Climate change impacts on woodland biomass C density and water-use: a modelling study of the Sudanese Gum Belt region

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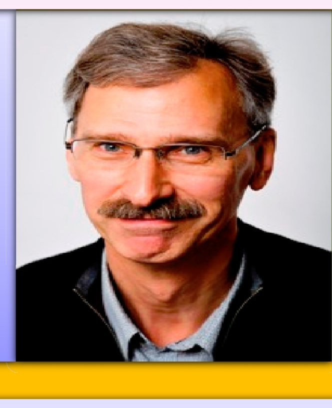

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Introduction

In the Sudan drylands, including savannah woodlands, cover 1.9 million km² and much of it lies within an area commonly known as the Gum Belt (10-16° N), where the bulk of gum producing *Acacias* grow. Mean annual precipitation (MAP) ranges from 300 mm in the north of the Gum Belt to 800 mm in the south. The relationship between biomass and water-use is critical, especially in water-limited environments, to understanding how dryland ecosystems function and how they may respond to climate change. Previous climate change studies in the Sudan have dealt with changing patterns in rainfall and temperature, impacts of rainfall change on hydrology and water-supply, particularly that of the Blue Nile. However, the impact of climate change on savannah woodlands, particularly in relation to biomass and water-use, remains unclear.

Objectives

The overall aim of our study is to assess the impact of various climate change scenarios on biomass and evapotranspiration of savannah woodlands across the Sudanese Gum Belt region. Specific objectives of this study were to:

1) construct baseline (1961-90) climate and various climate change scenarios for the 2080s (2070-2099)
2) predict the biomass C density under baseline climate and climate change scenarios using a relationship between woodland biomass C density and MAP, and
3) estimate annual actual evapotranspiration (AET, water-use) under baseline climate and the various climate change scenarios using a water balance model.

Material and methods

Eight study grids (1:250,000; 1.0° lat. x 1.5° long.; Fig. 1) covering semi-arid grassland and savannah woodland were selected from the Gum Belt region.

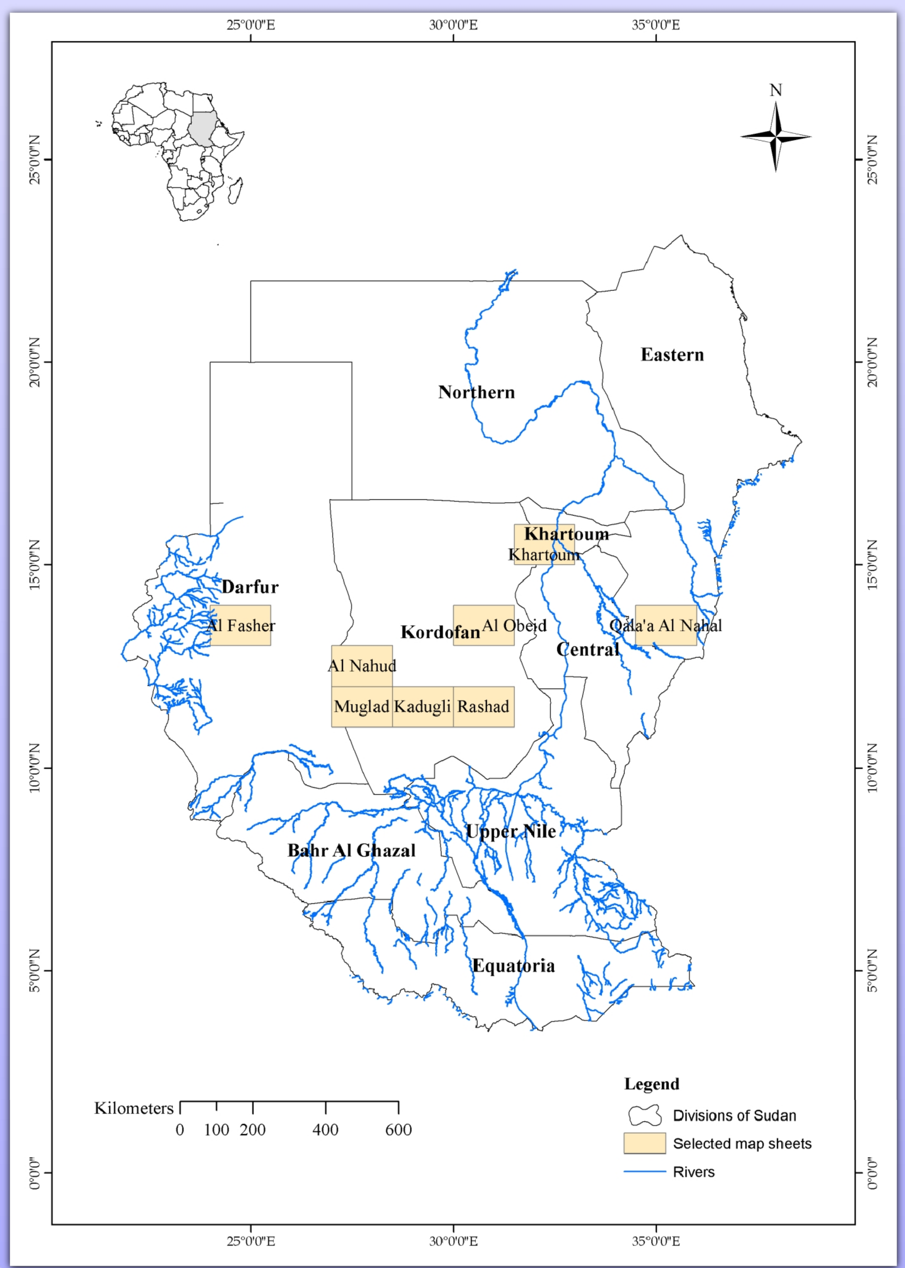

Figure 1. Map of Sudan showing administrative divisions (in bold letters) and the eight map sheets (1.0° latitude x 1.5° longitude) utilized in the study.

Monthly baseline (1961-1990) and climate change scenario data (2070-2099) for the study region were taken from the University of East Anglia (UEA) Climate Research Unit (CRU TS 2.1) and UEA Tyndall Centre for Climate Change Research (TYN SC 2.03), respectively. Climate change scenarios for the 2080s were constructed from five GCMs (CGCM2, CSIRO2, ECHam4, HadCM3, PCM) and the effects of two SRES emission scenarios (A1FI and B1). The climate data are available in 0.5° x 0.5° grids for the entire globe.

Data (temperature, precipitation and cloud cover) for the 48 0.5° x 0.5° grids corresponding to our eight 1° x 1.5° map sheets were extracted. Ten climate change scenario data sets corresponding to the combinations of the five GCMs and two SRES emission scenarios were formed. The data for the TYN/CRU grids corresponding to each of our eight map sheets were then averaged.

Using an exponential relationship (Fig. 2) between biomass C density and rainfall ($y = 6.798^{0.0054x}$, $R^2 = 70\%$), climate change scenario based biomass C densities (g C m^{-2}) were estimated. A water balance model, WATBAL, was parameterized for woodland vegetation and two soil types, arenosols (AR) and vertisols (VR) using Harmonized World Soil Database soil data, to give monthly AET (mm) values for the baseline data and each climate change scenario dataset.

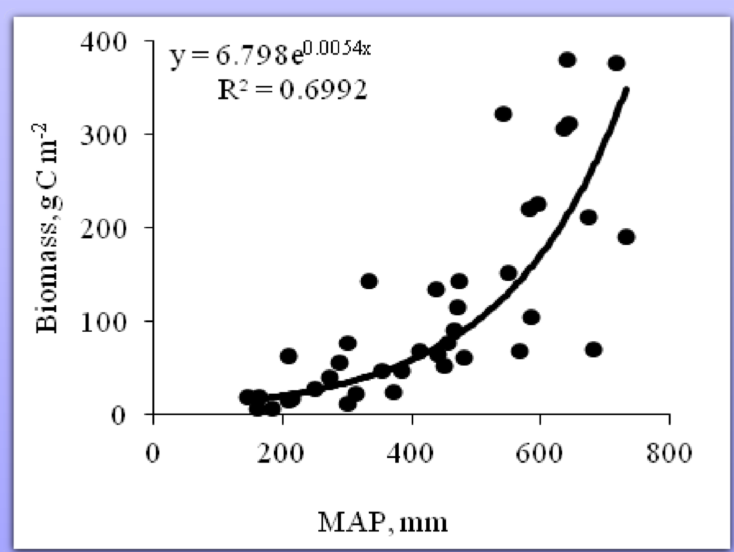

Figure 2. Relationship between map sheet mean (n = 39) above-ground biomass C density and long-term MAP (Alam et al., 2011), used in this study to estimate climate change scenario based biomass C densities.

Results

Baseline (1961-90) climate , biomass C density and AET

Baseline values of MAP, mean annual temperature (MAT), biomass C density and AET for the eight study map sheets were given in Table 1. MAP ranged from 140 to 654 mm and MAT from 23.3 to 29.1 °C. Mean biomass C densities varied between 14 and 232 g C m^{-2}. Annual AET varied from 140 to 595 mm for VR soil type while that of for AR soil type ranged between 140 and 464 mm.

Table 1. Map sheet wise baseline (1961-90) values for MAP, MAT, biomass C density and AET

Map sheet	MAP, mm	MAT, °C	Biomass, g C m^{-2}	AET, mm	
				AR	VR
Al Fasher	386	23.3	55	338	384
Al Nahud[a]	368	27.2	49	332	-
Al Obeid	264	28.1	28	256	263
Kadugli	598	27.1	171	456	564
Khartoum	140	29.1	14	140	140
Muglad	506	27.6	105	390	501
Qala'a Al Nahal[b]	603	28.8	177	-	497
Rashad	654	27.3	232	464	595

[a]Al Nahud map sheet only has AR soil type
[b]Qala'a Al Nahal map sheet only has VR soil type

Climate change scenario (2080s) based biomass C density and AET

Climate change scenario based estimates showed that MAP will either increase or decrease but MAT will increase only. In case of increase, MAP will vary from +112 to +221 mm and while in the case of decrease, it will vary from -13 to -188 mm. MAT will increase from +1.2 to +8.3 °C.

ECHam4_A1FI and CGCM2_A1FI combinations generated highest increasing and decreasing scenarios of MAP, respectively while, ECHam4_A1FI and PCM_B1 combinations generated highest and lowest increasing scenarios of MAT, respectively (Fig. 3).

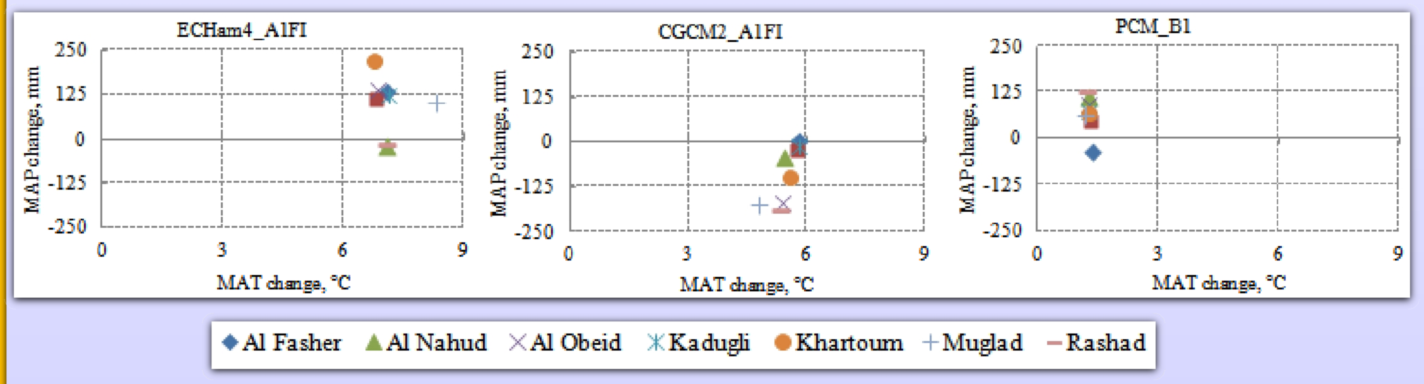

Figure 3. MAP and MAT changes in 2080s in comparison with baseline scenario, 1961-90

Likewise MAP, climate change scenario based biomass C densities will either increase or decrease. Increasing values will vary between +14 and +241 g C m^{-2}, while decreasing values will vary from -1 to -148 g C m^{-2}. ECHam4_A1FI and CGCM2_A1FI combinations generated highest increasing and decreasing scenarios, respectively (Fig. 4).

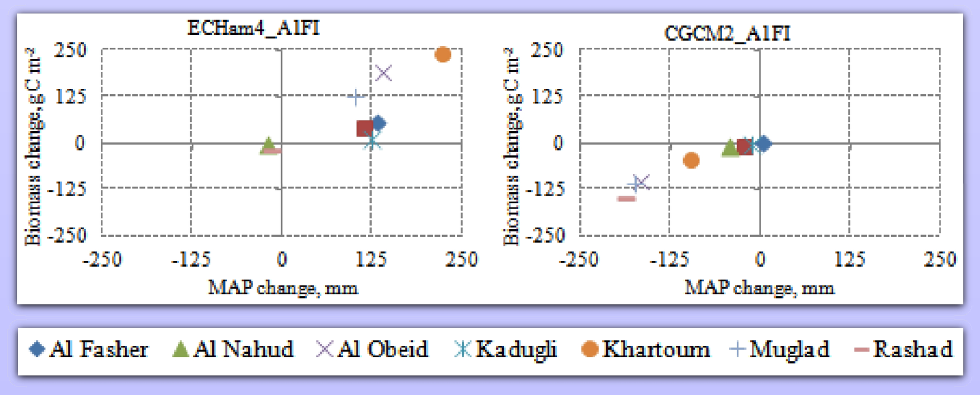

Figure 4. Biomass C density and MAP changes in 2080s in comparison with baseline scenario, 1961-1990

Similarly, AET of VR and AR soil types will either increase or decrease. For VR soil type, increasing values of AET will vary from 100 to 145 mm while that of decreasing values will vary from -12 to -178 mm. ECHam4_A1FI and PCM_A1FI combinations generated highest increasing and decreasing values for AET, respectively (Fig. 5a). For AR soil type, increasing values of AET will vary from 82 to 197 mm while that of decreasing values will vary from -12 to -132 mm. PCM_B1 and PCM_A1FI combinations generated highest increasing and decreasing values for AET, respectively (Fig. 5b).

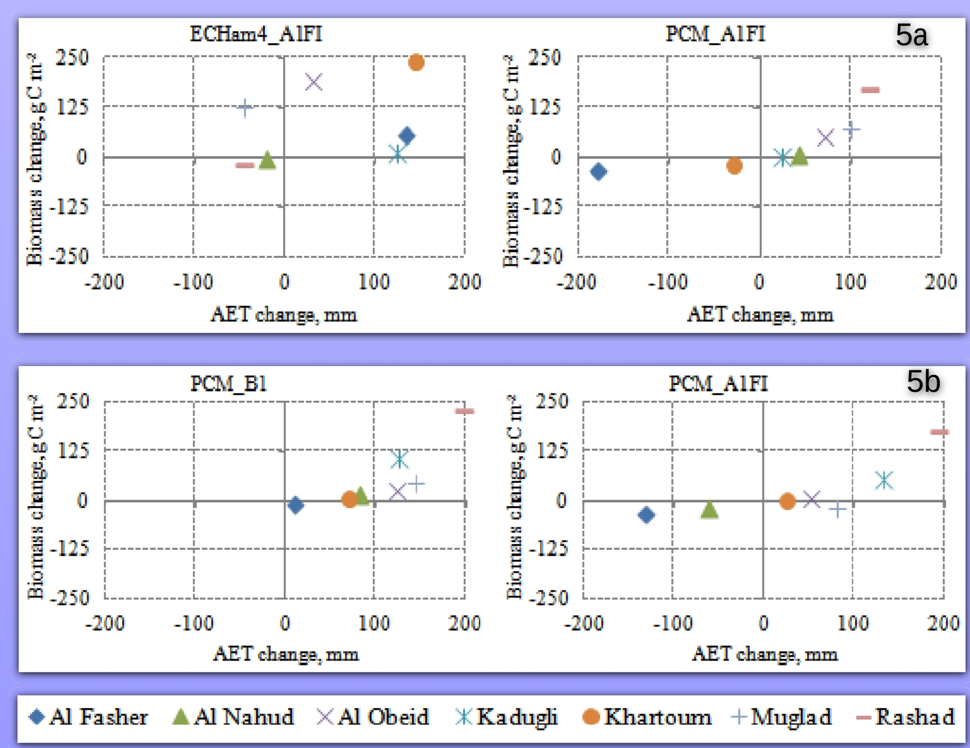

Figure 5. Biomass C density and AET changes in 2080s of VR (5a) and AR (5b) soil types in comparison with baseline scenario, 1961-1990.

Conclusions

Our results indicate that C sequestration and water-use of woodlands in Sudanese Gum Belt region will strongly depend on the degree and nature of climate change. 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. Compared to AR soils, VR soils had equal or greater water-use. To our knowledge, this is the first such regional scale climate change impacts study on the biomass and evapotranspiration of savannah woodlands in Africa.

Reference

Alam, S.A., Starr, M., Clark, B.J.F., 2011. Tree biomass and soil organic carbon densities across the Sudanese woodland savannah: a regional carbon sequestration study. Manuscript submitted for publication.