Understanding factors influencing the wetland parameters of a monthly rainfall-runoff model in the Upper Congo River basin

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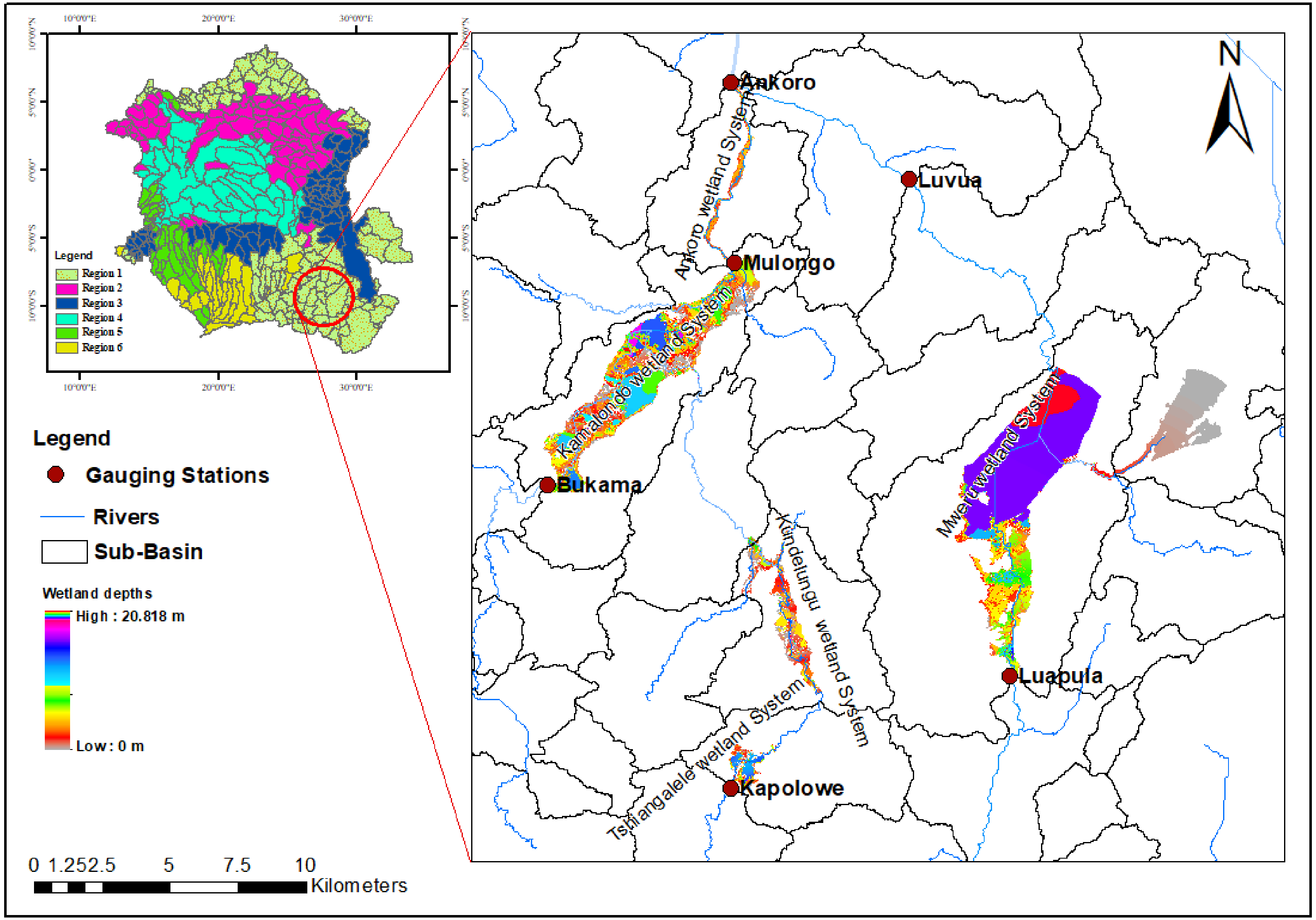
Background

- The presence of large wetland systems considerably influence ***the flow regime of the downstream river*** in the upper Lualaba drainage system of the Congo Basin;
- The hydrodynamic functioning (***filling and emptying mechanisms***) of these wetland systems is not well understood;
- Incorporating lake and wetland processes into modelling would provide a ***better representation of runoff generation*** within a basin scale hydrological model of this part of the Congo Basin;
- A ***wetland sub-model*** for the monthly time step Pitman hydrological model was developed to account for channel-wetland exchange processes;

Study sites

- Five study sites in the upper Lualaba drainage system of the Congo Basin



Objective

- Providing ***guidance to explicitly estimate the wetland parameters*** of this wetland sub-model rather than using a trial and error calibration approach;

✓ Calibrate the LISFLOOD-FP hydrodynamic model for specific sites;

✓ Quantify the wetland parameters of the PITMAN wetland sub-model;

✓ Quantify the hysteretic patterns observed in river channel and wetland exchanges;

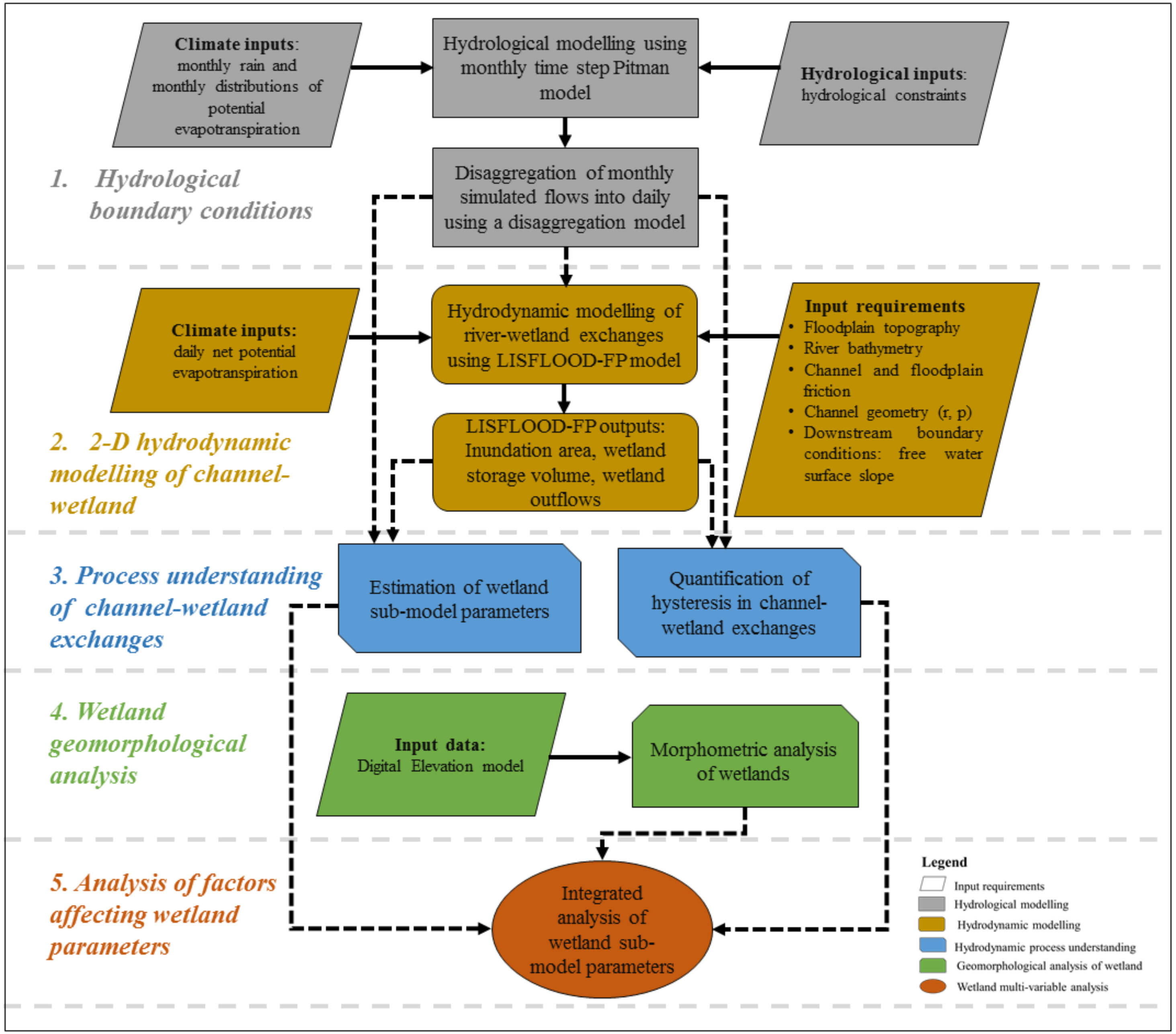
✓ Assess the influence of hysteresis and wetland morphometric characteristics on wetland sub-model parameters.

A wetland sub-model parameters of the monthly Pitman model

Parameter name	Description
Local catchment area (km^2)	The maximum inundated area including wetland area
Residual wetland storage, RWS (MCM)	Wetland storage below which there is no return flow
Initial storage (MCM)	Initial wetland storage at the start of a simulation
$A\ in\ Area\ (m^2) = A * Volume^B (m^3)$;	Coefficient in a power relationship between the wetland volume and area, when both are expressed in m^3 and m^2, respectively.
B $in\ Area\ (m^2) = A * Volume^B (m^3)$	Exponent in a power relationship between the wetland volume and area, when both are expressed in m^3 and m^2, respectively.
Channel capacity for spillage (MCM), Qcap	Channel capacity for the spill to the wetland to occur. Below this threshold there is no spill from the channel to the wetland.
Channel Spill Factor (Fraction), QSF in SPILL= QSF*(Q-QCap)	With Q: the channel upstream flow and SPILL: the flow volume added to the wetland.
AA in (Ret Flow= AA*$(Vol/RWS)^{BB}$	Coefficient in a power relationship between the ratio of the wetland storage volume over the residual wetland storage and the return flow.
BB in (Ret Flow= AA*$(Vol/RWS)^{BB}$	Exponent in a power relationship between the ratio of the wetland storage volume over the residual wetland storage and the return flow.
Annual Evaporation (mm)	Annual evaporation from the wetland (distributed into monthly values using a table of calendar month percentages).
Annual Abstraction (MCM)	Annual water abstractions from the wetland (distributed into monthly values using a table of calendar month percentages).
Max Return flow Fraction	Used for constraining the return flow from wetland to channel.

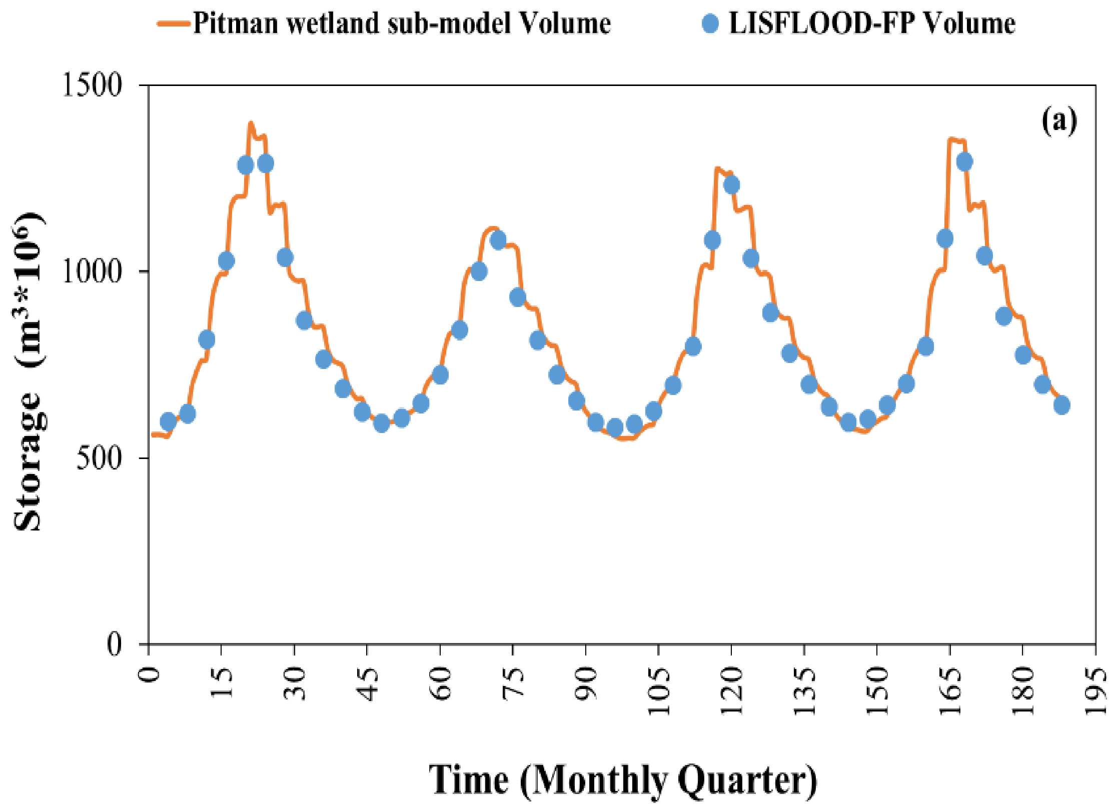
Methodological framework

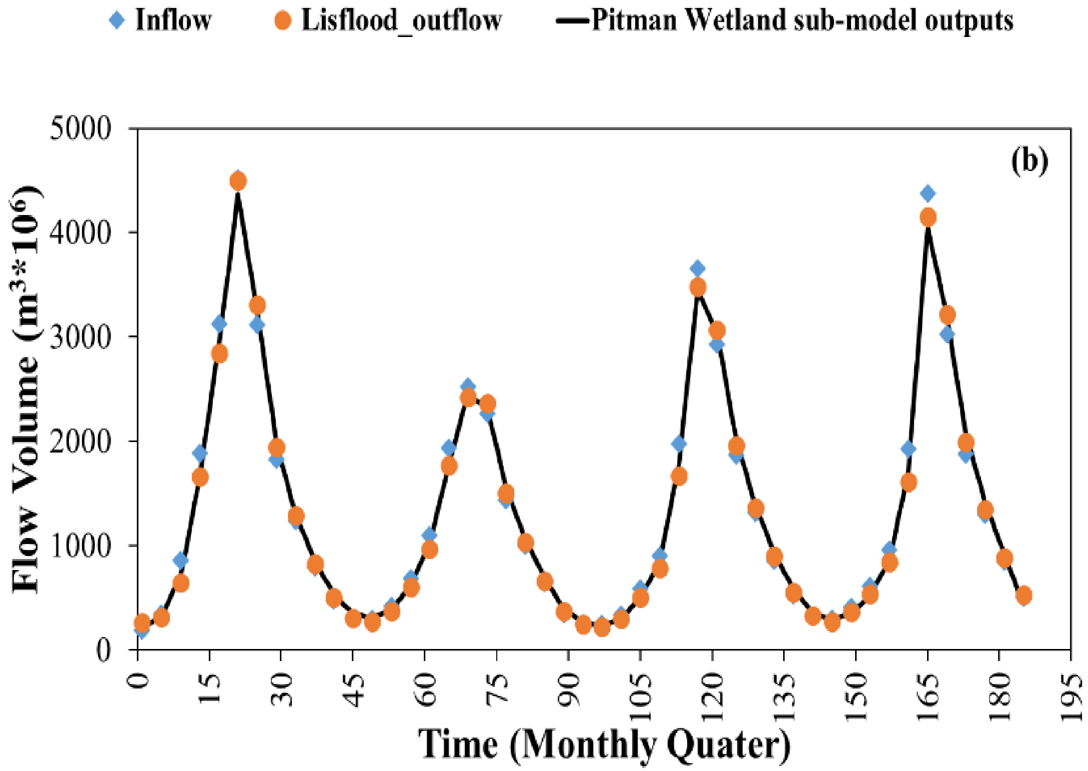
- A five steps methodological approach



Calibration of wetland sub-model parameters

- Using calibrated LISFLOOD-FP outputs to inform the choice of Pitman wetland model parameters.

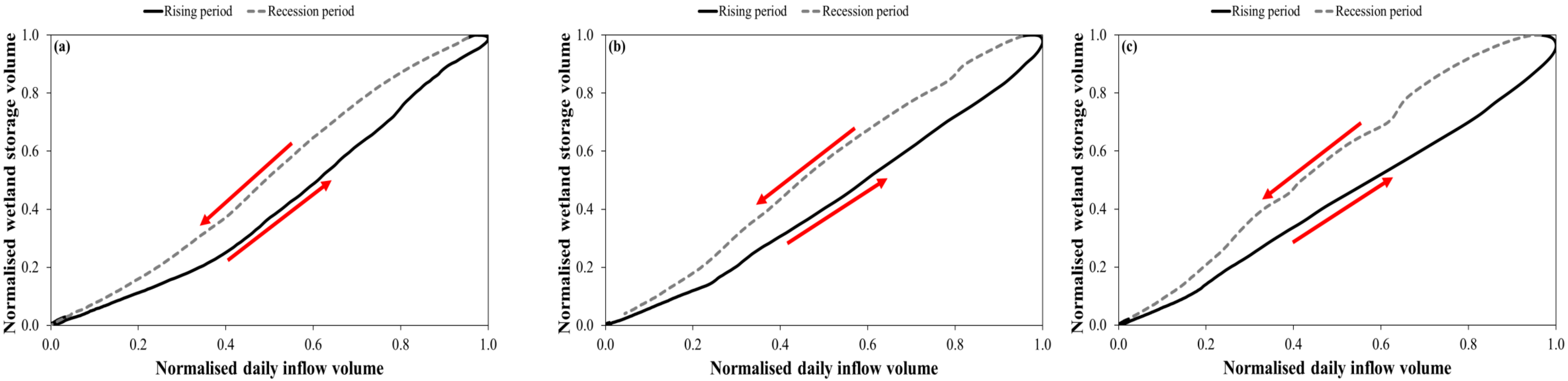




Graphical visualisation of the correspondence of the LISFLOOD-FP and PITMAN wetland sub-model wetland storages at Ankoro wetland system based on 270 m model resolution. **(a)** the Pitman wetland sub-model reproduced well the wetland storages and **(b)** the Pitman wetland sub-model was able to reproduce the outflow.

Types of hysteretic patterns

- **Anti-clockwise**: In channel inflow -wetland storage relationships across all five studied wetland systems.



Dimensionless hysteresis of inflow volume - wetland storage relationship at the Ankoro wetland system over three consecutive hydrological years. **(a)-(c)** show daily hysteresis for the consecutive hydrological years 2001-2002, 2002-2003, and 2003-2004, respectively.

- The magnitude of flood wave affects the shape and degree of hysteresis loop. Negative hysteresis index stands for anti-clockwise and positive as clockwise.

Types of hysteretic patterns

Hydrological Year (HY)	Ankoro		Kamalondo		Kundelungu		Mweru		Tshiangalele	
	HI_{zuecco} index	HI_{Lloyd} index	HI_{zuecco} index	HI_{Lloyd} index	HI_{zuecco} index	HI_{Lloyd} index	HI_{zuecco} index	HI_{Lloyd} index	HI_{zuecco} index	HI_{Lloyd} index
Magnitude of channel infow-wetland storage hysteresis										
2001-2002	-0.091	-0.103	-0.146	-0.168	-0.067	-0.078	-0.376	-0.443	-0.201	-0.235
2002-2003	-0.108	-0.124	-0.153	-0.178	-0.253	-0.284	-0.392	-0.457	-0.204	-0.235
2003-2004	-0.128	-0.146	-0.194	-0.221	-0.274	-0.323	-0.486	-0.592	-0.285	-0.325
Average	***-0.109***	***-0.125***	***-0.164***	***-0.189***	***-0.198***	***-0.229***	***-0.418***	***-0.497***	***-0.230***	***-0.265***
Magnitude of channel infow-inundated area hysteresis										
2001-2002	-0.112	-0.130	-0.069	-0.079	0.010	0.012	-0.057	-0.073	-0.229	-0.283
2002-2003	-0.109	-0.127	-0.081	-0.096	-0.011	-0.010	-0.070	-0.083	-0.277	-0.323
2003-2004	-0.105	-0.122	-0.107	-0.121	-0.003	0.003	-0.087	-0.096	-0.420	-0.502
Average	***-0.109***	***-0.126***	***-0.085***	***-0.099***	***-0.002***	***0.002***	***-0.071***	***-0.084***	***-0.309***	***-0.370***
Magnitude of wetland storage - inundated area hysteresis										
2001-2002	-0.022	-0.028	0.056	0.040	0.085	0.104	0.143	0.224	-0.048	-0.057
2002-2003	-0.017	-0.020	0.036	0.043	0.054	0.071	0.380	0.483	-0.147	-0.173
2003-2004	-0.014	-0.016	0.032	0.039	0.071	0.090	0.243	0.334	-0.145	-0.185
Average	***-0.018***	***-0.021***	***0.042***	***0.040***	***0.070***	***0.088***	***0.255***	***0.347***	***-0.113***	***-0.139***
Magnitude of wetland storage - outflow hysteresis										
2001-2002	-0.018	-0.020	-0.151	-0.176	-0.016	-0.022	-0.126	-0.167	0.000	-0.006
2002-2003	-0.036	-0.041	-0.189	-0.222	-0.020	-0.031	-0.107	-0.144	0.008	0.005
2003-2004	-0.051	-0.058	-0.204	-0.242	-0.015	-0.027	-0.138	-0.178	0.000	-0.002
Average	***-0.035***	***-0.040***	***-0.181***	***-0.213***	***-0.017***	***-0.027***	***-0.124***	***-0.163***	***0.002***	***-0.001***

Geomorphological analysis of wetlands

- Three properties of wetland geomorphology are derived using GIS techniques: Wetland surface slope, wetland length and an index representing the proportion of wetland storage volume below channel banks (IWM).

Characteristics	Wetland names				
	Ankoro	Kamalondo	Kundelungu	Mweru	Tshiangalele
Index of wetland morphology (IWM)	0.0071	0.035	0.0157	0.0762	0.0758
Wetland length (km)	166	200	115	212	45
Wetland average slope (%)	1.2	0.726	0.338	0.0099	0.831

Correlation matrix of wetland variables

	Inf_St	Inf_Area	St_Area	St_Outfl	Qcap	QSF	RFP	Res. storage	Ini. storage	A	B	Rs_St/T_St	Time Lag (days)	IWM	% of attenuation	Average slope (%)
Inf_St																
Inf_Area	0.15															
St_Area	0.91	-0.15														
St_Outfl	0.32	-0.12	0.08													
Qcap	-0.71	-0.48	-0.36	-0.69												
QSF	0.71	0.48	0.36	0.69	-1.00											
RFP	-0.72	0.38	-0.76	-0.30	0.41	-0.41										
Res. storage	0.58	-0.25	0.44	0.92	-0.66	0.66	-0.49									
Ini. storage	0.82	-0.26	0.77	0.67	-0.60	0.60	-0.68	0.91								
A	0.66	-0.59	0.86	0.11	-0.10	0.10	-0.89	0.43	0.70							
B	-0.37	0.64	-0.65	0.25	-0.24	0.24	0.78	-0.02	-0.32	-0.90						
Rs_St/T_St	-0.42	0.07	-0.65	0.65	-0.19	0.19	0.50	0.37	-0.04	-0.61	0.77					
Time Lag (days)	0.84	-0.35	0.86	0.52	-0.47	0.47	-0.75	0.81	0.98	0.82	-0.49	-0.22				
IWM	0.87	0.51	0.65	0.27	-0.85	0.85	-0.57	0.37	0.53	0.33	-0.11	-0.33	0.50			
% of attenuation	0.97	-0.05	0.95	0.26	-0.59	0.59	-0.86	0.54	0.81	0.82	-0.58	-0.54	0.86	0.81		
Average slope (%)	-0.66	0.51	-0.75	-0.28	0.29	-0.29	0.99	-0.49	-0.68	-0.93	0.83	0.50	-0.76	-0.45	-0.82	
Length (km)	0.25	-0.58	0.32	0.63	-0.09	0.09	-0.20	0.79	0.73	0.41	-0.09	0.36	0.70	-0.16	0.24	-0.28

***Legend**: Inf_St: stands for channel inflow-storage hysteresis, Infl_Area: channel inflow-inundated area hysteresis, St_Area: storage-inundated area hysteresis, St_Outfl: storage-outflow hysteresis, Qcap: channel capacity for spillage, QSF: channel spill factor, RFP: return flow coefficient, Res. Storage: Residual storage, Ini. storage: Initial storage, A: coefficient parameter of storage-area relationship, B: exponent parameter of the storage-area relationship, Rs_St/T_St: fraction of the residual storage related to maximum wetland storage, IWM: index of wetland morphology.*

Hysteresis in channel inflow-wetland storage is caused by wetland morphometric factors such as IWM, wetland average slope and length

A high degree of this hysteresis leads to longer time delay of the passage of flood wave ,resulting in high % of attenuation, and a low degree to shorter time lag.

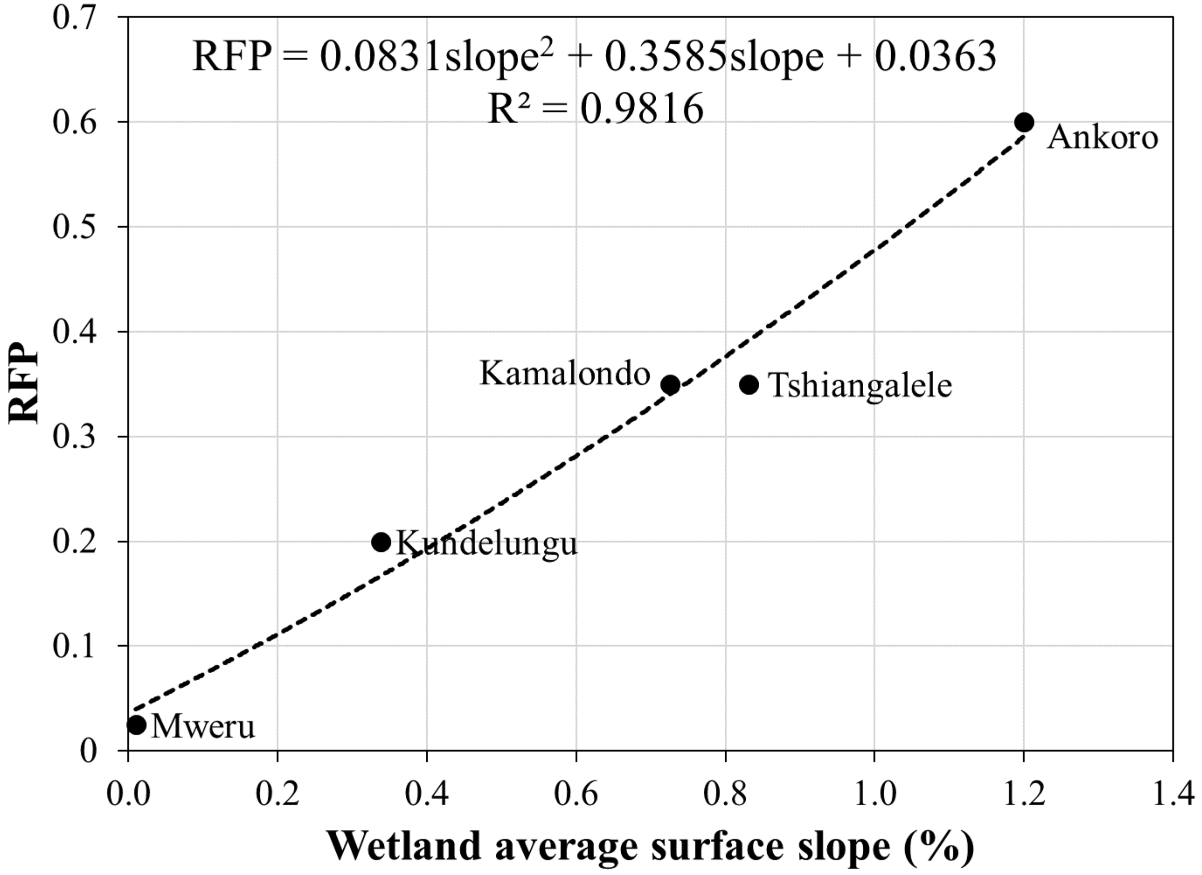
Spill (Qcap and QSF) are consistently correlated with the hysteresis found between the channel inflow and the wetland storage volume.

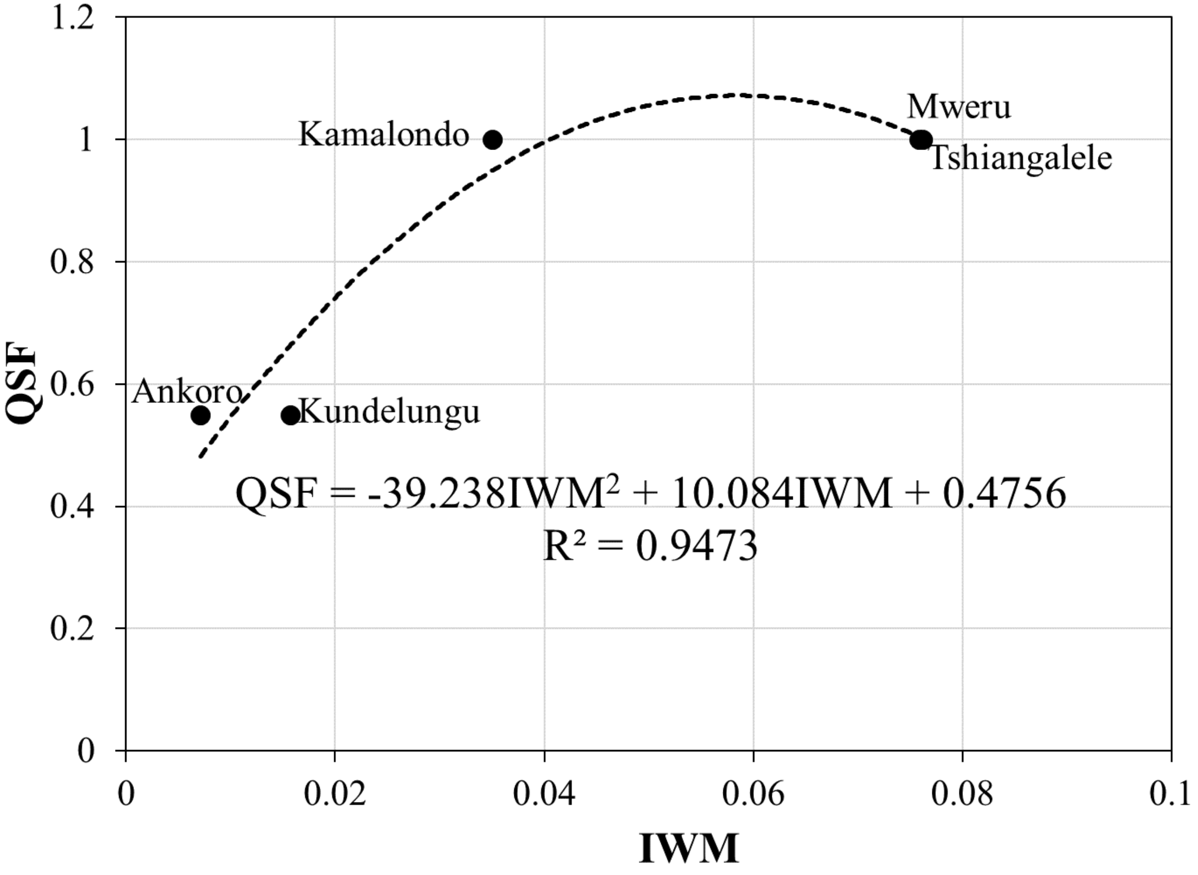
This anti-clockwise hysteresis represents the time delay between the inundation and drainage processes

The coeficient parameter of the return flow equation (RFP) has shown a strong consistent relationship with the channel inflow-wetland storage hysteresis

This parameter is strongly associated with the wetland average slope, which seems to be one of the factors causing hysteresis in channel inflow-wetland storage relationship

- There is a possibility of estimating wetland sub-model parameters from morphometric properties.





Conclusions

- The outputs from the LISFLOOD-FP hydrodynamic model provide an opportunity to inform the choice of Pitman wetland model parameters;
- These parameters vary according to wetland type and are affected by hysteresis behaviour found in channel-wetland exchanges;
- All the five wetland systems are characterised by anti-clockwise hysteretic pattern in the inundation processes;
- This anti-clockwise hysteresis is consistently correlated with the spilling parameters (QSF and Qcap) of the wetland sub-model;

- The channel spill factor (QSF), in addition to the inundation processes, is also connected with the drainage processes represented by the wetland storage-channel outflow anti-clockwise hysteresis;
- The degree of hysteresis is caused by the characteristics of individual flood waves and other geomorphological wetland properties such as the wetland surface slope, the proportion of wetland storage below channel banks and the length, thus affecting the time delay in the passage of flood wave and the attenuation of peak flow;
- This understanding has a practical advantage for the estimation of the Pitman wetland parameters in the many areas where it is not possible to run complex hydrodynamic models.

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