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Supplementary Material

Water Availability and Agricultural Demand: An assessment framework using global datasets in a data scarce catchment, Rokel-Seli River, Sierra Leone

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1 Model framework details, supplied by model providers:

1.1 IHACRES model description

IHACRES is a lumped parameter, hybrid conceptual-metric model based on the Catchment Moisture Deficit model of Evans and Jakeman (1998). The main emphasis of the model is to represent rainfall-runoff behaviour occurring dominantly within catchment scale, rather than the very fine scale processes that lead to generation of stream flow from rainfall. The IHACRES model is composed of a non-linear module and a linear module with the model parameters as listed in Table S1. IHACRES, being a spatially lumped model, requires fewer parameters than other metric models. Conversion of rainfall into effective rainfall through the non-linear module takes the form of:

$$u_k = [C(\varnothing_k - l)]^p r_k \tag{1}$$

where k is time, r_k is total rainfall, C is mass balance and l and p are the soil moisture index threshold and the power on soil moisture respectively. The soil moisture index $\varnothing_k$, is calculated from:

$$\varnothing_k = r_k + \left(1 - \frac{1}{\tau_k}\right) \tag{2}$$

with the drying rate τ_k given by:

$$\tau_k = \tau_w \exp[0.062 f(t_r - t_k)] \tag{3}$$

where τ_k is the drying rate at time t, τ_w is the reference drying rate and f, t_r and t_k are temperature modulation, reference temperature and temperature record at any time interval respectively.

The linear module of the model then uses a transfer function that converts effective rainfall to stream flow by routing rainfall through a number of stores in series or parallel to become stream flow. This linear equation for conversion of effective rainfall to stream flow is:

$$Q_k = -\alpha Q_{k-1} + \beta u_k \tag{4}$$

where Q_k is stream flow and α and β are recession rate and peak response respectively.

Table S1: Parameters in the IHACRES model

Module	Parameter	Description
Non-linear	c	Mass balance
	τ_w	Reference drying rate
	f	Temperature modulation of drying rate
Linear	α_q, α_s	Quick and slow flow recession rate
	β_q, β_s	Fractions of effective rainfall for peak response
	τ_s	Slow flow recession time constant, $\tau_s = -\Delta/\ln(-\alpha_s)$
	τ_q	Quick flow recession time constant, $\tau_q = -\Delta/\ln(-\alpha_q)$

1.2 CROPWAT model description

CROPWAT version 8.0, the latest version, employs a water balance method to compute crop water requirements (FAO, 1998), which is then used to determine irrigation water needs. All CROPWAT computations are based on the FAO publications; Crop Evapotranspiration - Guidelines for computing crop water requirements (No. 56) and Yield response to water (No. 33), both from the Irrigation and Drainage Series (FAO, 1998).

Crop Water Requirements (ET_c) and Irrigation water requirements using CROPWAT are derived from an algorithm that is based on ET_o, derived using the Penman-Monteith Method. Jensen et al., (1990) argued that the Penman-Monteith method uses adequate climatological data as compared to other means of estimating evapotranspiration, boosting its accuracy. The FAO (1998) Penman-Monteith equation is expressed as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (5)$$

where,

ET_o reference evapotranspiration [mm day^{-1}],

R_{n-} net radiation at the crop surface [MJ m^{-2} day^{-1}],

G soil heat flux density [MJ m^{-2} day^{-1}],

T mean daily air temperature at 2 m height [°C],

u_2 wind speed at 2 m height [m s^{-1}],

e_s saturation vapour pressure [kPa],

e_a actual vapour pressure [kPa],

e_s e_a saturation vapour pressure deficit [kPa],

Δ slope vapour pressure curve [kPa °C^{-1}],

γ psychrometric constant [kPa °C^{-1}].

Crop Water Requirement (ET_c) is given by $ET_c = ET_o \times K_c - P_e$, where, K_c is the crop coefficient and P_e, is the effective rainfall (part of the rainfall that meets actual crop water needs i.e. total rainfall minus runoff , evaporation and deep percolation losses) calculated by the USDA soil conservation service method (USDA, 2004).

1.2.1 Estimation of Crop coefficient (K_c) values for Sugarcane (ratoon)

Crop coefficient of sugarcane is necessary for the water requirement estimation in irrigation water planning and management. This study used FAO Irrigation and Drainage paper 56 guidelines (*FAO, 1992*) to determine the crop coefficient (K_c) of sugarcane (Ratoon) in the Makeni climate.

Table S2: The crop coefficient (K_c) values for sugarcane ratoon, relating water requirements to reference evapotranspiration (ET_o) for the different growth stages

Sugarcane Ratoon	Stages of Development				
	Initial, $K_{c\ ini}$	Development	Mid-season, $K_{c\ mid}$	Late, $K_{c\ end}$	Total
Crop Coefficient, K_c	0.4	>>	1.25	0.75	
Root depth, M	-	-	-	1.5	
Yield response Factor,	0.75	-	0.5	0.1	1.2

1.2.2 Calculation of Net and Gross Irrigation Water Needs in CROPWAT

The net irrigation water needs on a monthly basis were determined using CROPWAT. The method involved steps that, sequentially, determined the reference crop evapotranspiration ET_o and crop factors (K_c), calculated the crop water needs ($ET_c = ET_o \times K_c$), determined the effective rainfall: P_e, then finally, established the net irrigation water needs:

$$I_{net} = ET_c - P_e \quad (6)$$

The gross irrigation water need (I_{gross}), is the total amount of water necessary for crop production during a growth season. This water can be supplied in phases as need arises, say during dry seasons. In this case study, between November and May when monthly rainfall drops to below 10 mm.

The amount of water required to meet crop water needs, minus the effective rainfall, assuming a constant average irrigation need, I_{net}, of 1 litre per second per hectare (see *FAO, 1992*) for the entire season, can be calculated by multiplying the irrigation need with the area (in Ha). This equates net scheme irrigation water needs as:

$$I_{net}\ (l/s) = Area\ (ha) \times I_{net}\ (l/s/ha) \quad (7)$$

To determine the gross scheme water needs (I_{gross}), which is the water needed for the entire scheme, inclusive of water losses during delivery, the product of field application efficiency and conveyance efficiency(scheme irrigation efficiency) is divided by the net Irrigation Need (I_{net}).
Since the scheme irrigation efficiency (expressed as a percentage) has been factored in earlier calculations within CROPWAT (at 70%), the gross irrigation water needs can be calculated separately using the formula:

$$I_{gross}\ (l/s) = 100/e \times I_{net}\ (l/s) \quad (8)$$

2 IHACRES model calibration/validation

2.1 Optimum calibration parameters

Table S3: IHACRES calibration parameters for full and low flows using CRU, GPCC and Observed datasets

IHACRES Parameter Values			CRU FF	GPCC FF	OBS FF	CRU LF	GPCC LF	OBS LF
Module	**Parameter**	**Description**	**Optimum**	**Optimum**	**Optimum**	**Optimum**	**Optimum**	**Optimum**
Non-linear	c	Mass balance	0.000085	0.000068	0.000044	0.000044	0.000129	0.000936
	τw	Reference drying rate	30	30	27	27	17	5
	f	Temperature modulation of drying rate	4	0	0	0	4	12
	tref	moisture threshold for producing flow	0	20	20	20	20	20
Linear	α q, α s	Quick and slow flow recession rate	-0.07	-0.16	-0.28	-0.28	-0.92	-0.11
	β q, β s	Fractions of effective rainfall for peak response	0.94	0.84	0.72	0.72	0.08	0.01
	τs	Slow flow recession time constant, $\tau s = -1/\ln(-\alpha s)$	0.37	0.55	0.78	0.78	12.16	5.81

2.2 Full-flow/Low-flow calibration/validation

Table S4: R^2 and NSE for calibration/validation using CRU, GPCC and Observed datasets

	Calibration						Validation					
	CRU-FF	GPCC-FF	OBS-FF	CRU-LF	GPCC-LF	OBS-LF	CRU-FF	GPCC-FF	OBS-FF	CRU-LF	GPCC-LF	OBS-LF
Mean	136.62	154.72	120.19	34.93	38.39	37.21	135.65	162.96	136.15	39.78	47.82	38.24
Stdev	101.74	107.62	122.65	37.34	33.95	26.40	112.61	108.56	126.11	38.34	46.38	27.41
Min	30.45	39.85	4.19	4.20	6.11	14.93	10.05	33.18	2.85	2.25	2.79	10.14
Max	405.63	390.64	412.42	143.70	121.28	117.44	421.71	448.29	431.52	163.56	187.46	118.83
R^2	0.82	0.89	0.94	0.49	0.56	0.40	0.84	0.88	0.86	0.89	0.88	0.74
NSE	0.80	0.80	0.93	0.21	0.44	0.31	0.82	0.74	0.83	0.80	0.44	0.73

2.3 Log Transformed Full-flow/Low-flow calibration/validation

Table S5: Log Transformed R^2 and NSE for calibration/validation using CRU, GPCC and Observed datasets

	Calibration						Validation					
	CRU-FF	GPCC-FF	OBS-FF	CRU-LF	GPCC-LF	OBS-LF	CRU-FF	GPCC-FF	OBS-FF	CRU-LF	GPCC-LF	OBS-LF
Mean	2.02	2.08	1.77	1.61	1.67	1.59	1.93	2.11	1.84	1.65	1.74	1.61
Stdev	0.33	0.31	0.60	0.51	0.49	0.46	0.48	0.31	0.61	0.56	0.53	0.49
Min	1.48	1.60	0.62	0.62	0.79	0.47	1.00	1.52	0.45	0.35	0.45	0.48
Max	2.61	2.59	2.62	2.24	2.30	2.18	2.63	2.65	2.63	2.33	2.34	2.25
R^2	0.69	0.77	0.77	0.71	0.77	0.87	0.91	0.91	0.87	0.87	0.86	0.91
NSE	0.49	0.42	0.73	0.58	0.71	0.69	0.80	0.37	0.84	0.84	0.86	0.83

3 Modelled Crop Water Requirements

Table S6: Irrigation water demands against water availability ranked in order of driest years

Probability of exceedance		CRU-LF			GPCC-LF			OBS-LF		
		River flow	Addax flow	Demand %	River flow	Addax flow	Demand %	River flow	Addax flow	Demand %
driest		30.3	42.8	18.4%	32.5	45.9	17.1%	32.0	45.2	17.4%
1 in 10 years	90	55.0	77.6	10.1%	68.7	96.9	8.1%	33.8	47.7	16.5%
1 in 5 years	80	58.4	82.4	9.5%	74.6	105.3	7.5%	37.1	52.4	15.0%
1 in 2 years	50	70.9	100.0	7.9%	91.9	129.7	6.1%	44.9	63.4	12.4%

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