Impact of Climate Change on River Discharge in the White Volta River Basin, West Africa

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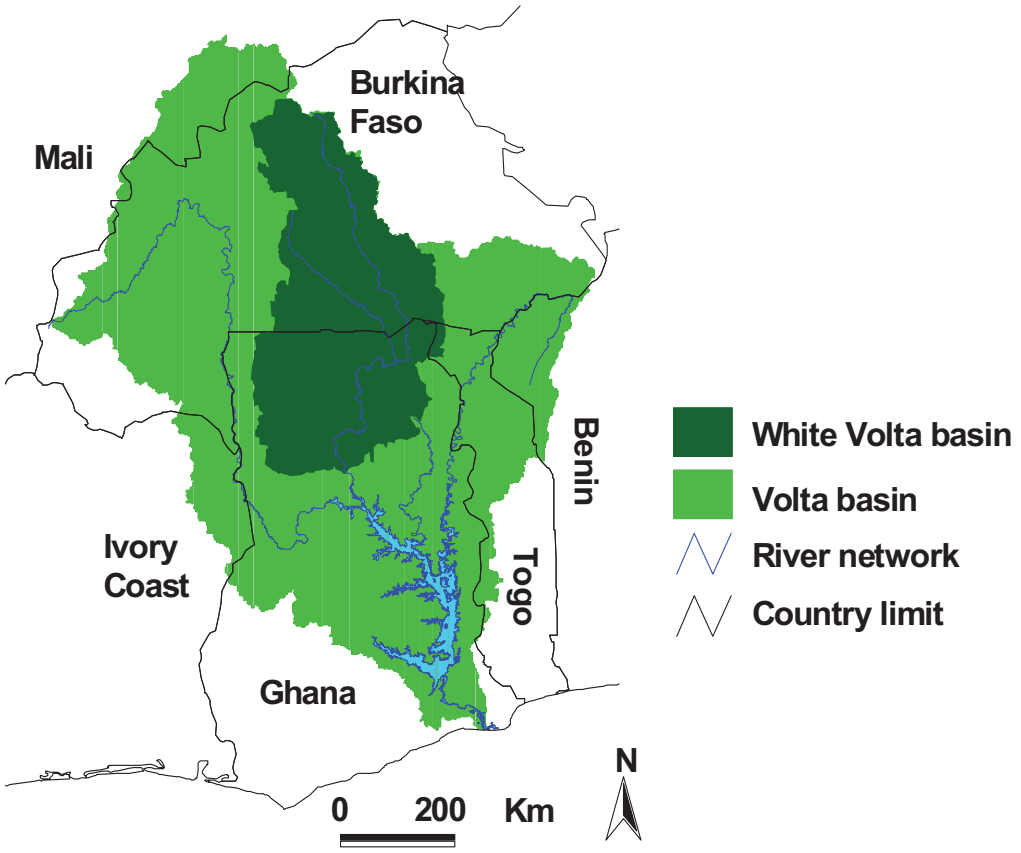
Background

- **Basin characteristics**

– 4.6 million inhabitants; annual growth rate of 2.5%

– Settlement is largely rural

– 70 - 90% inhabitants are peasant farmers



Background

- **Climate**
  - Semi-arid to sub-humid climate
  - Mean annual rainfall: 600 – 1200 mm (80% occurs in July-Sept.)
  - Mean annual temperature: 27 ^{o}C
  - Mean annual potential evapotranspiration: 1800 mm
- **Soils**
  - Luvisols, Regosols and Lithosols

Background

- **Water Resource Challenges**

  - High spatial and seasonal variability of rainfall
  - Prolonged dry season of 7 months
  - Land degradation
  - Forecasted increase in mean annual temperature of 1.2 ^{o}C between 1991-2000 and 2030-2039
    - increase in mean annual rainfall of 5% (Kunstmann and Jung, 2005)

Objective

- **Goal**

  Use future climate projections to generate impact-specific information for decision-making on sustainable management of water resources.

- **Specific Objectives are to:**

  - Evaluate the ability of a regional scale hydrological model to simulate hydrological fluxes
  - Estimate the impact of future climate change on water resources

Method

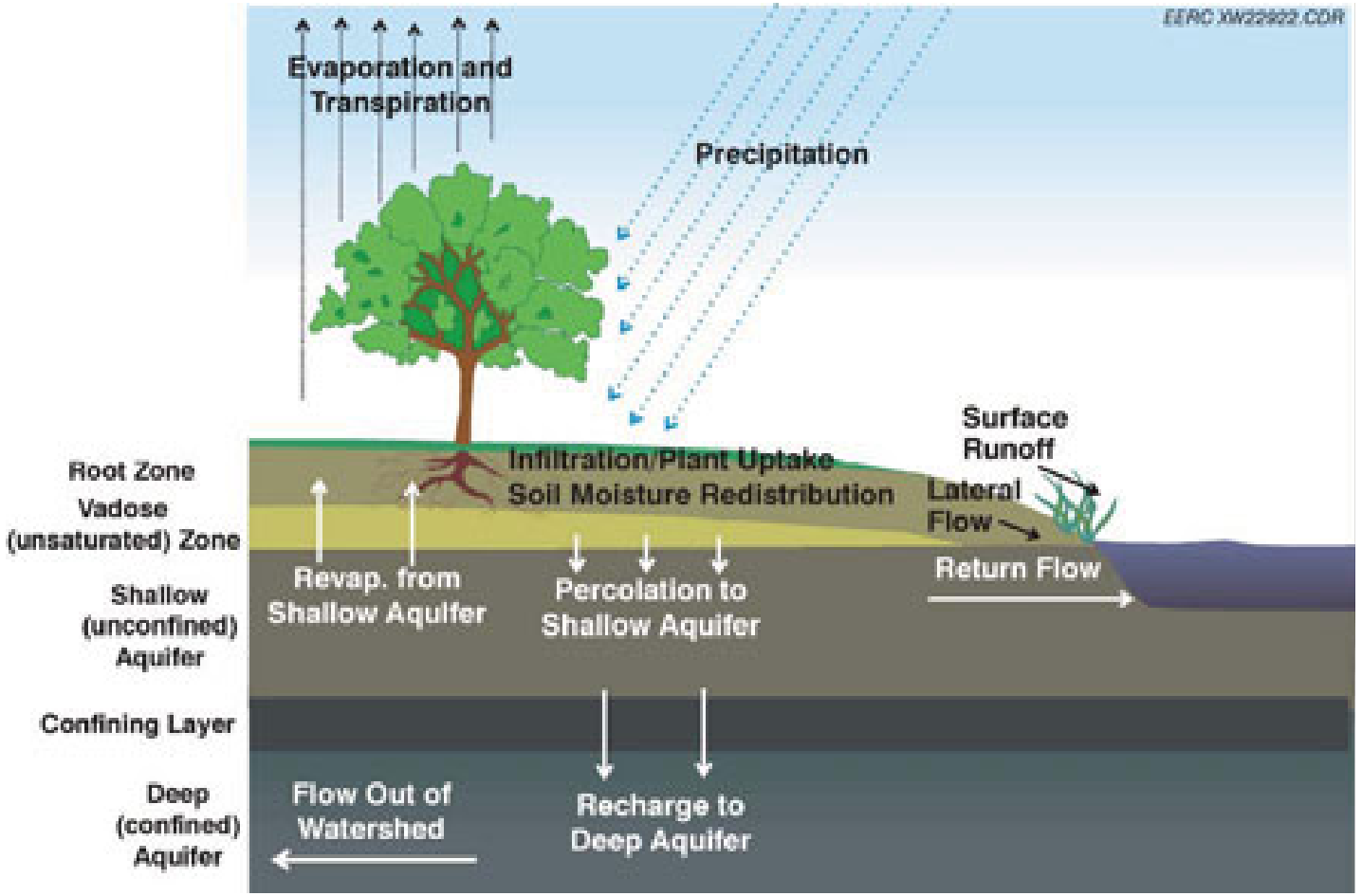
- **Soil and Water Assessment Tool (SWAT)**

  Model Characteristics:

  - Semi-distributed model
  - Uses a GIS interface
  - Uses readily available inputs data
  - Wide use
  - Freely available

Method

SWAT Hydrologic cycle



SWAT hydrologic cycle (EERC-University of North Dakota, 2008, modified from Neitsch et al., 2005)

Method and Data

SWAT water balance equation (Neitsch et al., 2005):

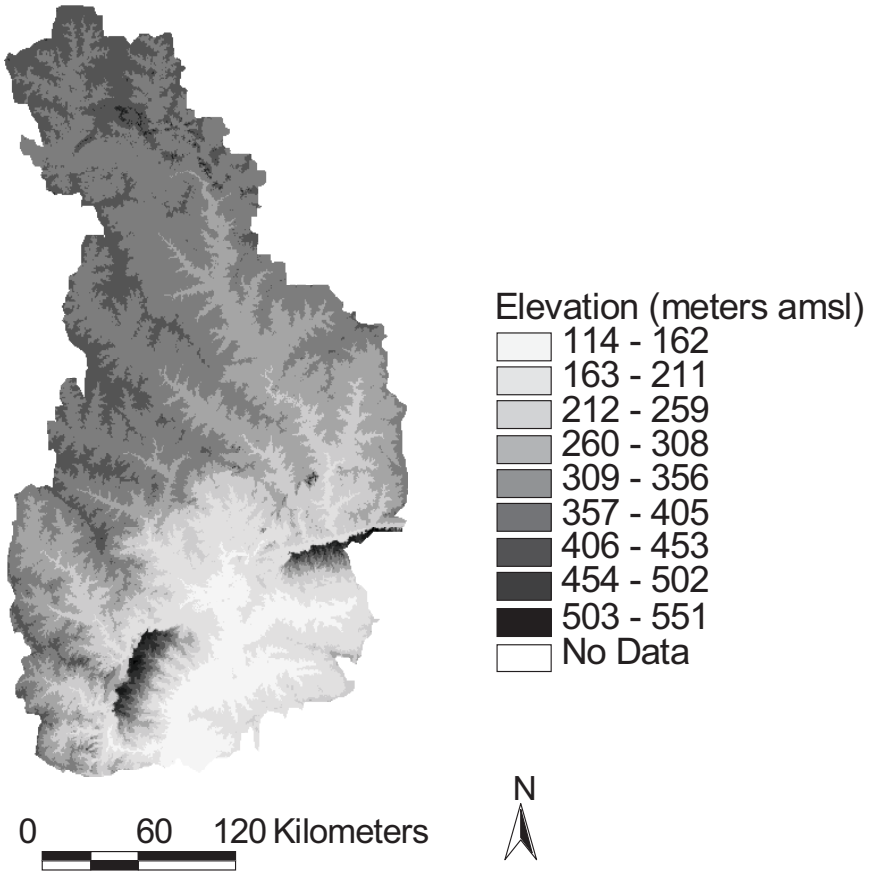
$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right)$$

where SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

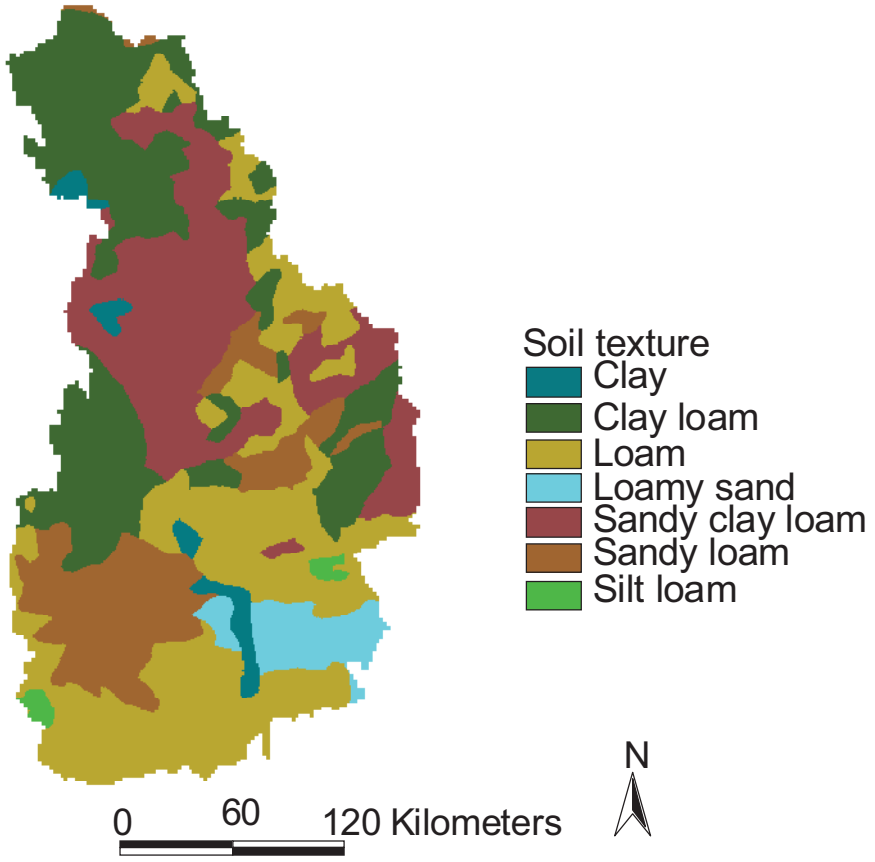
Method and Data

SWAT key input data

90m SRTM DEM (Source: NASA server)



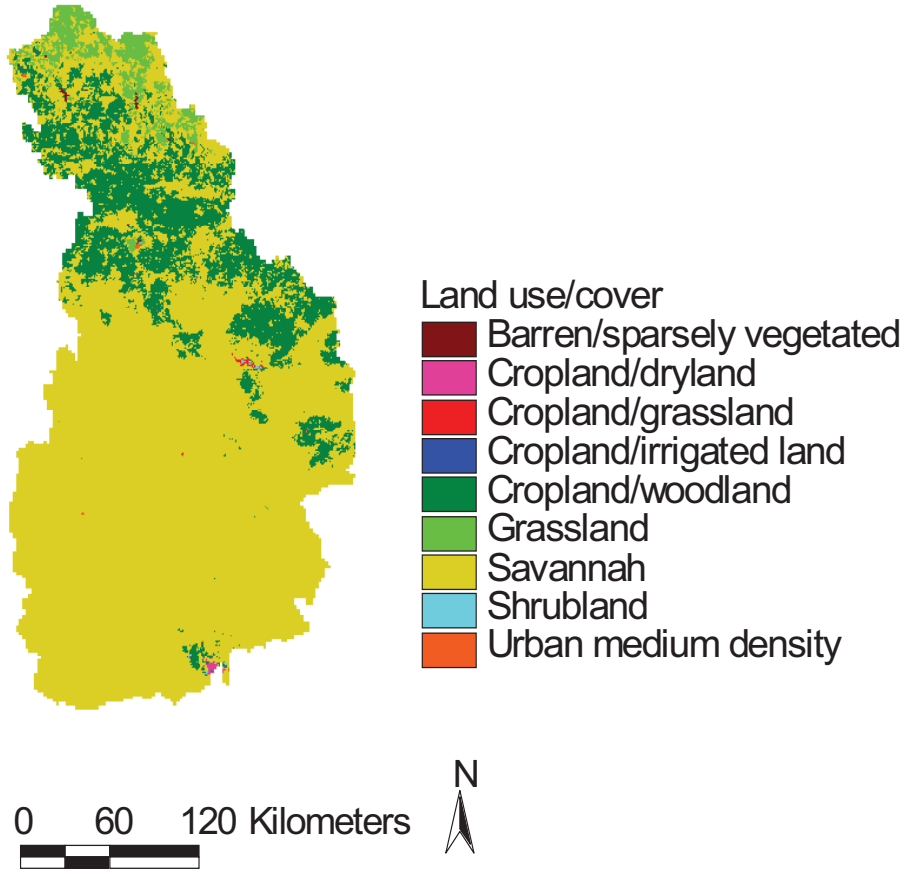
Map of soil texture (Source: FAO, 1995)



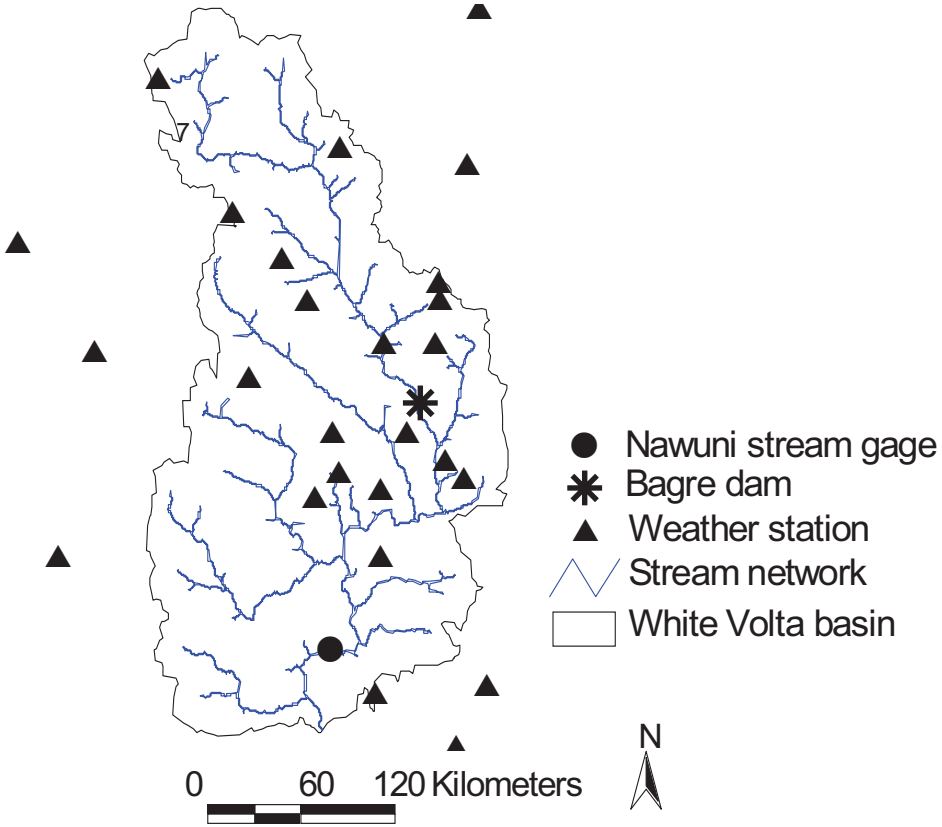
Method

SWAT input data

Land-use/-cover (Source: USGS-GLCC)



Climate data (Sources: Meteorological agencies in GH & BF)



Method

Model calibration and validation:

- Model calibrated at Nawuni (91,000 km^2)
  - Calibration: 1980-1991; warm up:1980-1985
  - Validation: 1992-1999

Model performance evaluation:

- Nash-Sutcliffe model efficiency (NSE)
- Coefficient of determination (R^2)
- Index of agreement (IA)

Conditions for successful calibration (Santhi et al., 2001):

- Simulated mean monthly/daily flow differs from observed within **±**15 %
- NSE > **0.50**
- R^2 > **0.60**

Method

Climate change scenario:

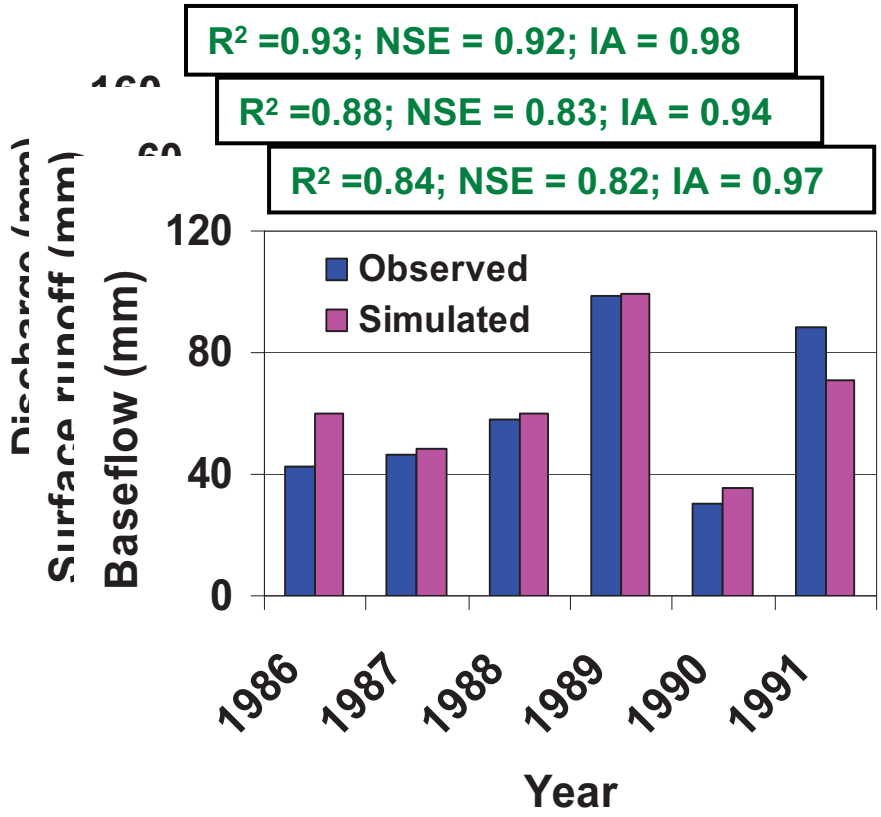
- GLOWA Volta climate change scenario MM5 (ECHAM4, IS92a)
- Data time slices (baseline:1991-2000 and future: 2030-2039)
- Mean annual temperature increase: 1.2 ^{o}C; mean annual rainfall increase: 5 %

MM5 data are gridded, not suitable for direct use in SWAT….

- Climate series generated with stochastic weather generator LARS-WG
- Baseline and future water resources simulated with calibrated SWAT model and compared

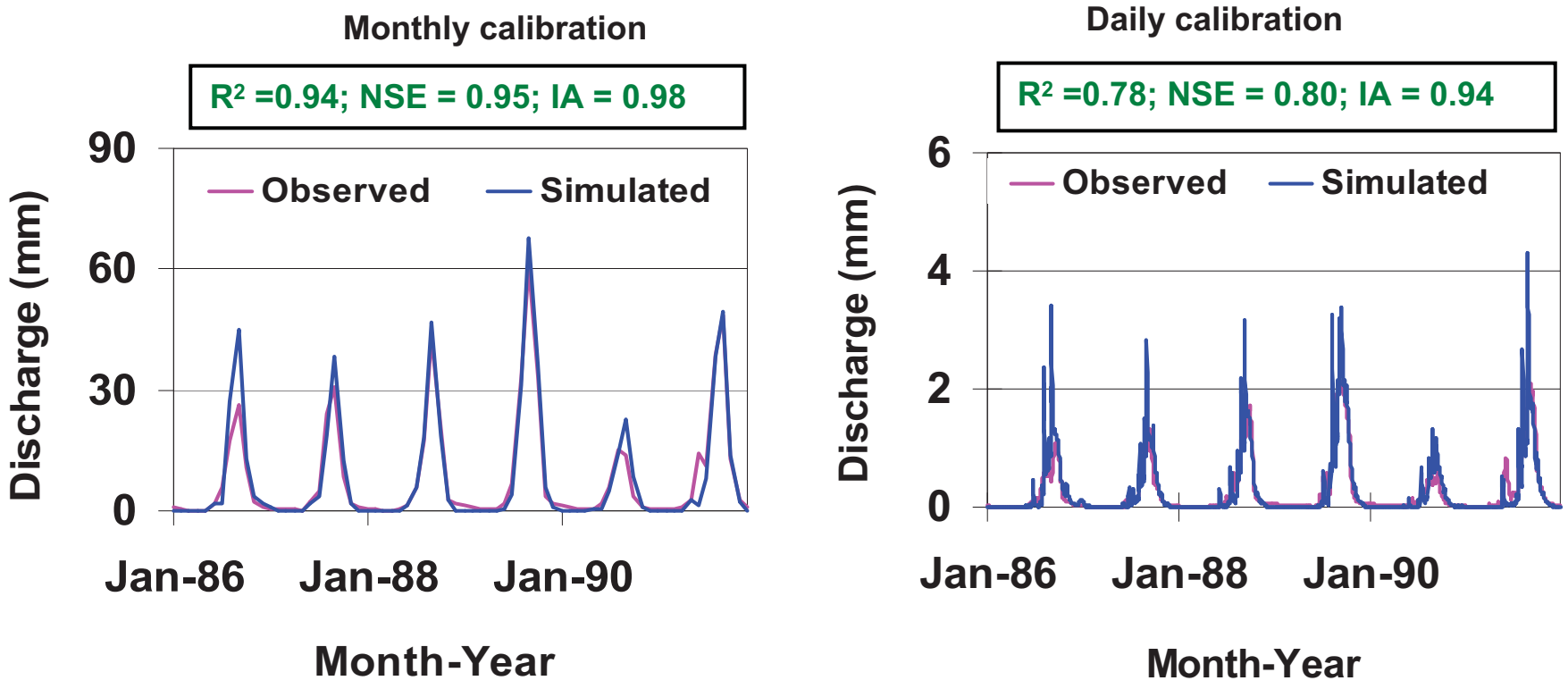
Results

– Annual calibration



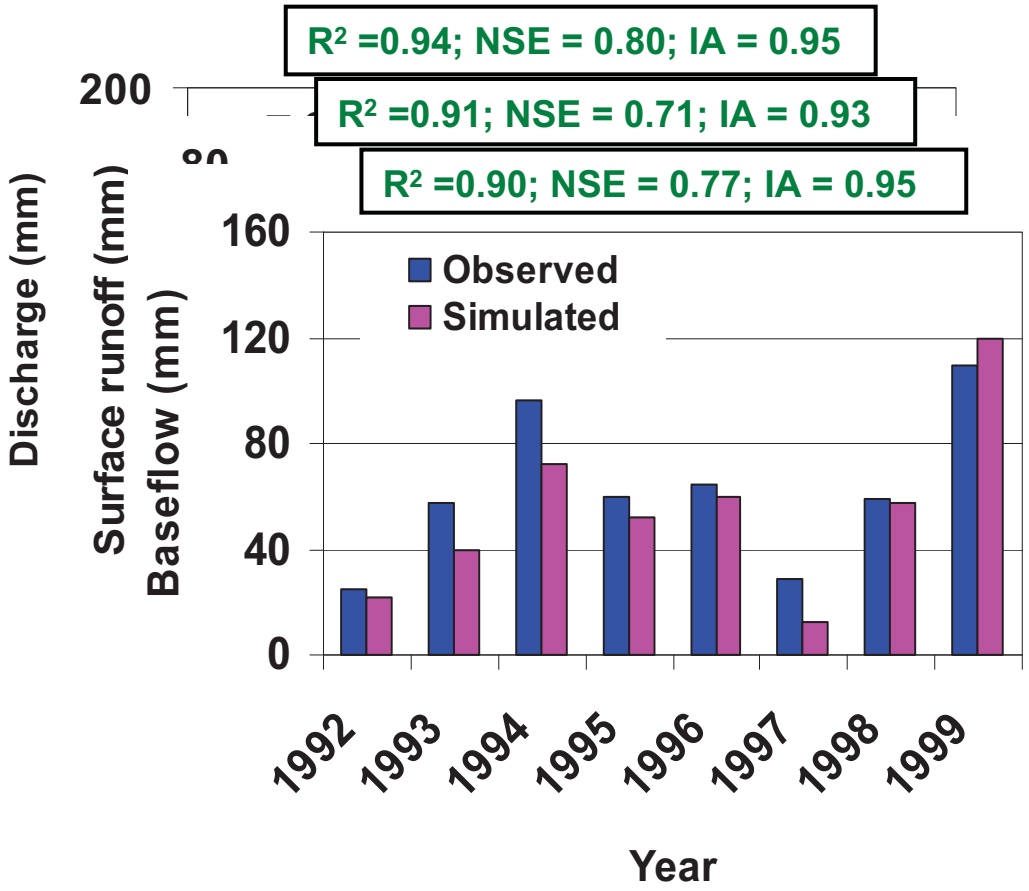
Results

– Monthly and daily calibration



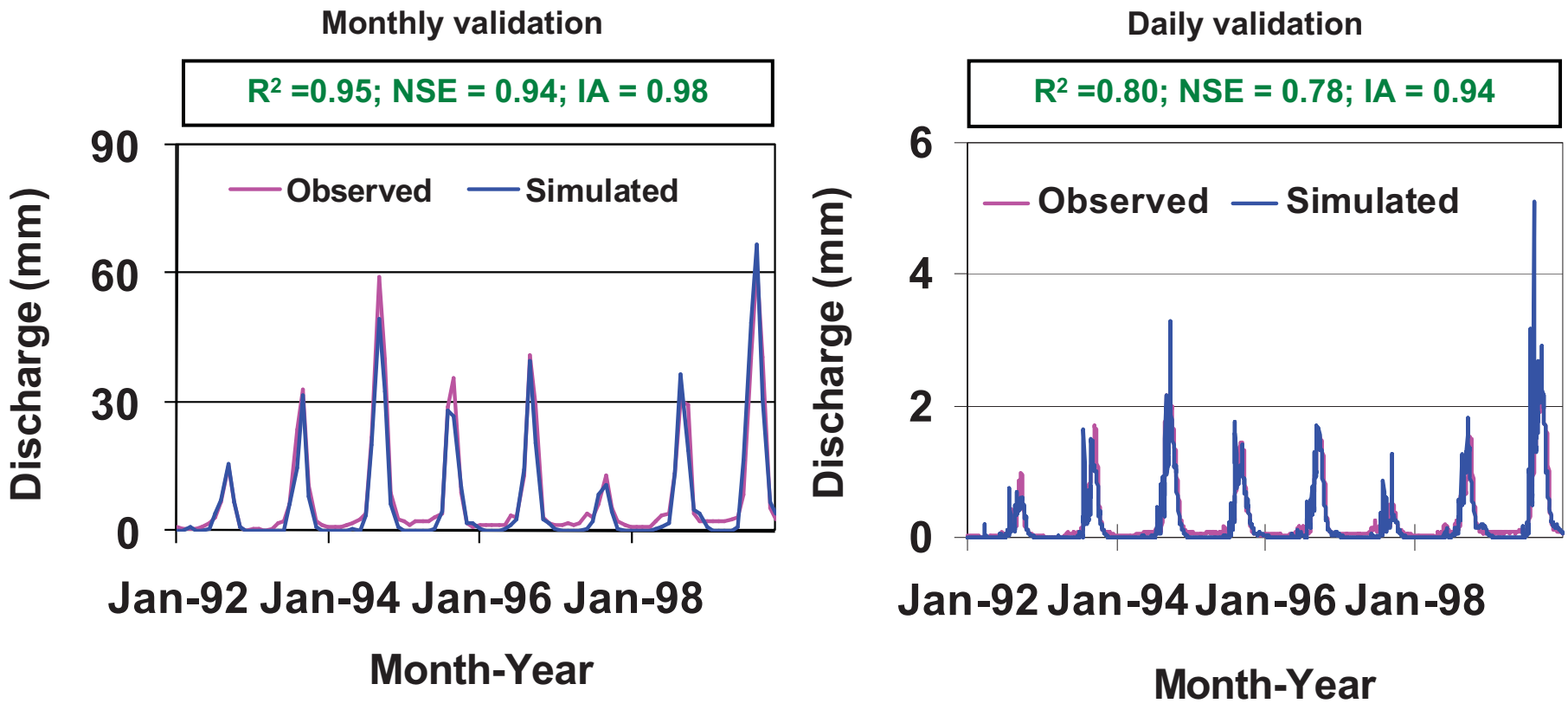
Results

– Annual validation



Results

– Monthly and daily validation



Results

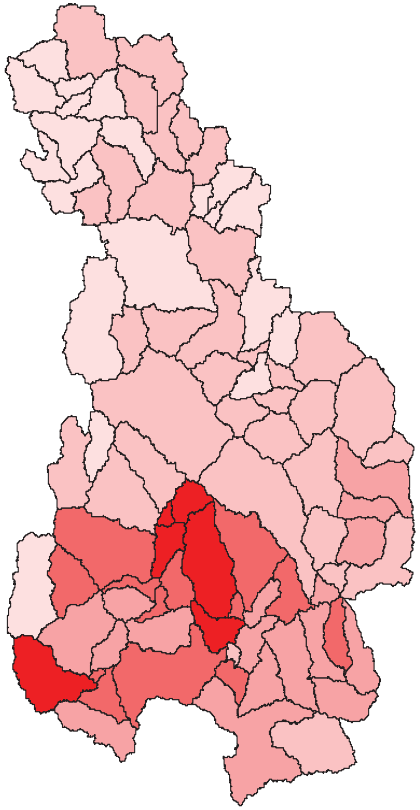
- **Climate change impact on river discharge**
  - Change in mean annual discharge

Scenario	Simulation period	Rainfall (mm)	Discharge (mm)
Baseline	1991-2000	851 (8%)	89 (27%)
Future	2030-2039	904 (14%)	118 (41%)
Change (%)		6	33

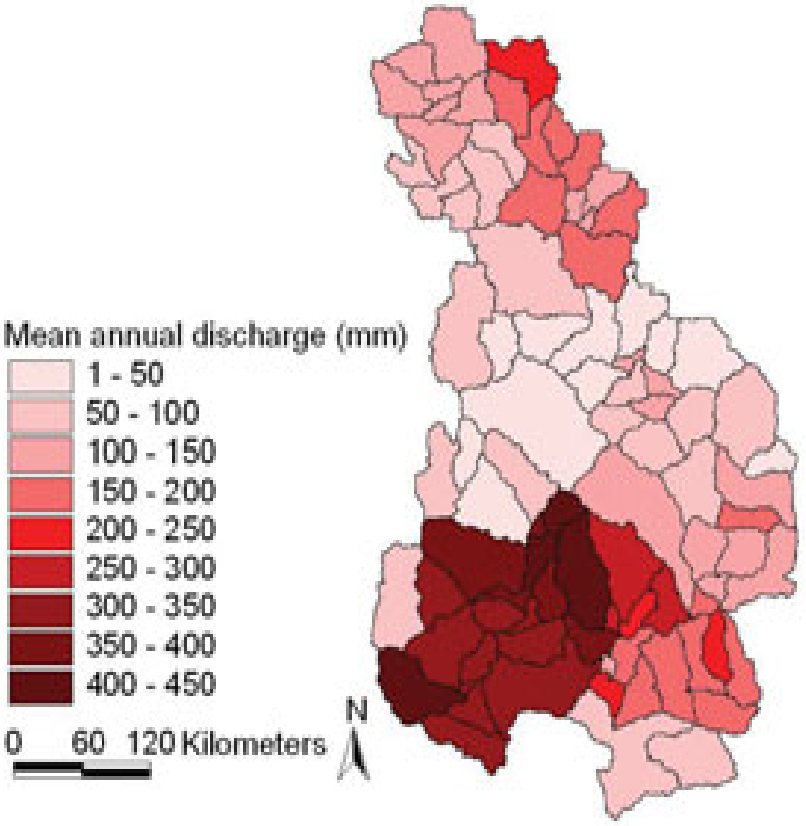
Results

- **Climate change impact on recharge**
  - Change in spatial distribution of mean annual discharge

Baseline (1991 - 2000)



Future (2030 - 2039)



Conclusions

- SWAT is able to accurately reproduce the hydrological fluxes of the White Volta Basin: Total runoff, surface runoff and baseflow
- Estimated future (2030-2039) mean annual discharge shows important increase over the baseline (1990-1999)
- The frequency of extreme events (drought and flood) are expected to increase

Recommendations

- More floods: permanent re-settlement of persons living in low lying areas/close proximity to the main water course
- More droughts: exploring water or moisture storage facilities to lessen the effects of drought
- Use of climate model ensembles and multiple future climate scenarios, e.g., best- and worst-case scenarios to estimate the range of impact that can be expected

Previous studies

Climate change projections of HADCM3 and statistics for the Volta Basin, based on the SRE A2 and B2 scenarios (Andah et al., 2003)

Scenario	Period	Rainfall (mm)			Temperature (°C)		
		Annual Mean	Standard deviation	Coefficient of variation	Annual Mean	Standard deviation	Coefficient of variation
SRE A2	1961-1990	1079	115	0.11	27.3	0.5	0.02
	2020-2039	1161	105	0.09	28.5	0.5	0.02
	2070-2099	1147	123	0.11	31.8	0.8	0.03
SRE B2	1961-1990	1079	117	0.11	27.3	0.5	0.02
	2020-2039	1181	144	0.12	28.4	0.5	0.02
	2070-2099	1173	118	0.10	30.4	0.5	0.02

Previous studies 2

Mean annual inflow into Lake Volta (taken to be the outlet of the Volta Basin) together with standard deviation and coefficient of variation of the respective simulation periods for Hadley A2 and B2 (Andah et al., 2003)

Scenario	Time slice	Mean discharge (km^3)	Percent change (%)	Standard deviation	Coefficient of variation
Historical	1961-1990	32.8 (82)	-	17.1	0.52
HA2	2020-2039	41.6 (104)	27	14.0	0.34
HB2	2020-2039	43.8 (110)	34	15.4	0.35
HA2	2070-2099	37.2 (93)	13	19.9	0.54
HB2	2070-2099	44.0 (110)	34	17.6	0.40

NB: Figures in brackets are discharge in mm; the Volta Basin covers 400,000 km^2

Previous studies 3

Comparison of the mean annual increases (%) of selected water balance variables, between the baseline simulation (1991-2000) and the future (2030-2039) simulation, at Nawuni in the White Volta Basin

Source	Rainfall	Discharge	Surface runoff	Baseflow
Study	6	33	37	29
Jung, 2006	5	15	57	13

Thank You