Impacts of climate on water-use and water-use efficiency of woodlands in the Sudanese Sahel region: a modelling study

UNIVERSITY OF HELSINKI
FACULTY OF AGRICULTURE AND FORESTRY

Syed Ashraful Alam* and Mike Starr

Department of Forest Sciences, University of Helsinki, Finland

Viikki Tropical Resources Institute (VITRI)

Email: Ashraful.Alam@helsinki.fi and Mike.Starr@helsinki.fi

Introduction

The Sahel belt of Africa has been identified as a "hot spot" of global environmental change. However, the response of this semi-arid region to climate change, particularly in relation to woodland vegetation cover and water-use, remains unclear. Climate change could cause major ecological disruption and conflict in the region.

Aims

To model the impact of various climate change and emission scenarios on the water-use and water-use efficiency of woodlands across the Sudanese Sahel region for the 2080s.

Material and Methods

The modelling approach is shown on Figure 1. Modelled monthly mean scenarios of climate variables (temperature, precipitation and cloud cover) for the period 2070-2099 were derived using five GCMs (CGCM2, CISRO2, ECHam4, HadCM3 and PCM) run with A1FI (greatest climate forcing caused by fossil fuel usage) and B1 (least climate forcing caused by fossil fuel usage) SERS emission scenarios.

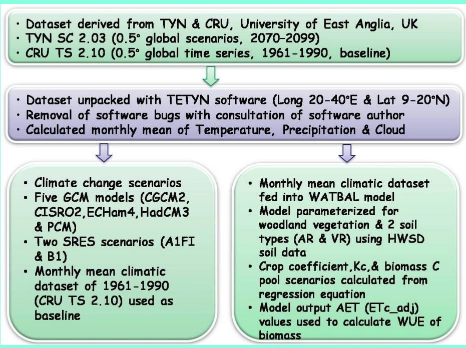

Figure 1. Sources of data and modelling approach

The climate data were generated for nine map sheets (1.0º latitude x 1.5º longitude), covering 11.5–17.5 ºN by 24–36 °E, were selected so as to cover the current climate conditions of Sudanese Sahel region (Fig. 2). Climate data from TYN SC 2.0 dataset were extracted. Baseline (1961-1990) observed monthly mean values of same climate variables were extracted from the CRU TS 2.1 dataset. The climate data were calculated as the average of the resulting six TYN/CRU grids per map sheet.

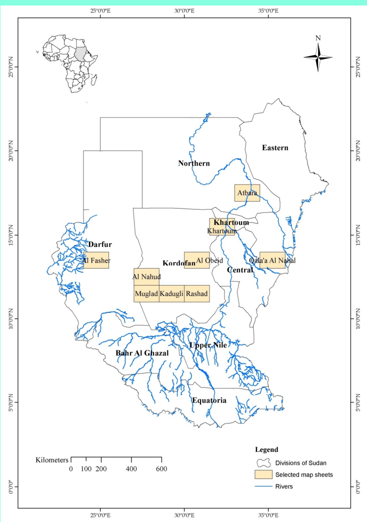

Figure 2. Map of Sudan showing nine map sheets

A simple water balance model, WATBAL, was parameterized for woodland vegetation and two soil types, arenosols (AR) and vertisols (VR), using HWSD (Harmonized World Soil Database) soil data to give monthly water-use, AET (ETc_adj), values for the baseline and climate change scenario periods.

Water-use efficiency (WUE, g C m^{-2} mm^{-1}) for each map sheet was calculated as mean above-ground biomass C density (g C m^{-2}) divided by AET (mm). Current biomass C density (baseline period) was calculated using forest inventory of above-ground volume (m^{-3} ha^{-1}) data. Map sheet C density values were calculated using a wood density value of 0.65 t dm m^{-3} and assuming a C content of 50%. An exponential model relating biomass C density to annual rainfall was used to estimate biomass C density under climate change scenarios of 2070- 2099.

Results

Climate change scenarios, 2070-2099

- Map sheet baseline annual rainfall ranged from 5 to 55 mm and temperature from 23.3 to 29.2 °C.
- Mean annual air temperature increased under all 10 climate change and SERS scenarios and for all nine map sheets (+1.2 to +8.3 °C), while mean annual rainfall either increased (+1 to +30 mm) or decreased (-1 to -16 mm), depending on scenario and map sheet.
- In case of mean annual rainfall, ECHam4_A1FI and PCM_B1 generated highest and lowest scenarios, respectively for all nine map sheets.

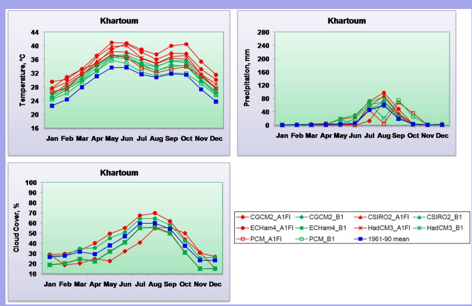

Figure 3. Climate change scenarios of Khartoum map sheet for 2070-2099

Water-use (AET) of woodlands, 2070-2099

- Baseline modelled AET varied from 56 to 595 mm
- Depending on climate change scenario and map sheet, relative AET (scenario/baseline) generally ranged between :
  - 0.61 (Al Fasher, PCM_A1FI) and 1.89 (Khartoum, ECHam4_A1FI) for AR soils
  - 0.54 (Al Fasher, PCM_A1FI) and 1.88 (Khartoum, ECHam4_A1FI) for VR soils
  - But PCM_B1 generated highest relative AET for Atbara map sheet both for VR (6.79) & AR (4.33) soil types. The PCM GCM may not be suited for dry regions?

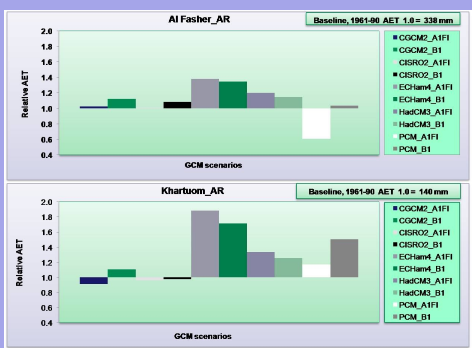

Figure 4. AET of woodlands 2070-2099, relative values for AR and for Al Fasher & Khartoum map sheets

Figure 5. AET of woodlands 2070-2099, relative values for VR and for Al Fasher & Khartoum map sheets

Water-use efficiency (WUE) of woodlands, 2070-2099

- WUE during baseline period varied from 0.106 to 0.462 g C m^{-2} mm^{-1}, depending on map sheet and soil type
- Depending on climate change scenario and map sheet, relative WUE (scenario/baseline) varied from:
  - 0.46 (Rashad, CGCM2_A1FI) to 2.22 (Muglad, ECHam4_A1FI) for AR soils
  - 0.50 (Rashad, CGCM2_A1FI) to 2.44 (Muglad, ECHam4_A1FI) for VR soils

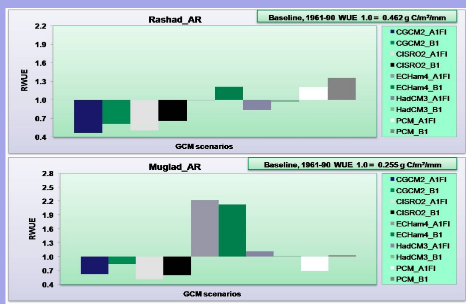

Figure 6. WUE of woodlands 2070-2099, relative values for AR and for Rashad and Muglad map sheets

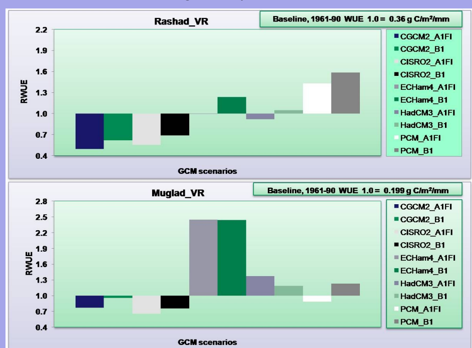

Figure 7. WUE of woodlands 2070-2099, relative values for VR and for Rashad and Muglad map sheets

Conclusions

- For map sheets with higher rainfall (southern), AET values were higher for VR soils than for AR soils. Largest relative changes in AET were associated with the drier map sheets. Depending on climate change scenario and map sheet, annual rainfall and AET increased, decreased or remained little changed.
- Compared to AR soils, VR soils had equal or greater water-use and equal or less WUE. WUE decreased for drier map sheets, but either decreased or increased for wetter map sheets, depending on climate change scenario
- Future water-use in the Sahel region will strongly depend on the degree and nature of climate change and adaptation of woodlands.

Acknowledgements

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