SURFACE WATER RESOURCES POTENTIAL ASSESSMENT OF UNGAUGED CATCHMENTS IN LAKE TANA BASIN, ETHIOPIA

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10^{th} AvH Conference 2015
Addis Ababa, Ethiopia

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Contents

1. Introduction

Problem

- The major problem for hydrological modeling
  - Estimation of streamflow in ungauged catchments

Possible solution

- The model parameters need to be estimated by using information from gauged catchments and then hydrological models can be used for streamflow estimation

How?

Objective

❑ General objective

✓ To assess the surface water potential of ungauged catchments in Lake Tana basin.

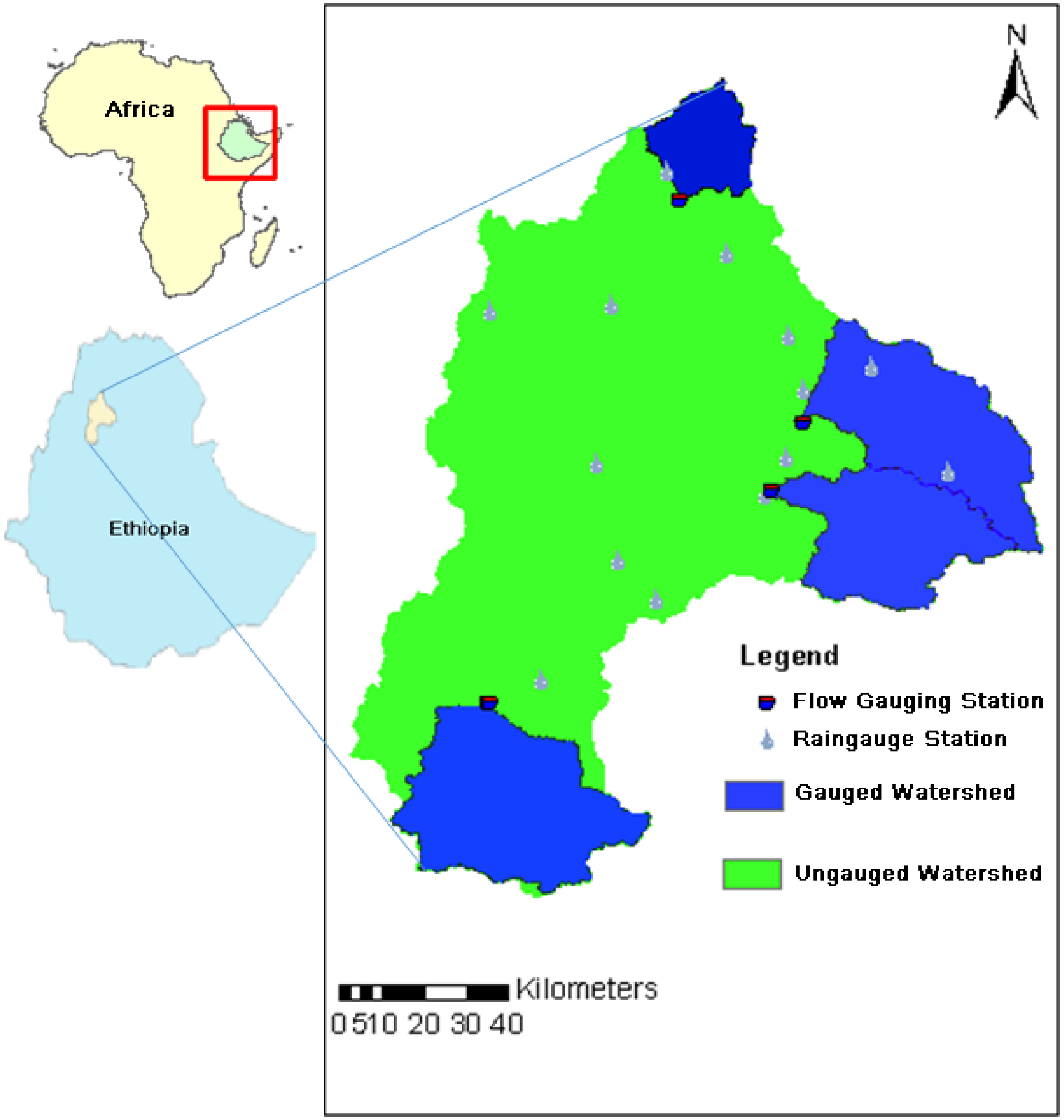
❑ Specific objectives

✓ To evaluate the three proposed parameter transfer schemes,

✓ To compare the performance of generalized likelihood uncertainty estimation (GLUE) and particle swarm optimization (PSO) tools for optimization of model parameters in gauged catchments.

2. Location and Description of the Study Area

- Area of Basin – 15,114 km2
- Geographically it extends between 10.95 oN to 12.78 oN latitude and from 36.89 oE to 38.25 oE longitude.
- The elevation ranges between 914 m to 4096 m +MSL,
- The mean annual rainfall amount ranges between 813 mm and 2328 mm.
- The mean annual minimum temperature and maximum temperature are 9.3 oC and 29.6 oC respectively
- Dominant land use: Agriculture – 51.37%
- Dominant soil use: Halpic luvisol – 20.68%



- ✓ Area of gauged catchment is 5236 km^2
- ✓ Area of ungauged catchment is 9878 km^2

Figure 1: Location map of the study area.

3. Methodology

3.1 Hydrological Model

- Soil and Water Assessment Tool (SWAT)
  - Physically based semi-distributed hydrological model.
  - The hydrological balance is calculated based on the following equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Qsurf - Ea - Wseep - Qgw \right)_i$$

where; SWt= the final water content (mm H2O), SWo= the initial soil water content on day i (mm H2O), t = time, days, Rday= is the amount of precipitation on day i (mm H2O), Qsurf = is the amount of surface runoff on day i (mm H2O), Ea= is the amount of evapotranspiration on day i (mm H2O), Wseep = is the amount of water entering the vadose zone from the Soil profile on day i, Qgw= is the amount of ground water flow on day i (mm H2O).

3.2 SWAT Model Setup

3.2.1 Watershed Delineation

- Delineation of the watershed into several hydrologically connected sub-watersheds.

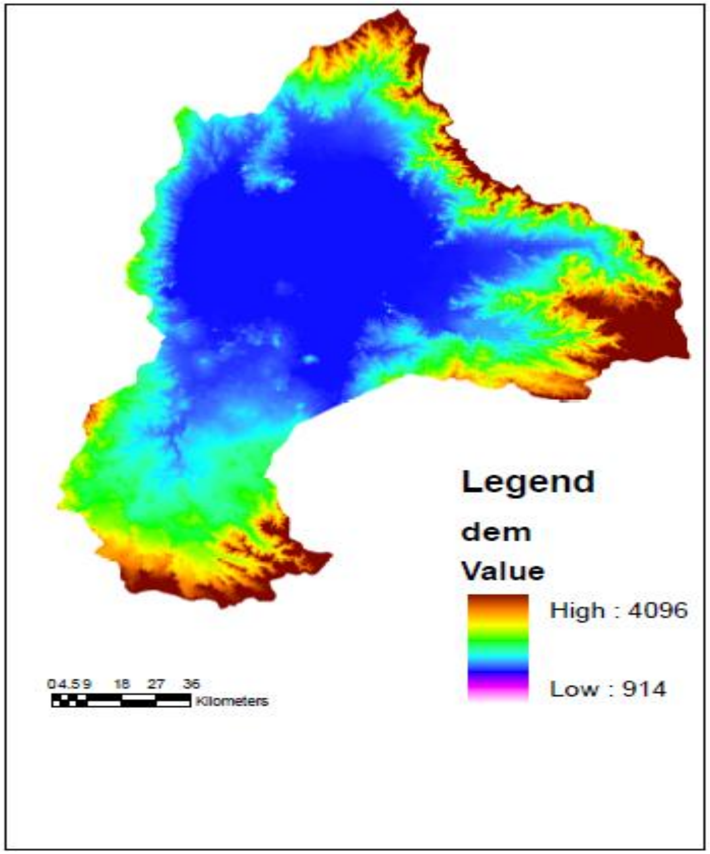


Figure 2: DEM of study area

3.2.2 Land Use/Soil/Slope Reclassification and Overlay

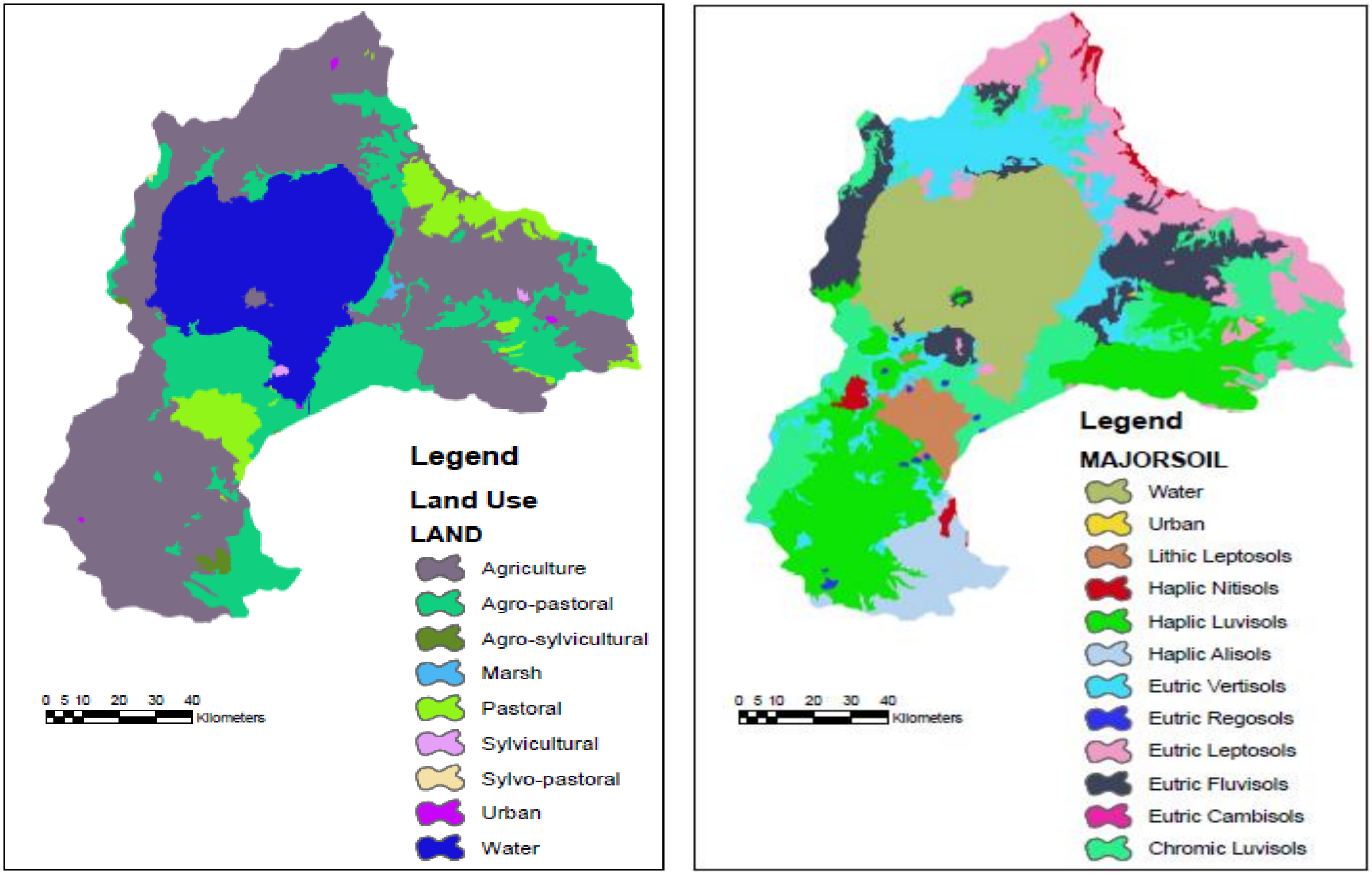


Figure 3: Land use and soil map of the study area

3.2.3 Hydrologic Response Unit Analysis

- 23 sub-basins and 142 HRUs

3.2.4 Importing Weather Data

- The climatic variables required by SWAT consist of daily precipitation, maximum & minimum temperature, solar radiation, wind speed and relative humidity.

3.3 Sensitivity Analysis

- A sensitivity analysis is conducted using the built-in SWAT-CUP sensitivity analysis tool.

3.4 Model Performance

- Model parameters are optimized in four gauged catchments using the SWAT-CUP built-in calibration techniques.
- The model simulation has been evaluated using coefficient of determination (R2), and Nash and Sutcliff efficiency (NSE) criteria.

3.5 Parameter Optimization

- ❑ Particle Swarm Optimization (PSO)
- ❑ Generalized Likelihood Uncertainty Estimation (GLUE)

Objective Function

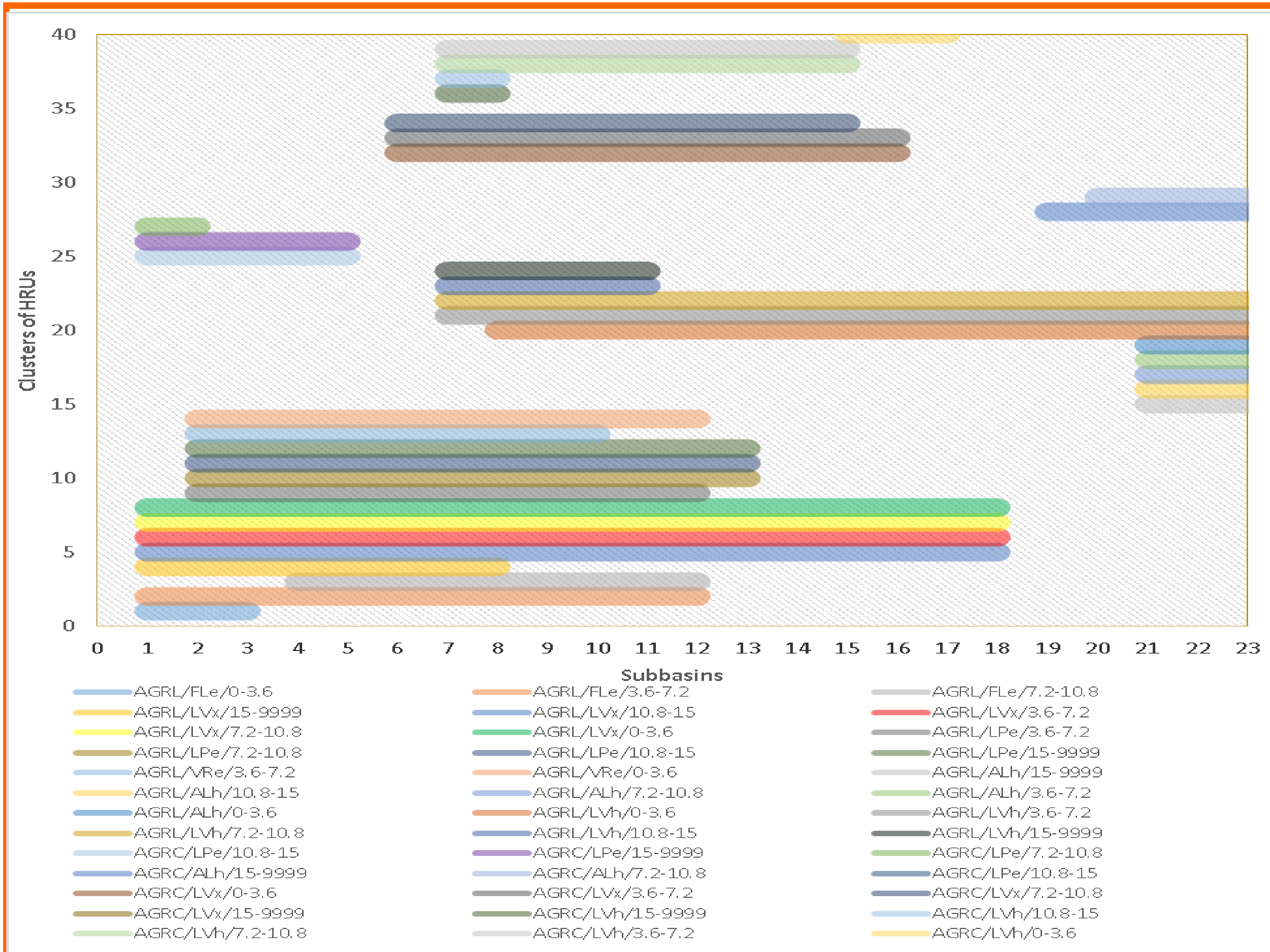
- ➢ Nash and Sutcliff efficiency (NSE)

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

3.6 Parameter transfer schemes

1. Identification of homogeneous regions (PT-I) based on annual precipitation totals of the study area
2. Global averaging method (PT-II).
3. Considering one representative gauged catchment as a donor for all ungauged catchments (PT-III).

- Total no. of HRUs = 142
- Total no. of clustered HRUs = 39



Clusters of HRUs
Subbasins
0
5
10
15
20
25
30
35
40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
AGRL/FLe/0-3.6
AGRL/FLe/3.6-7.2
AGRL/FLe/7.2-10.8
AGRL/LVx/15-9999
AGRL/LVx/10.8-15
AGRL/LVx/3.6-7.2
AGRL/LVx/7.2-10.8
AGRL/LVx/0-3.6
AGRL/LPe/3.6-7.2
AGRL/LPe/7.2-10.8
AGRL/LPe/10.8-15
AGRL/LPe/15-9999
AGRL/VRe/3.6-7.2
AGRL/VRe/0-3.6
AGRL/ALh/15-9999
AGRL/ALh/10.8-15
AGRL/ALh/7.2-10.8
AGRL/ALh/3.6-7.2
AGRL/ALh/0-3.6
AGRL/LVh/0-3.6
AGRL/LVh/3.6-7.2
AGRL/LVh/7.2-10.8
AGRL/LVh/10.8-15
AGRL/LVh/15-9999
AGRC/LPe/10.8-15
AGRC/LPe/15-9999
AGRC/LPe/7.2-10.8
AGRC/ALh/15-9999
AGRC/ALh/7.2-10.8
AGRC/LPe/10.8-15
AGRC/LVx/0-3.6
AGRC/LVx/3.6-7.2
AGRC/LVx/7.2-10.8
AGRC/LVx/15-9999
AGRC/LVh/15-9999
AGRC/LVh/10.8-15
AGRC/LVh/7.2-10.8
AGRC/LVh/3.6-7.2
AGRC/LVh/0-3.6

4. Results and Discussion

4.1 Modelling of Gauged Catchments

4.1.1 Results of Global Sensitivity Analysis

Table 1: t-stat and p-values for parameter sensitivity for all gauged catchments.

So. No.	Parameter	Gilgel Abay		Gummera		Rib		Megech	
		t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value
1	r_CN2.mgt	47.62166	0	47.33963	0	-19.4022	6.25E-77	-35.1301	1.09E-210
2	v_GW_REVAP.gw	-1.44449	0.148759	-5.53714	3.48E-08	17.05032	6.09E-61	10.19484	7.98E-24
3	v_GW_DELAY.gw	-17.1551	1.27E-61	-24.4188	2.21E-115	15.33219	3.12E-50	8.454244	5.36E-17
4	v_ALPHA_BF.gw	10.05271	3.18E-23	11.32075	7.76E-29	-14.9617	4.88E-48	-6.68043	3.08E-11
5	v_ALPHA_BNK.rte	9.940337	9.36E-23	5.056669	4.66E-07	1.706526	0.088066	-5.61328	2.26E-08
6	r_SOL_K.sol	1.186936	0.235395	-6.07157	1.51E-09	6.923138	5.94E-12	4.592259	4.66E-06
7	r_SOL_BD.sol	8.030916	1.64E-15	3.940134	8.43E-05	-3.21987	0.001303	-4.3572	1.38E-05
8	v_CH_N2.rte	2.725109	0.006484	3.576792	0.000356	0.759129	0.447865	2.663424	0.007797
9	v_GWQMN.gw	1.731878	0.083451	-1.29791	0.194469	4.805065	1.66E-06	2.282674	0.022555
10	v_SFTMP.bsn	1.691544	0.09089	0.301472	0.763086	-1.71986	0.085614	-1.69683	0.089885
11	v_ESCO.hru	0.527894	0.597632	1.50548	0.13236	-5.96981	2.81E-09	-1.17015	0.24208
12	v_CH_K2.rte	3.764889	0.000171	0.67859	0.497477	-5.85183	5.67E-09	-0.68028	0.496406
13	r_SOL_AWC.sol	3.559494	0.00038	1.75567	0.079299	-1.93864	0.052687	-0.32425	0.74578

t-stat : larger in absolute values are more sensitive

p-values: a values close to zero has more significance.

4.1.2 Dotty Plots

- Sampling point distribution of the first ranked sensitive parameter, curve number (CN2), using GLUE and PSO.

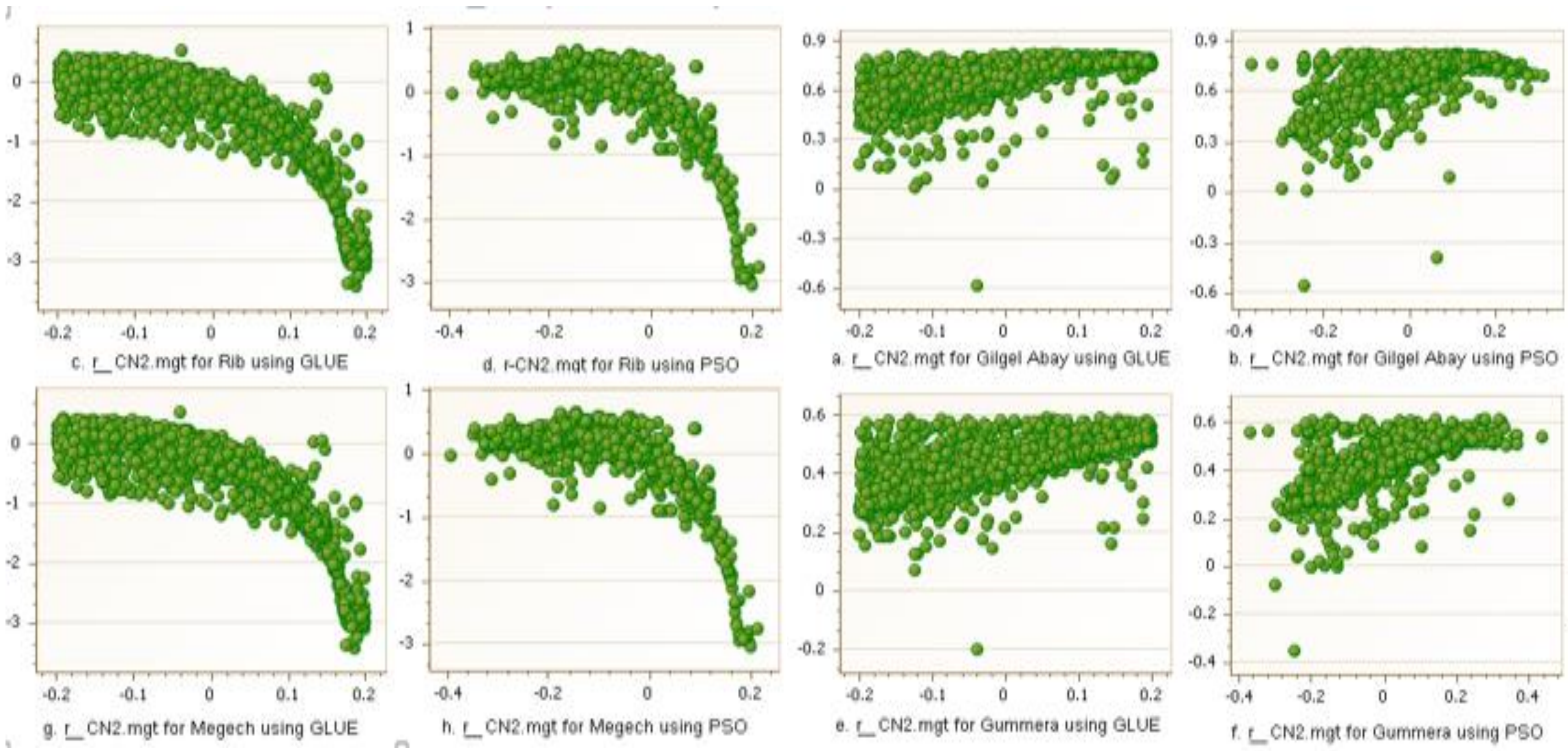


Figure 4: Plots of parameter values (x-axis) vs values of objective function (y-axis)

4.1.3 Model Performance

Table 2: Performance measure values for all gauged catchments

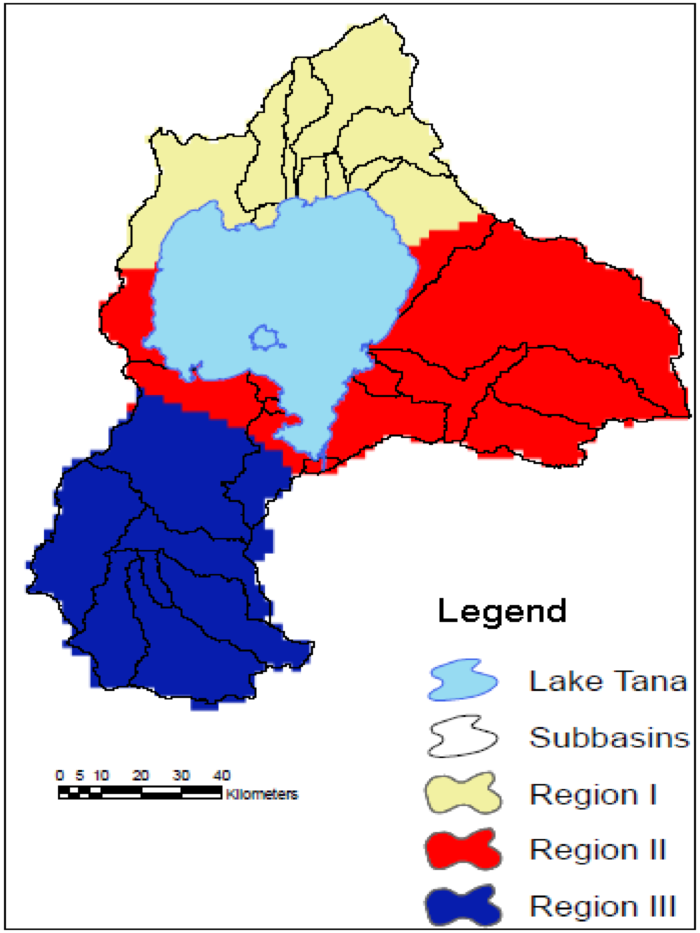
Performance Measure	Gilgel Abay		Gummera		Rib		Megech	
	GLUE	PSO	GLUE	PSO	GLUE	PSO	GLUE	PSO
R2	0.83	0.83	0.55	0.63	0.56	0.67	0.58	0.7
NSE	0.82	0.82	0.51	0.62	0.53	0.64	0.53	0.66

4.1.4 Optimized Model Parameters

S.No.	Model parameters	Optimized Values of Model Parameters					Range	
		Gilgel Abay	Gummera	Rib	Megech	Global Average	Lower	Upper
1	**r_CN2.mgt**	-0.143	-0.151	-0.224	-0.144	-0.166	-0.2	0.2
2	**v_ALPHA_BF.gw**	0.318	0.261	0.046	0.046	0.167	0	1
3	**v_GW_DELAY.gw**	24.149	10.961	397.342	292.211	181.165	0	500
4	**v_GWQMN.gw**	0.699	0.239	0.035	0.859	0.457	0	5000
5	**v_GW_REVAP.gw**	0.200	0.150	0.147	0.177	0.168	0	0.2
6	**v_ESCO.hru**	0.841	0.839	0.866	0.796	0.836	0.8	1
7	**v_CH_N2.rte**	0.215	0.212	0.133	0.183	0.186	-0.01	0.3
8	**v_CH_K2.rte**	81.502	123.973	89.445	42.751	84.417	-0.01	500
9	**v_ALPHA_BNK.rte**	0.796	0.290	0.509	0.061	0.414	0	1
10	**r_SOL_AWC.sol**	-0.013	0.054	-0.143	-0.120	-0.056	-0.2	0.4
11	**r_SOL_K.sol**	0.794	0.780	0.696	0.406	0.669	-0.8	0.8
12	**r_SOL_BD.sol**	-0.013	0.102	0.218	0.222	0.132	-0.5	0.6
13	**v_SFTMP.bsn**	-0.109	1.6197	-1.344	-0.848	-0.171	-5	5

4.2 Parameter transfer Schemes

4.2.1 Identification of homogeneous regions (PT-I)



- ✓ Gauged Gilgel Abay catchment for ungauged catchment in region-III,
- ✓ Gauged Gummera & Rib catchment for ungauged catchment in region-II,
- ✓ Gauged Megech catchment for ungauged catchment of region-I.

- ✓ weighted average – for common sub-basins of the homogeneous regions

Figure 5: Delineated three homogenous regions of LTB

4.2.2 Global averaging method (PT-II)

- This approach is based on the average of optimized model parameter values of all gauged catchments, that is obtaining one value for each of the parameters.

4.2.3 PT-III

- Gauged Gilgel Abay catchment is considered as the representative catchment based on its model performance value.

4.3 Performance comparison of parameter transfer schemes

I. Hydrograph based model comparison

- Evaluation Indicators: R^2 and NSE

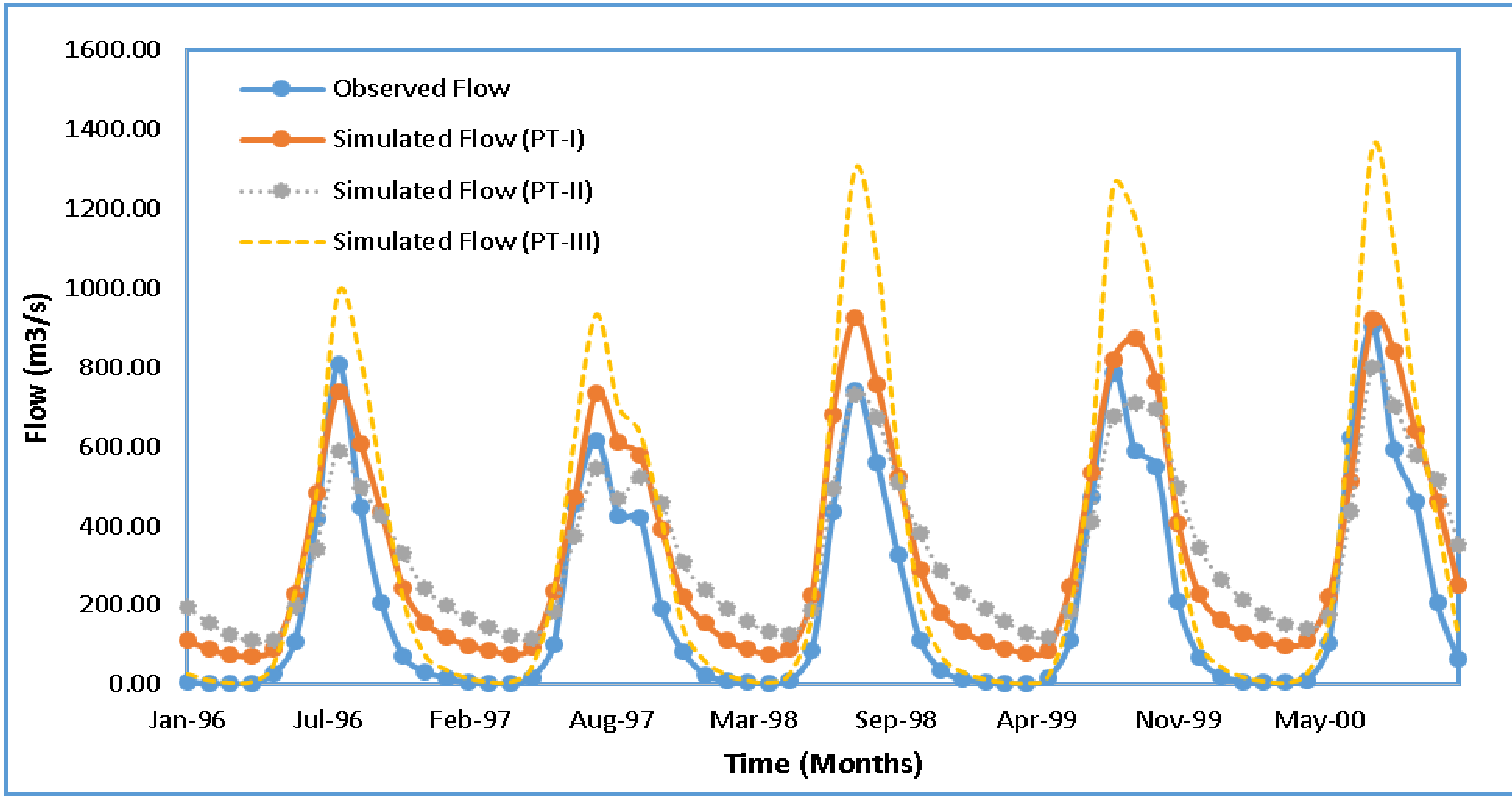


Figure 6: Plot of observed vs simulated total stream outflow from Lake Tana Basin.

Table 4: Values of performance measure

Performance measure	PT-I	PT-II	PT-III
R2	0.93	0.82	0.95
NSE	0.71	0.58	0.31

II. Flow Duration Curve Based Model Comparison

- Evaluation Indicators: R-Bias and R^2 on Flow Duration Curve

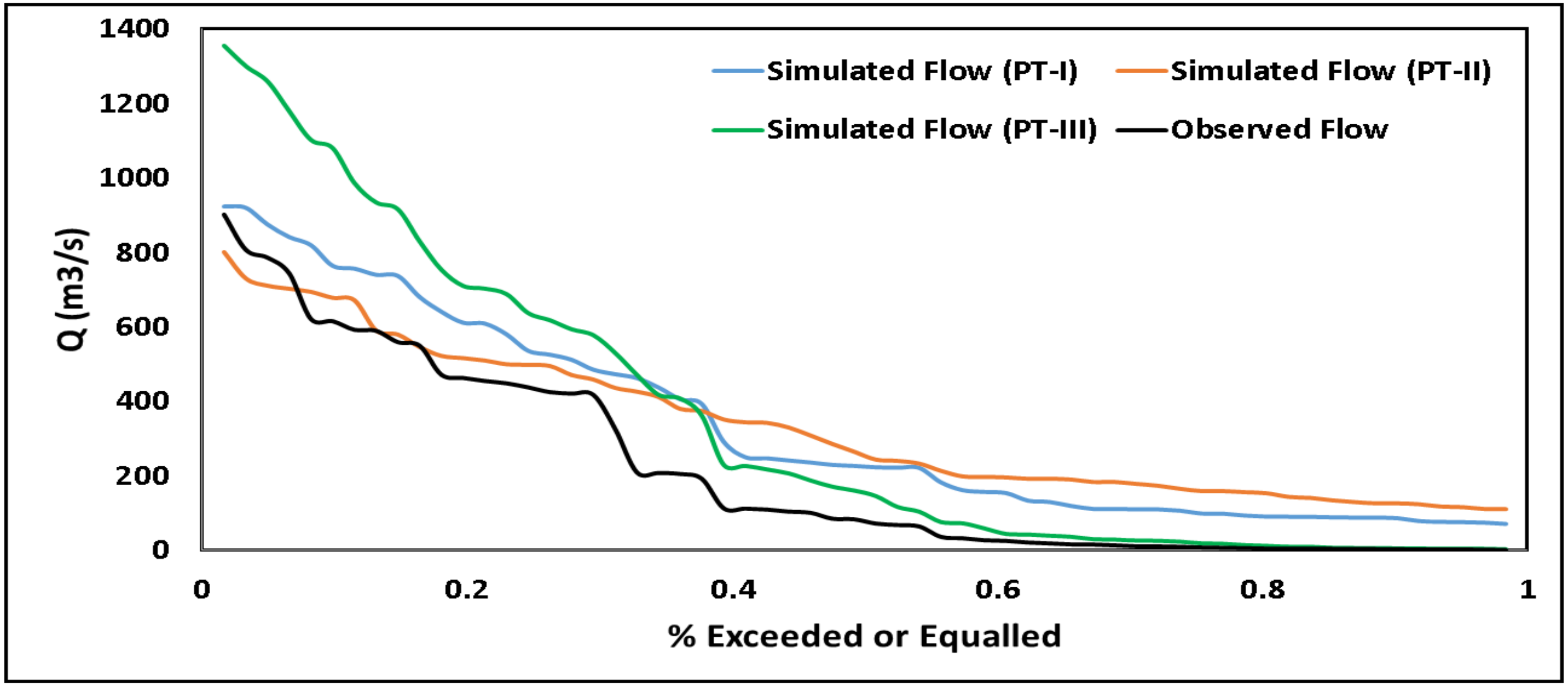


Figure 7: Flow duration curve

Table 5: Flow duration curve based performance measure of parameter transfer

Flow Range	PT-I		PT-II		PT-III		Best Method
	R-Bias	R2	R-Bias	R2	R-Bias	R2	
peak flow	0.1493	0.854	-0.035	0.790	0.626	0.966	PT-II
moist flow	0.369	0.899	0.200	0.891	0.588	0.941	PT-II
mid range flow	1.900	0.9188	2.573	0.938	0.946	0.971	PT-III
dry flow	8.662	0.970	13.985	0.847	-3.247	0.955	PT-III
low flow	32.950	0.796	50.717	0.749	0.976	0.922	PT-III

4.4 Surface water potential of the basin.

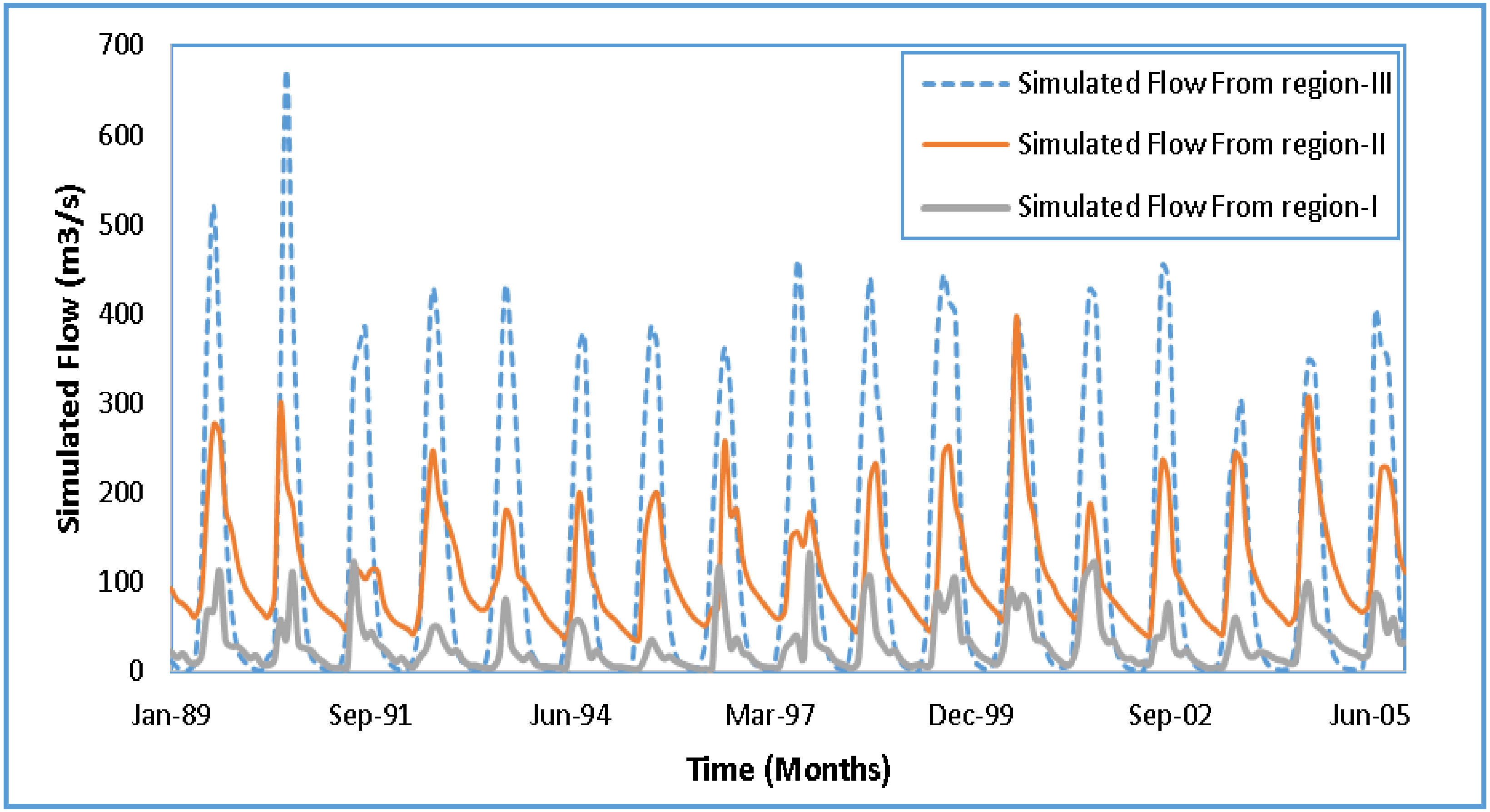


Figure 8: Inflow hydrograph from all homogeneous regions to Lake Tana

4.5 Hydrologic Model Uncertainty

The values of P-factor and r-factor are 0.78 and 0.84 respectively.

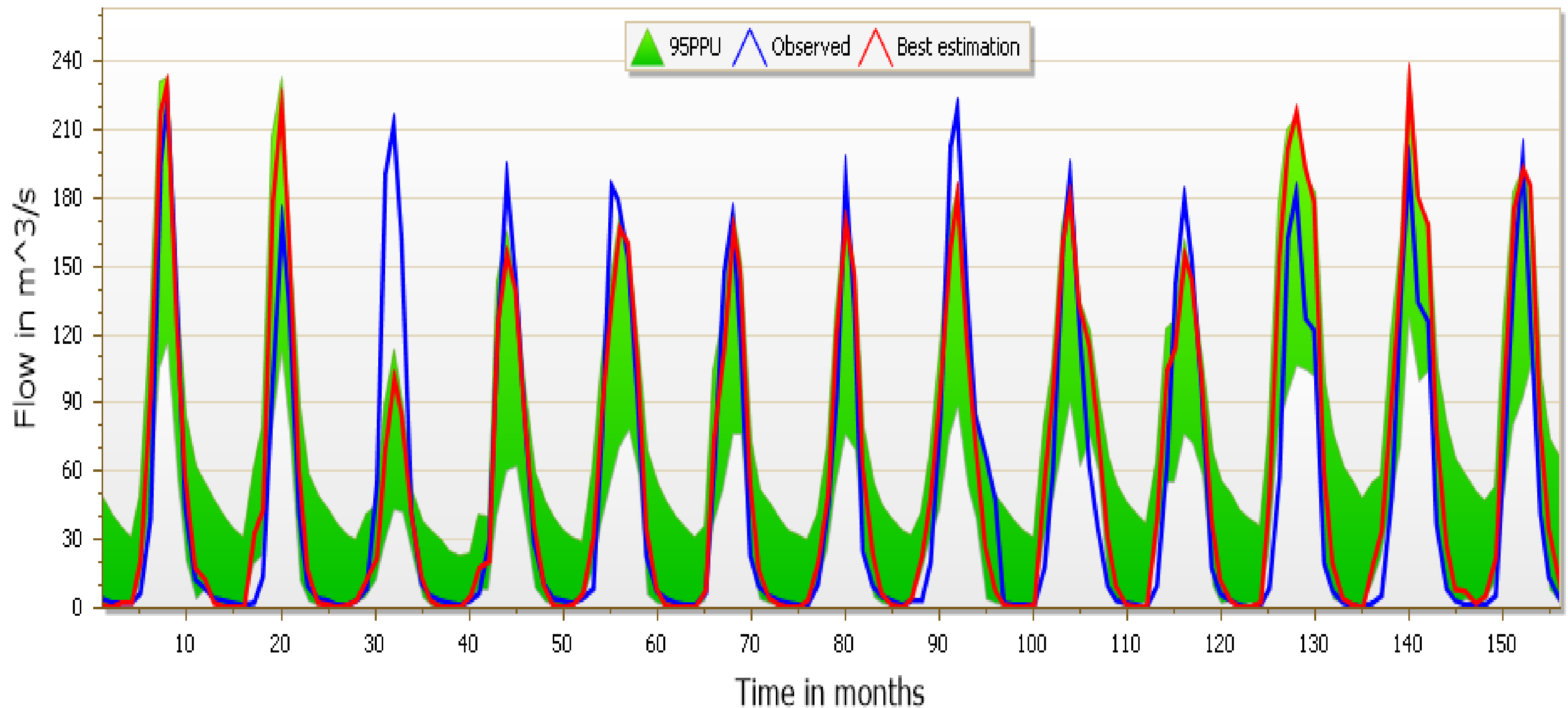


Figure 9: 95% prediction uncertainty (95PPU) plot for Gilgel Abay watershed

5. Conclusion

- ✓ PSO method outperforms GLUE
- ✓ SCS curve number (CN2) has been found the most sensitive parameter in all gauged catchments.
- ✓ PT-I parameter transfer scheme performs better to reproduce the exact hydrograph whereas PT-II is best for high and moist flow simulation and PT-III is best for mid-range, dry, and low flow simulation.
- ✓ Yearly average surface flow for the homogeneous regions was found 29.54 m3/s, 112.92 m3/s, and 130.10 m3/s for time periods of (1989 – 2005) for region-I, region-II, and region-III respectively where PT-I parameter transfer scheme was used.
- ✓ PT-II and PT-III were found good for climate change impact assessment study.

6. References

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Thank You!