.92	2400.83	643.1746
2009	336.1957	265.1784	204.7612	316.2872	565.1704	502.543	331.8714	550.7661	489.8823	1201.657	681.2013	395.8553
2010	295.3918	219.9163	1147.873	1117.254	2774.227	1531.561	944.0763	905.2506	1504.971	1400.566	1070.287	467.1219
2011	245.1104	155.5575	143.3288	122.6747	788.1335	1138.783	847.8979	949.9778	1371.119	1958.111	2033.905	1691.857
2012	466.2582	266.4407	200.8317	311.5359	999.4456	521.2244	638.1363	722.069	1163.443	1284.047	1319.413	576.3004
2013	307.6931	196.7179	201.543	1540.098	1712.097	792.8188	772.3548	1510.685	1522.11	1872.091	2275.883	839.306
2014	401.7988	247.3877	233.9779	398.1955	750.2274	955.7247	724.5277	805.7377	1499.313	3254.167	1815.887	924.2777
2015	412.9294	244.0131	217.8179	1054.612	1098.878	1046.375	634.1852	856.7029	687.7229	1027.4	1842.363	691.0631
2016	15.75167	9.933581	8.567424	9.12505	14.60022	44.82164	27.56894	23.34407	29.9046	52.81874	96.3792	44.82164
2017	292.8525	172.0273	156.8681	334.9451	907.1773	968.6275	540.1595	824.3673	1329.756	2276.843	2687.83	636.5407
2018	350.7529	242.3121	565.4297	2559	2762.257	2662.845	1260.635	928.4623	1367.776	1288.246	1968.615	935.0179
2019	422.9566	184.0697	79.75489	103.0664	937.8998	1004.415	531.4219	555.9971	554.999	2520.93	1610.684	1611.419

Table 3: Data sources used in the Juba River Basin WEAP model

	Data type	Scale	Format	Description	Source
Water supply and resources	Meteorology	Daily (1985–2017)	Excel	Precipitation; air temperature, relative humidity (RH), wind speed and solar radiation	National Meteorological Information Center
	River flow	Daily (2002–2019)	Excel, csv Format		
	Hydrology		Shapefile	River	
	Land use		Shapefile	Forest land, construction land, grassland, farm land, water area	
Water demand	Municipal water	Yearly (2010–2014)	PDF	Annual water use rate	
	Agricultural water	Yearly (2010–2014)	PDF		
Social-economic data	Population	Yearly (2010–2014)	PDF		

Parameters Used for the model

Soil moisture method

Accounting soil moisture method based on empirical functions that is used to explain the deep percolation, evapotranspiration, surface runoff, and interflow for basin or sub-basins (Figure 1)

The mathematical formula of the soil moisture method is as follows:

$$Rd_j \frac{dz_{,j}}{dt} = P_e(t) - PET\ (t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t)\ z_{1,j}^{RRF_j} - f_j k_{s,j}\, z_{1,j}^2 - \left(1 - f_j\right) k_{s,j}\ z_{1,j}^2$$

Where z1, j = [1, 0] is the relative soil water storage, Pe is the effective precipitation (mm), PET (t) is the reference potential evapotranspiration, kc,j is the crop coefficient, and RRFj is the Runoff Resistance.

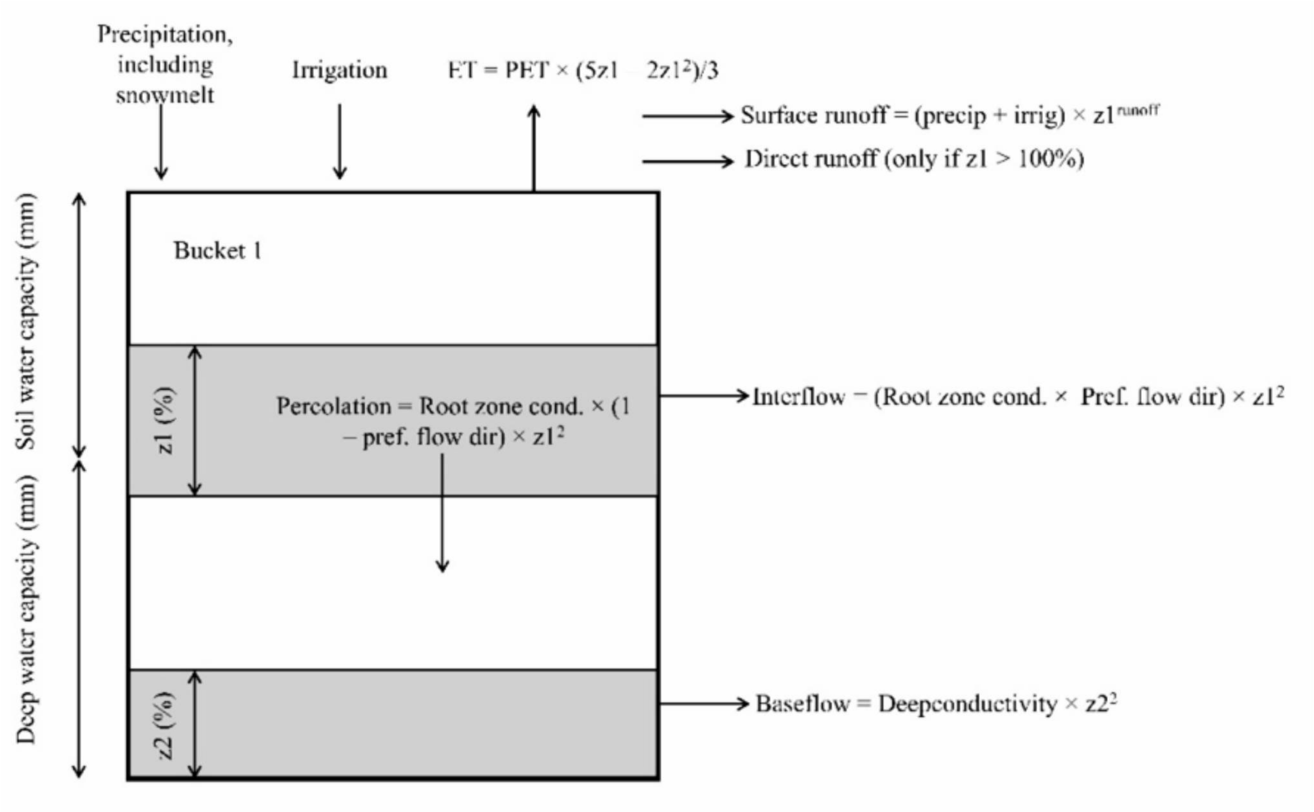


Figure 1. The conceptual diagram and equations used in the soil moisture method

Model Calibration

WEAP includes an interface to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP results with historical observations and to modify the model parameters to improve its accuracy. The PEST tool is a non-linear parameter, considered as a unique calibration tool. PEST executes, as many times as necessary, the control of a model, while changing its parameters until the differences between the simulations of the selected model and a set of observed data are minimized (Sieber J, 2007)

In this section, simulated results are compared with the naturalized flows for control station (Bardere gauge station). Monthly simulated and observed stream flows for the calibration period (2000 - 2018).

The results of the hydrologic model performance are compared using two statistical parameters which include the observed and simulated mean flows, Coefficient of determination and Correlation also Nash-Sutcliffe Coefficient.

Nash-Sutcliffe Efficiency for streamflow (NSE) and coefficient of determination (R^2) according to Equation

$$\text{NSE}= 1 - \frac{\sum(Q_{obs}-Q_{sim})^2}{\sum(Q_{obs}-\bar{Q}_{obs})^2}$$

$$R^2 = \frac{\left(\sum(Q_{obs}-Q_{sim}(Q_{sim}-\overline{Q_{sim}}))^2\right)}{\sum(Q_{obs}-\bar{Q}_{obs})^2\sum(Q_{sim}-\bar{Q}_{sim})^2}$$

Where Q_{obs} is observed disc$h$arge, Q_{sim} is simulated discharge, $\bar{Q}_{obs}$ is mean of the observed discharge $\bar{Q}_{sim}$ is the mean of the simulated discharge

Table 4: Classification criteria for hydrological models (Moriasi et al., 2015)

Goodness-of-Fi	**NSE**	**R2**
Very Good (V	0.75 < NSE ≤ 1.00	R 2 ≥ 0.75
Good (G)	0.60 < NSE ≤ 0.75	0.70 < R 2 ≤ 0.75
Satisfactory (S)	0.50 < NSE ≤ 0.60	0.60 < R 2 ≤ 0.75
Unsatisfactory (U)	NSE ≤ 0.50	R 2 < 0.60

Results and Discussion

Model Calibration and Validation

The hydrological data of the Juba river basin were used to calibrate and validate the Hydro-Economic WEAP model for the period of 2002–2019.

$\bar{Q}_{obs} = 2.166887$ mean observed discharge

$\bar{Q}_{sim} = 2.233781$ mean simulated discharge.

$\sum Q_{obs} = 455.0463$

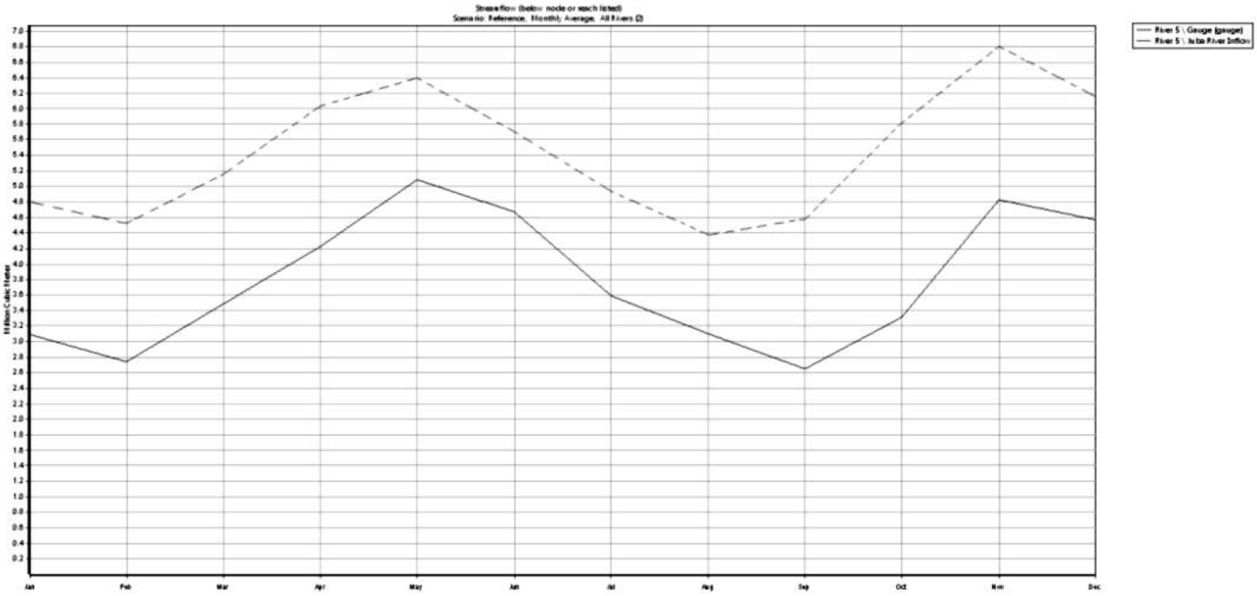
$\sum Q_{sim} = 469.0939$

$$R^2 = \frac{\left(\sum\left(455.0463_{obs} - 469.0939_{sim}(469.0939_{sim} - \overline{2.233781_{sim}})\right)^2\right)}{\sum(455.0463_{obs} - \overline{2.166887}_{obs})^2 \sum(469.0939_{sim} - \overline{2.233781}_{sim})^2} = 0.6$$

$$NSE = 1 - \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - \bar{Q}_{obs})^2}$$

$$NSE = 1 - \frac{\sum(455.0463Q_{obs} - 469.0939Q_{sim})^2}{\sum(455.0463_{obs} - \overline{2.66887}_{obs})^2} = 0.9$$

The graphical comparison of the monthly average observed streamflow with the simulated streamflow for a period from 2002 to 2019.



Reference Scenario

The Reference scenario (2002 to 2020) contains the same data and structure as the Current accounts year (2002). The results are presented on availability of water, demand and demand coverage. Focus in this part will be on the options WEAP offers to present results.

Demand Analysis for Study periods

In this section the water demand of the three sectors of the basin in different periods found in the basin is being presented. The domestic water demand of all Juba river basin from current (2020) and future terms years 2030 and 2050.

And using WEAP expression build the model project the population growth to each year up to 2050.

Table 5. Domestic Demand Analysis at different Time Schedule

Period	**Total Population (Million)**	**Water Requirements (Mm3 /Year)**
Current (2020)	3.11	120.14
Short Term Plan (2030)	5.85	362.79
Long Term Plan (2050)	9.20	1255.83

Table 6. Irrigation Demand Analysis at different Time Schedule

Period	Irrigation area (Ha)	Water Requirements (Mm3 /Year)
Current (2020)	15000	230.13
Short Term Plan (2030)	25,000	594.1
Long Term Plan (2050)	52,000	1332.4

The recent irrigation coverage is about 15000 ha while the potential irrigation expansion area is 25,000 ha and 52,000 ha for the short term plan and future long term plan respectively. Their water requirement is get from their agronomy report in the (CWR) cropwat requirements.

Table 7. Livestock Demand Analysis at different Time Schedule

Period	**Total Population (Million)**	**Water Requirements (Mm3 /Year)**
Current (2020)	5.6	56.1
Short Term Plan (2030)	6.3	63.3
Long Term Plan (2050)	7.8	77.7

Conclusions

Using historical hydrological data from the WEAP model, the study has evaluated the available water resources in the Juba basin and the water demand under several future scenarios. It has been found that there is an increase in the demand for water for a variety of uses, with agriculture becoming the catchment's top water consumer. The results of this study show that agriculture is the major water use in the basin. Current agricultural water demands are 230.13 MCM while domestic water demand is 120.14MCM. For the short term plan (2030) the agricultural water demand will be 594.1 MCM while domestic water demand is 362.79 MCM. For the Long Term Plan (2050) agricultural water consumption will be1332.4 MCM. It is feasible to meet the water needs of the sub-catchments' expanding population and related socioeconomic development activities. However, this necessitates the implementation of effective water resource management and monitoring measures.

Recommendation

The possibilities recommended for the catchment of the Juba River include:

In order to enhance or change EFR, environmental flow requirements must be critically examined and continuously monitored.

Since Juba River Basin is trans-boundary River shared between Somalia and Ethiopia, it is necessary to do EFR assessment for the whole basin. This will ensure that the interests of the downstream country are considered by all developments to be undertaken by the upstream country.

The use of water harvesting techniques, such as check dams, ponds, weirs, and micro dams, to capture extra runoff during the wet season and use it to make up for the water shortage during the dry season.

For the sustainability of groundwater supplies and the baseflow of the Juba River, groundwater recharge ponds are being introduced, and recharge sites are being protected.

Collaboratively with the community and all water users, comprehensive catchment management strategies are developed and implemented.

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