SUPPORTING INFORMATION

S 1. Input data

The table presents the main input data used to build the SWAT model along with their sources and resolution for the Wełna River basin area.

Description	Data source	Data resolution
Map of Poland hydrographical divisions	State Water Holding-Polish Waters, https://isok.gov.pl/hydroportal.html	5m, 1:10000
Digital elevation model (DEM)	Nation Protection IT System, https://isok.gov.pl/index.html	10m, 1:20000
Cross-sections of river channels	Nation Protection IT System - https://isok.gov.pl/hydroportal.html	-
Land use map (development of the river banks)	Corine Land Cover (CLC 2012), images from the Landsat 8 satellite http://clc.gios.gov.pl/index.php/26-clc-2012, https://bdl.stat.gov.pl/BDL	10 m
Soil map	Institute of Soil Science and Plant Cultivation, forest soil maps	2.5m, 1:100 000, 1: 10 000
Meteorological data - air temperature, precipitation, humidity, wind speed, and total radiation	Institute of Meteorology and Water Management - National Research Institute - https://danepubliczne.imgw.pl/	for 250 stations located directly in the basin, and within 20 km from its borders
Drained areas - average depth of drains, average drainage time	Chief Inspectorate for Environmental Protection - https://www.gios.gov.pl/pl/stan-srodowiska/monitoring-wod	-
Point sources of wastewater, population not connected to the sewage system and fish ponds	National Program for Urban Waste Water Treatment - https://www.wody.gov.pl/nasze-dzialania/krajowy-program-oczyszczania-sciekow-komunalnych, Central Statistical Office - https://bdl.stat.gov.pl/BDL, State Water Holding-Polish Waters	-
Agrotechnical treatments, livestock breeding, the amount of mineral and natural fertilizers	Central Statistical Office - https://bdl.stat.gov.pl/BDL/	-
Atmospheric deposition, water erosion and geochemical background	Chief Inspectorate for Environmental Protection - http://powietrze.gios.gov.pl/pjp/archives	-

S 2. Sensitivity analysis results

The sensitivity analysis was performed using the SWAT-CUP program and the Sequential Uncertainty Fitting Algorithm (SUFI-2) which captures as many optimal simulations within the 95% prediction certainty as possible. The algorithm does not obtain a unique value for these parameters, but an interval that includes all the processes uncertainties in the basin. It is very efficient not only in terms of localizing an optimum parameter range but also in terms of simulations number. The only drawback of SUFI-2 is that is a semi-automated process that requires the interaction of the modeler to check set of suggested parameters, which requires a good knowledge of parameters and their impact on the output. The sensitivity analysis allows us to assess the reaction of the model to the change of input parameters, and permits to identify the most important parameters of the model for the analyzed basin. The sensitivity of parameters presented in the table is measured using t-stat values, where the values are more sensitive to larger absolute values. The p-values are used to determine the significance of the sensitivity, and the parameter becomes significant if the p-values are close to zero.

Parameter Name	Definition		t-Stat	p-Value
		Flow		
CN2.mgt	Initial SCS runoff curve number for moisture condition	-	-5.15	0.00
NDTARGR.res	Number of days to reach target storage from current reservoir storage	m3 H2O	3.95	0.00
CH_N2.rte	Manning's "n" value for the main channel	-	3.41	0.00
GWQMN.gw	Threshold depth of water in the shallow aquifer required for return to occur	mm H2O	3.1	0.00
ALPHA_BF.gw	Baseflow alpha factor	1/days	-2.3	0.02
EPCO.hru	Plant uptake compensation factor	-	-2.24	0.03
SURLAG.hru	Surface runoff lag coefficient	-	-2.13	0.03
CH_K2.rte	Effective hydraulic conductivity in the main channel alluvium	mm/hr	1.92	0.06
RCHRG_DP.gw	Deep aquifer percolation fraction	-	1.63	0.10
ESCO.hru	Soil evaporation compensation factor	-	-1.46	0.15
TDRAIN.mgt	Time to drain soil to field capacity	hours	1.24	0.22
GW_DELAY.gw	Groundwater delay time	days	-1.1	0.27
SOL_AWC(1).sol	Available water capacity of the soil layer	mm H2O/mm soil	1.06	0.29
GDRAIN.mgt	Drain tile lag time	hours	1	0.32
DEP_IMP.hru	Depth to impervious layer in soil profile	mm	-0.85	0.40
GW_REVAP.gw	Groundwater "revap" coefficient	-	-0.38	0.71
		Nitrogen		
CDN.bsn	Denitrification exponential rate coefficient	-	3.62	0.00
N_UPDIS.bsn	Nitrogen uptake distribution parameter	-	-2.98	0.00
NSETLR2.lwq	Nitrogen settling rate in reservoir for months	m/year	2.01	0.04
SDNCO.bsn	Denitrification treshold water content	-	-1.62	0.11
FIXCO.bsn	Nitrogen fixation coeficient	-	-1.55	0.12
SOL_NO3.chm	Initial NO3 concentration in the soil layer	mg N/kg	-1.54	0.12
CMN.bsn	Rate factor for humus mineralization of active organic nutrients	-	-1.47	0.14
SHALLST_N.gw	Initial concentraction of nitrate in shallow aquifer	mg N/l	-1.46	0.15
NPERCO.bsn	Nitrate percolation coefficient	-	1.22	0.22
ERORGN.hru	Organic N erichment ratio for loading with sediment	-	0.73	0.47
NSETLR1.lwq	Nitrogen settling rate in reservoir for months	m/year	-0.58	0.56
SOL_ORGN.chm	Initial organic N concentration in the soil layer	mg N/kg	-0.25	0.80
		Phosphorus		
PSP.bsn	Phosphorus availability index	-	4.28	0.00
ERORGP.hru	Phosphorus enrichment ratio for loading with sediment	-	-2.39	0.02
SOL_LABP.chm	Initial concentration of the potentially soluble phosphorus	mgP/kg	-1.88	0.06
PSETLR1.lwq	Phosphorus settling rate in reservoir for months	m/year	-1.4	0.16
RS5.swq	Required if in-stream nutrient cycling is being modeled	-	1.39	0.17
RSDCO.bsn	Residue decomposition coefficient	-	-1.1	0.27
PSETLR2.lwq	Phosphorus settling rate in reservoir for months	m/year	-1.07	0.29
SOL_ORGP.chm	Initial organic P concentration in soil layer	mg P/kg	-0.97	0.34
LAT_ORGP.gw	Organic P in the base flow	mg/l	0.15	0.88
		Sediment		
PRF_BSN.bsn	Peak rate adjustment factor for sediment routing in the main channel	-	9.71	0.00
CH_COV1.rte	Channel erodibility factor	-	7.43	0.00
SPEXE.bsn	Exponent parameter for sediment retention	-	-6.26	0.00
SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment	-	5.94	0.00
ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in the subbasin	-	5.79	0.00
CH_COV2.rte	Channel cover factor	-	3.44	0.00
RES_SED.res	Initial sediment concentration in the reservoir	mg/l	0.29	0.77
RES_NSED.res	Equilibrium sediment concentration in the reservoir	mg/l	-0.15	0.88

S 3. Model calibration verification and validation

S 3-1. Classification of value ranges for statistical measures used during calibration, verification and validation.

Calibration, verification and validation of the model have been assessed with the statistical measures, R2, PBIAS, and KGE. The range of these measures based on the initial performance evaluation criteria for watershed and field-scale models [1-3] to assess the fit of the model to the monitoring results has been presented in the table.

Performance Rating		very good	good	satisfactory	unsatisfactory
R^2	flow	> 0.85	0.75<R2<0.85	0.6<R2<0.75	< 0.6
	total nitrogen	> 0.7	0.6<R2<0.7	0.3<R2<0.6	< 0.3
	total phosphorus	> 0.8	0.65<R2<0.8	0.40<R2<0.65	< 0.4
	suspended sediment	>0.65	0.5<R2<0.65	0.2<R2<0.5	<0.2
PBIAS %	flow	< 5	5<PBIAS<10	10<PBIAS<15	> 15
	total nitrogen/total phosphorus	< 15	15<PBIAS<20	20<PBIAS<30	> 30
	suspended sediment	<25	≤25 PBIAS<40	40≤PBIAS<70	≥70
KGE	flow/total nitrogen/total phosphorus/suspended sediment	>0.75	0.5 - 0.75	0 - 0.5	<0

S 3-2. Calibration, verification and validation results.

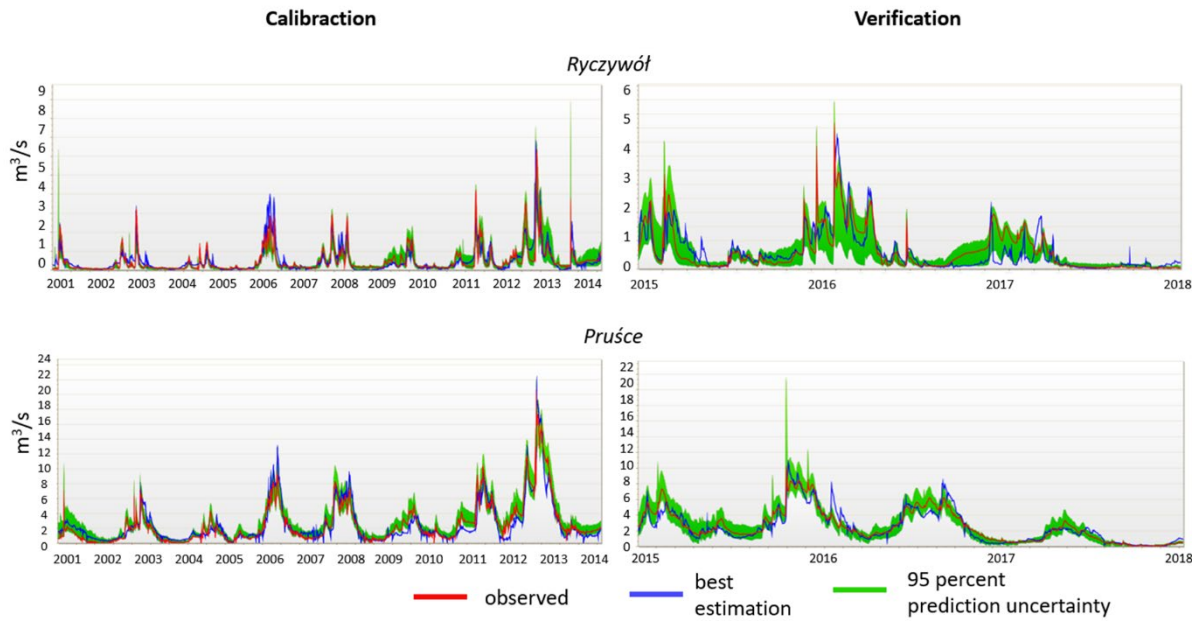
The SWAT model for the Welna River was calibrated, verified, and validated to capture both aspects of simulation, quantitative (flow) and qualitative (total nitrogen, total phosphorus, and suspended sediment). The choice of the time periods and calculation profiles was imposed by availability of the monitoring data. For the quantitative part of the SWAT model, the daily flow data for the period of 18 years (2001-2018) from the gauging stations at the Welna River (Prusce and Kowanówko) and its tributary (Flinta River - Ryczywół) were used. The data for the examination of the qualitative part of the SWAT model (total nitrogen, total phosphorus, suspended sediment, and chlorophyll a) originated from the State Monitoring System stations localised at the Welna River (Oborniki and Rogoźno) and covered a period of 15 years (2001-2015). Selected calculation profiles included a total of 399 data for total nitrogen and total phosphorus, 84 data for suspended sediment and only 51 data for chlorophyll a.

Calculation profile	Parameter	R^2	PBIAS	KGE
	Calibration			
Flinta - Ryczywól	flow (m^3/s)	0.71	-8	0.78
Wełna - Prusce		0.85	-5	0.9
Wełna - Oborniki	total nitrogen (kg/day)	0.86	-20	0.7
	total phosphorus (kg/day)	0.6	30	0.53

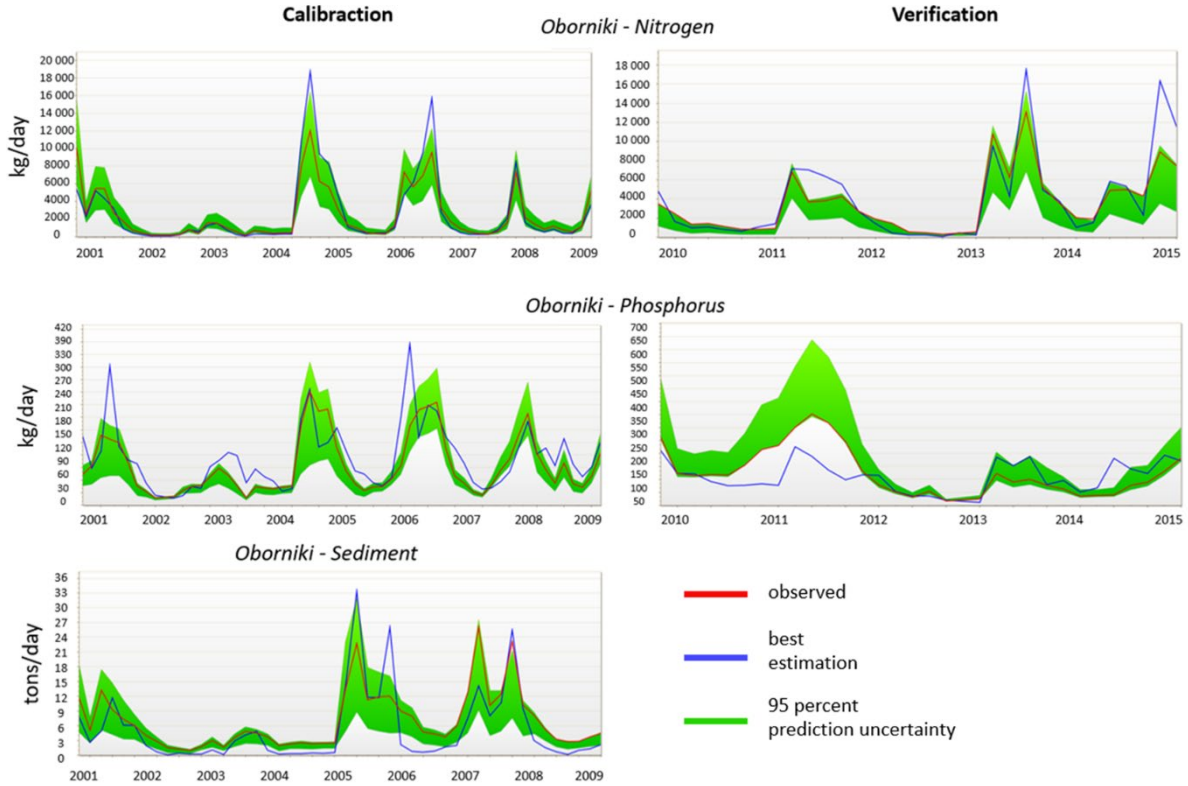
	suspended sediment (tons/day)	0.81	-22	0.65
	chlorophyll a (µg/l)	0.52	-	-
	Verification			
Flinta - Ryczywól	flow (m^3/s)	0.66	2	0.62
Wełna - Prusce		0.83	10	0.86
Wełna - Oborniki	total nitrogen (kg/day)	0.86	12.5	0.67
	total phosphorus (kg/day)	0.38	-25	0.21
	Validation			
Wełna - Kowanówko	flow (m^3/s)	0.8	15	0.81
Wełna - Rogoźno	total nitrogen (kg/day)	0.9	-14	0.51
	total phosphorus (kg/day)	0.35	23	0.47
	suspended sediment (tons/day)	0.77	-20	0.52
	chlorophyll a (µg/l)	0.48	-	-

S 3-3. Comparison of the simulation with the observed results for the calculation profiles of Ryczywół and Prusce in the process of flow calibration and verification

The visual evaluation of the obtained results is complementary to the statistical evaluation of the model. It allows for a more intuitive characterization of the model's ability to reproduce the characteristics of the flow regime characteristic for the analyzed catchment (quantitative model) and the natural and anthropogenic variability of pollutant loads (qualitative model).



S 3-4. Comparison of the simulation with the observed results in the Oborniki calculation profile in the total nitrogen, total phosphorus and suspended sediment calibration and verification process.

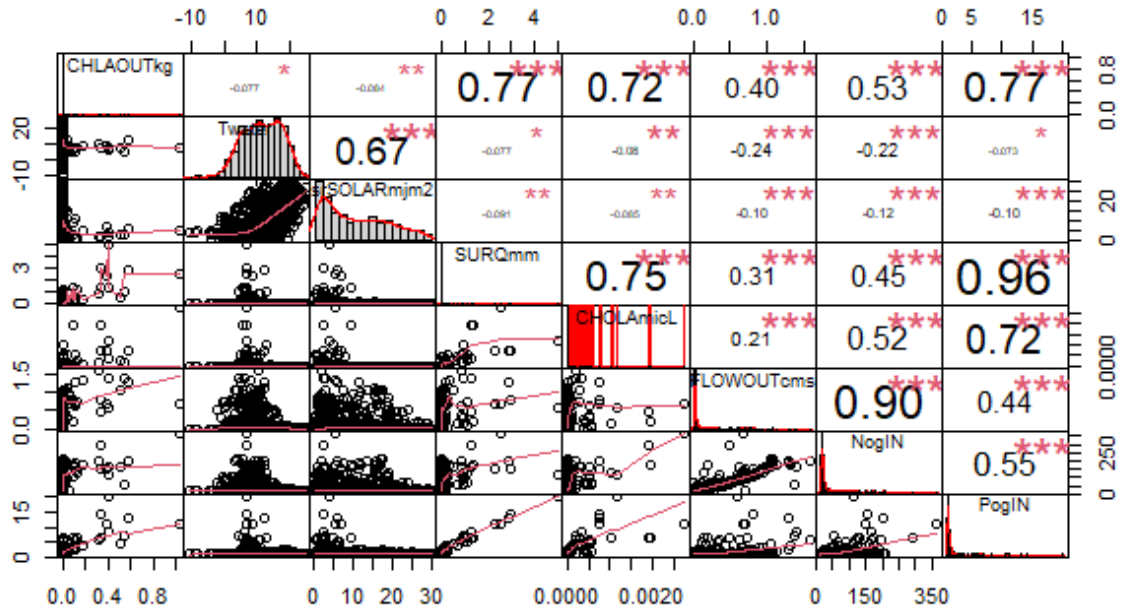


S 4. Correlation matrices for the sub-basins.

Correlation matrix for the daily values in 2005-2007 and all seven sections of the Nielba River were used to analyze the mutual interdependence of all the investigated parameters.

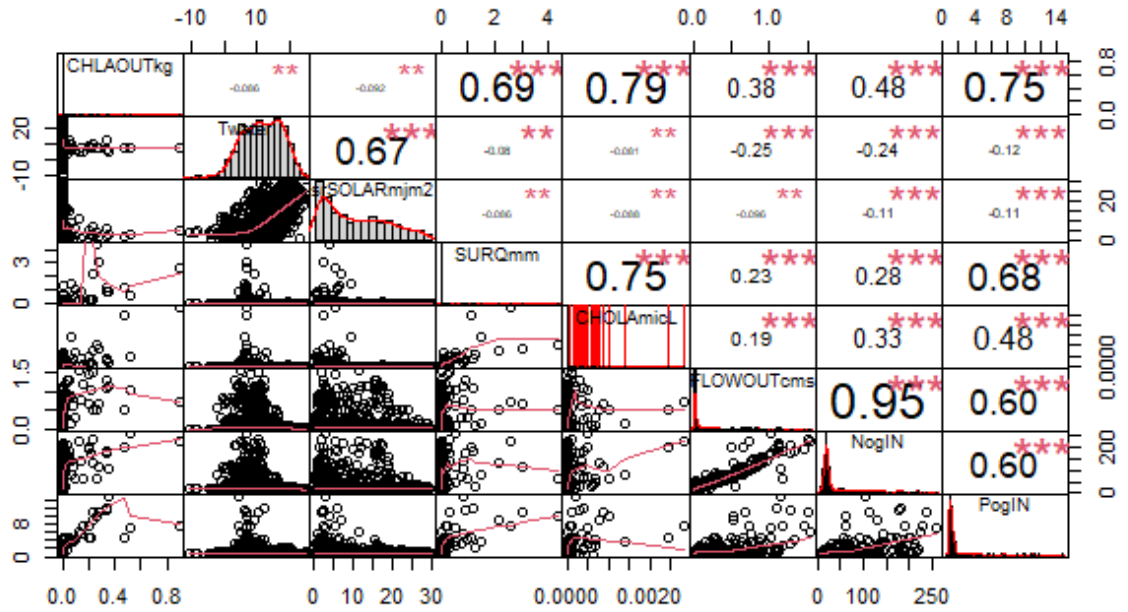
abbreviations used in correlation matrix	definition	unit
CHLAOUTkg	chlorophyll a load	kg/d
Twater	water temperature	°C
SOLARmjm2	solar radiation	MJ/m^2/hr
SURQmm	surface runoff	m^3/s
CHOLA	chlorophyll a land delivery	µg chla/l
FLOWOUTcms	flow	m^3/s
NogIN	nitrogen load	kg/d
PogIN	phosphorus load	kg/d

S 4-1. Correlation matrix for sub-basin 1.



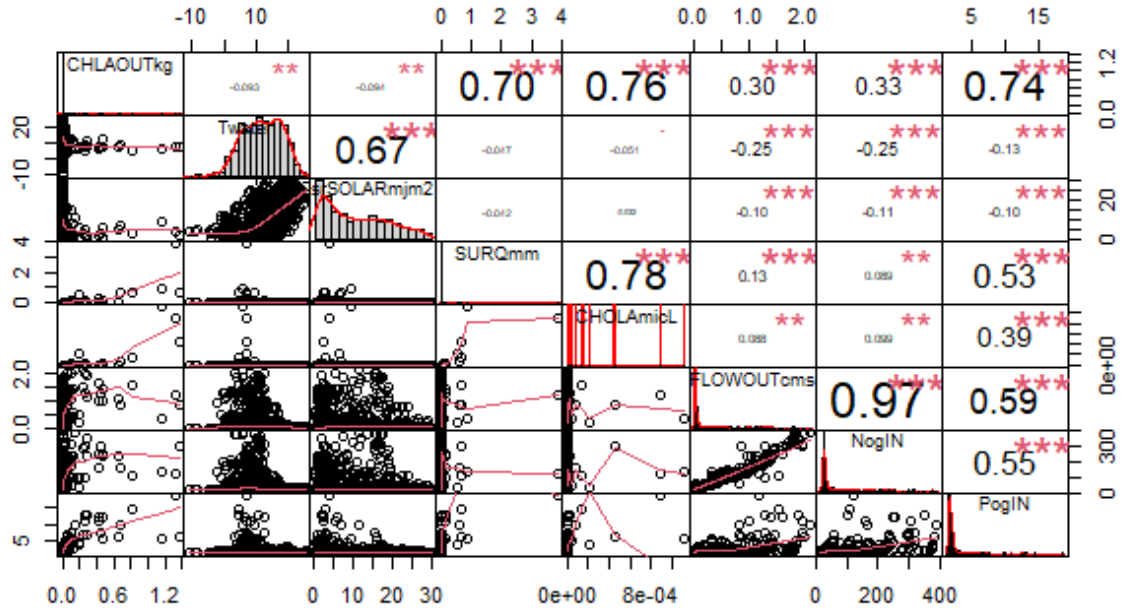
Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.

S 4- 2. Correlation matrix for sub-basin 2.



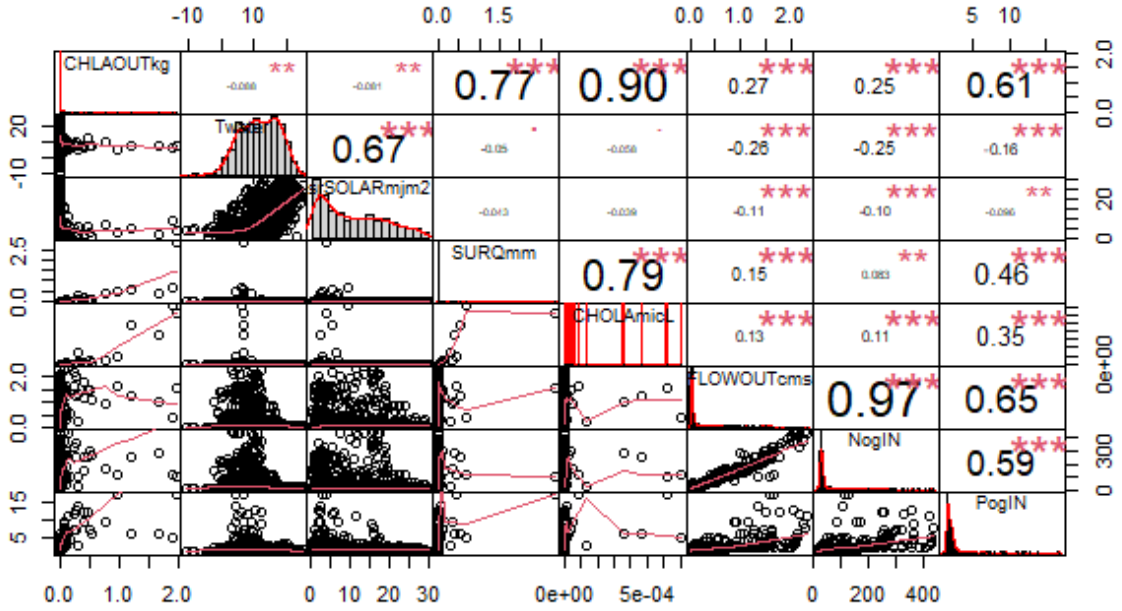
Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.

S 4- 3. Correlation matrix for sub-basin 3.



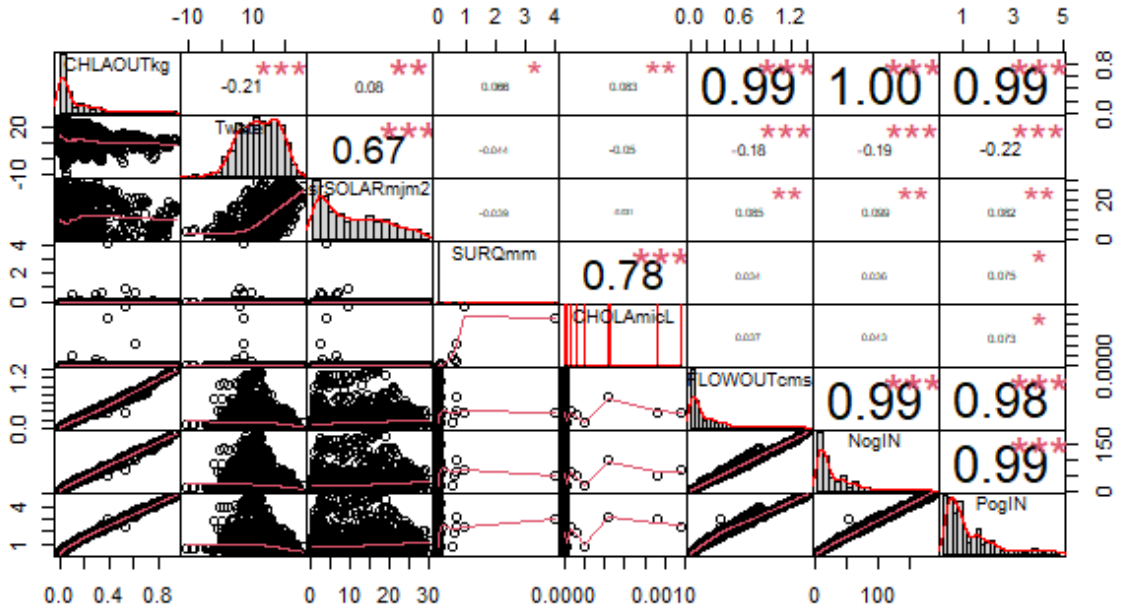
*Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.*

S 4- 4. Correlation matrix for sub-basin 4.



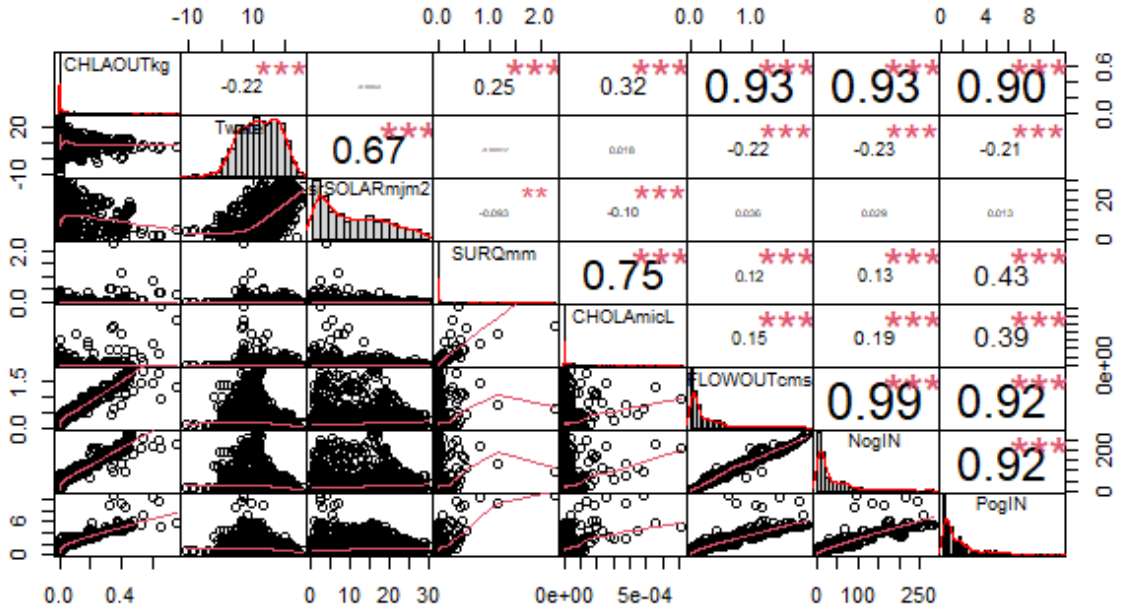
Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.

S 4- 5. Correlation matrix for sub-basin 5.



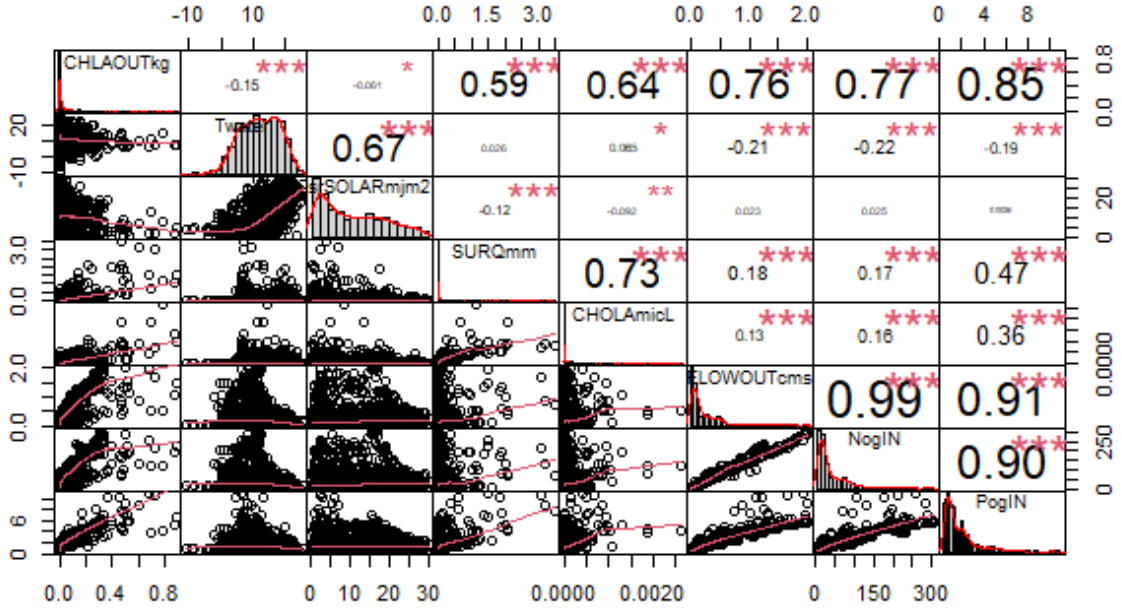
*Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.*

S 4- 6. Correlation matrix for sub-basin 6.



Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.

S 4- 7. Correlation matrix for sub-basin 7.



*Correlation analysis matrix-significance level is associated with a symbol: P-value below 0.001 as "***", between 0.001 and 0.01 as "**",0.05–0.1 as "*", and higher than 0.1 without a symbol.*

References

[1] Patil, S. D., & Stieglitz, M. (2015). Comparing spatial and temporal transferability of hydrological model parameters. *Journal of Hydrology*, *525*, 409-417. https://doi.org/10.1016/j.jhydrol.2015.04.003

[2] Libera, D. A., & Sankarasubramanian, A. (2018). Multivariate bias corrections of mechanistic water quality model predictions. *Journal of Hydrology*, *564*, 529-541. https://doi.org/10.1016/j.jhydrol.2018.07.043

[3] Moriasi, D. N., Gitau, M. W., Pai, N., & Daggupati, P. (2015). Hydrologic and water quality models: Performance measures and evaluation criteria. *Transactions of the ASABE*, *58*(6), 1763-1785. https://doi.org/10.13031/trans.58.10715