2012 International Conference on Environmental, Biomedical and Biotechnology
IPCBEE vol.41 (2012) © (2012) IACSIT Press, Singapore

Modeling Climate Change Impact in the Geba Basin, Ethiopia

Haddush Goitom[1,2], Florimond De Smedt[1], Tesfamicheal G.Yohannes[3], Kristine Walraevens[4], Kindeya Gebrehiwot[5], Hans Bauer[6], Jozef Deckers[6]

[1] Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Brussels, Belgium
[2] Department of Civil Engineering, Mekelle University, Mekelle, Ethiopia
[3] Department of Earth Sciences, Mekelle University, Mekelle, Ethiopia
[4] Department of Geology and Soil Science, Ghent University, Ghent, Belgium
[5] Department of Land Resources Management and Environmental protection, Mekelle University, Ethiopia
[6] Department of Earth and Environmental Sciences, K.U.Leuven, B-3001 Heverlee, Belgium

Abstract. This study investigates potential climate change impact on river flow in the Geba basin in northern Ethiopia. Application of a spatially distributed hydrological model with downscaled climate prediction data reveals that river flow will significantly reduce in the future, likely leading to increased water stress in the forthcoming decades.

Keywords: Climate change, Hydrological modeling, WetSpa, River flow, Geba basin.

1. Introduction

Semi-arid and arid areas are particularly vulnerable to climate change and are projected to suffer a decrease in water resources due to reduced precipitation expected over the next century, e.g. [1] [2] [3] [4] [5] [6]. The purpose of this study is to assess the impact of climate change on river flow in the Geba River, Northern Ethiopia. The Geba River is a major tributary of the Tekeze (Atsbara) River, which is a tributary of the Nile. The basin is mountainous with rugged topography and elevation ranging from 945 m to 3293 m. Figure 1 shows the Geba basin with topography and the locations of meteorological and flow gauging stations. The basin has a total area of 5150 km^2. The Kiremt season is the main rainy season from June to September and the Bega season is the dry season from October to May. The basin is characterized by a high water stress and recurrent droughts, as the annual precipitation is only about 600 mm.

Data sets used in this study are: daily precipitation and potential evapotranspiration (PET) at Quiha (Mekelle airport) from 1961 to 1990 and daily precipitation and PET from 1999 to 2006 in 11 meteorological stations obtained from the Ethiopian National Meteorological Agency (ENMA); observed river flows at Adikumtsi gauging station from 1999 to 2006 obtained from the Hydrology department of the Ministry of Water and Energy (MoWE), Ethiopia; HadCM3 (Hadley Centre Coupled Model, version 3) general circulation model predictor variables from 1961 to 2099, downloaded from the Canadian Institute for Climate Studies (http://www.cics.uvic.ca/scenarios/sdsm/select.cgi); digital maps of river basin characteristics, i.e. a digital elevation model (DEM) of 90 m grid size obtained from the Shuttle Radar Topography Mission (SRTM) dataset of the National Aeronautics and Space Administration (NASA), a land use map derived from 30 m grid size Landsat-7 Enhanced Thematic Mapper (ETM+) satellite data of January 27 and February 5, 2000, and soil map data obtained from the Soil and Terrain Database for north-eastern Africa CD-ROM, Food and Agriculture Organization of the United Nations [7].

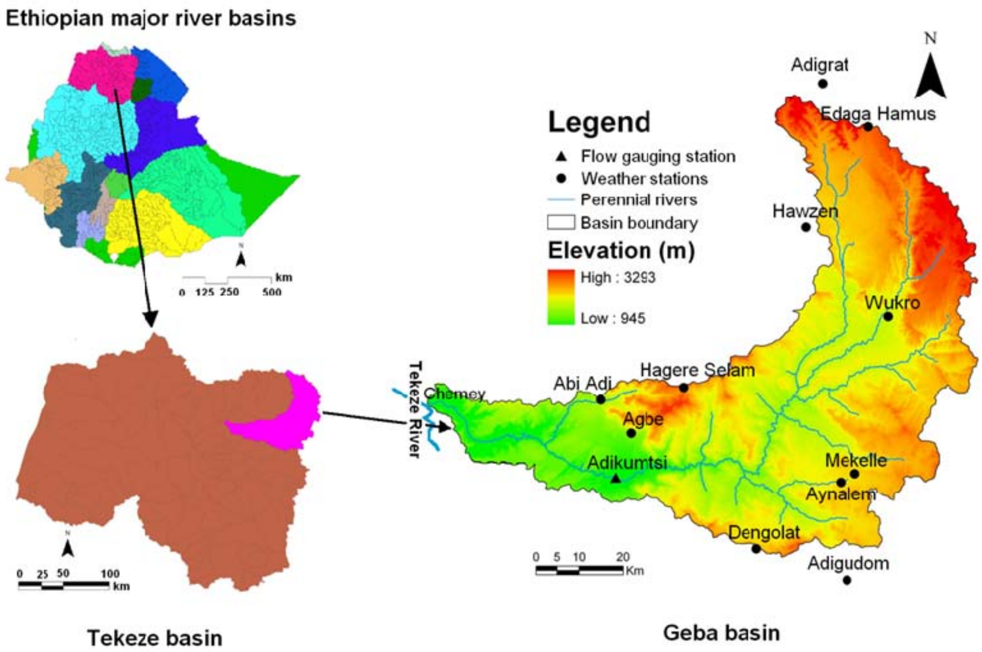

Fig. 1: Map of the Geba basin with topography and locations of meteorological and river flow gauging stations.

2. Methodology

The prediction of future climate scenarios involves two steps: (i) downscaling of regional climate data using SDSM version 4.2 (statistical downscaling model) [8] [9] [10], which involves the selection of climate predictor variables which are best correlated with the observed local daily precipitation and temperature series at Quiha (Mekelle airport) for the baseline period 1961-1990, and (ii) scenario generation, i.e. predictions using the HadCM3 data predictors selected by downscaling to obtain synthetic precipitation and temperature time series for three future time periods (2010–2039, 2040–2069 and 2070–2099) and two climate scenarios A2 (large population and regionally oriented economic development) and B2 (less population growth and local economical development) [11] [12].

Flows in the Geba basin for present and future periods are simulated with WetSpa (Water and energy transfer in soil, plants and atmosphere) [13] [14]. The model has been widely applied for climate change impact on river flow, e.g. [1] [15] [16]. The model is calibrated for the Geba basin by comparing predicted and observed flows from 1999 to 2004. Figure 2 shows observed and simulated daily river flows, indicating that the model predictions are fairly accurate.

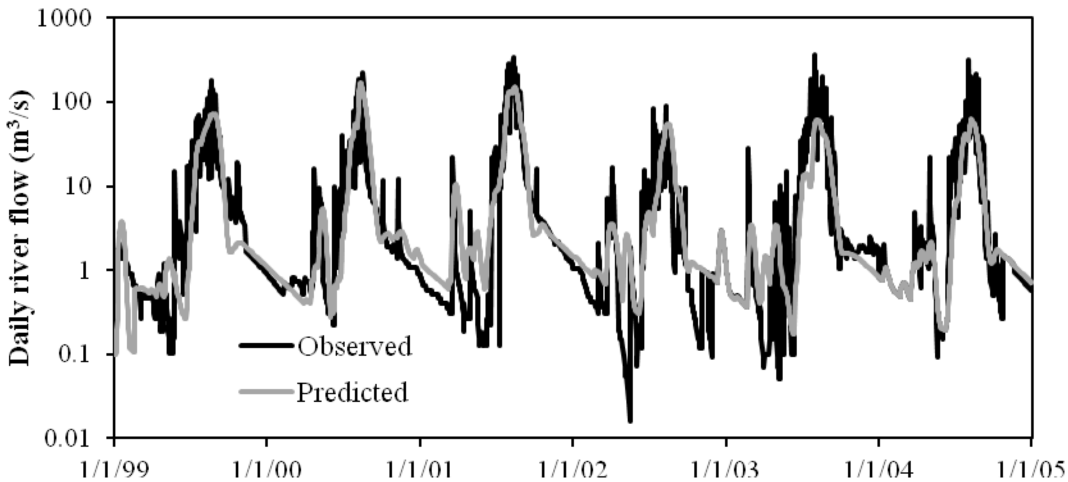

Fig. 2: Observed and predicted river flow in the Geba River.

3. Results and Discussion

Figure 3 shows the predicted daily mean precipitation and PET in each month for the A2 and B2 climate scenarios. Both scenarios reveal that the precipitation will experience a decreasing trend in the future, with an overall annual change in precipitation of -0.21 mm/d, -0.38 mm/d and -0.59 mm/d for the A2 scenario, and -0.03 mm/d, -0.21 mm/d and -0.50 mm/d for the B2 scenario in the 2020s, 2050s and 2080s, respectively. PET is predicted to increase by 0.17 mm/d, 0.36 mm/d and 0.61 mm/d for the A2 scenario, and by 0.07 mm/d, 0.10 mm/d and 0.17 mm/d for the B2 scenario in the 2020s, 2050s and 2080s, respectively. The decrease in precipitation and increase in PET will be predominantly significant in the Kiremt season, while there may be less difference in precipitation or PET in the Bega season. As Kiremt is the only cropping season in the northern part of Ethiopia, these results imply a very severe impact of climate change on rain-fed agriculture and natural vegetation.

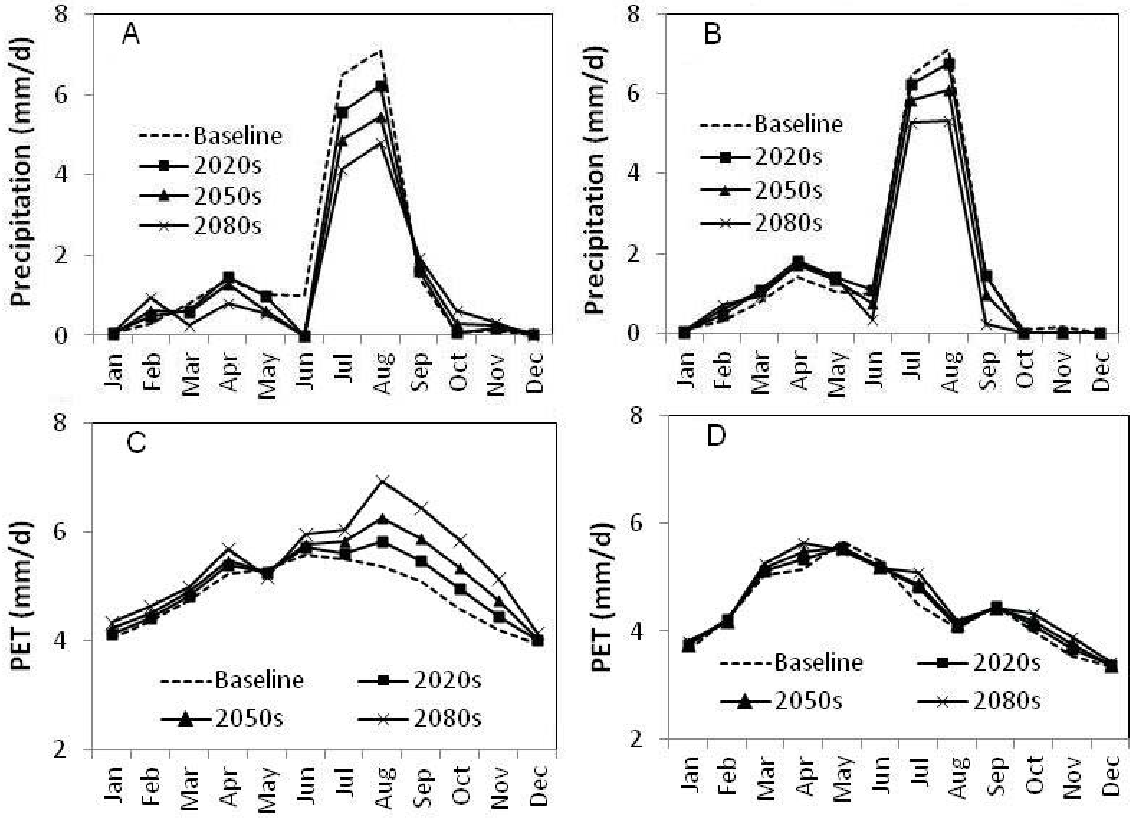

Fig. 3: Predicted daily mean precipitation and PET in each month: (a,b) precipitation and (c,d) PET for the A2 and B2 climate change scenarios, respectively.

The projected effect of climate change in daily mean river flow in each month between the future and baseline periods for the A2 and B2 climate scenarios simulated with the WetSpa model is given in Figure 4, and shows that there will be a significant decrease in river flow for both climate scenarios. The overall annual reduction in river flow account for 23.1%, 35.8% and 50.2% of the present river flow for the A2 climate scenario and for 26.1%, 36.6% and 42.7% for the B2 climate scenario in the 2020s, 2050s and 2080s, respectively. Reduction in stream flow due to climate change has been confirmed by other studies in the region (e.g. [2], [17], [18]) and is attributable to the decrease in precipitation and increase in PET.

Table 1 gives the projected effect of climate change on mean seasonal and annual river flow. The seasonal predictions show that there will be a substantial decrease in the Geba river flow in the Kiremt season, while the decrease in the Bega season is much less. The decrease of the Kiremt season streamflow accounts for 40% to 76% of the mean Kiremt flow in the baseline period for the A2 climate scenario, and for 43% to 69% for the B2 climate scenario. As surface water harvesting for irrigation has been considered as an aid to rain-fed agriculture, present results show that this will become more and more difficult to achieve in the future.

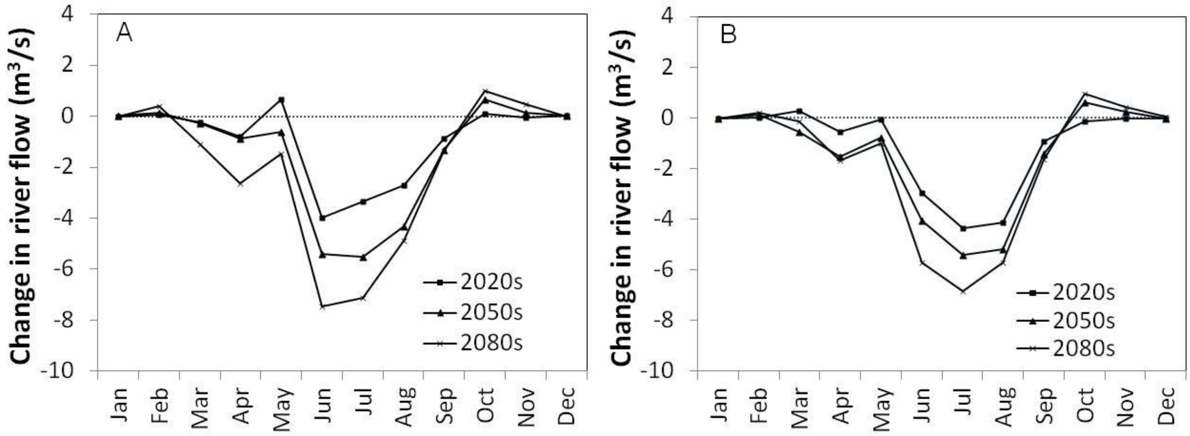

Fig. 4: Predicted changes in daily river flow: (a) for the A2 climate scenario, and (b) for the B2 climate scenario.

Table 1: Predicted future change in river flow (m^3/s) in the Geba basin.

Period	A2 climate scenario			B2 climate scenario		
	2020s	2050s	2080s	2020s	2050s	2080s
Kiremt (June-Sep)	-2.72	-4.14	-5.21	-3.10	-4.02	-4.97
Bega (Oct-May)	-0.04	-0.09	-0.43	-0.06	-0.24	-0.14
Annual	-0.93	-1.44	-2.02	-1.07	-1.50	-1.75

4. Conclusions

The climate change predictions indicate that overall precipitation will decrease and PET will increase, especially in the Kiremt season. This will lead to a decrease in river flow by as much as 50% for the A2 climate scenario and by 43% for the B2 climate scenario. The reduction in river flow is more pronounced in the Kiremt season. Because natural vegetation and rain-fed agriculture strongly depend on the Kiremt season, it can be concluded that the climate change impact may be severe. Very likely this will lead to increased water stress in the forthcoming decades. This study suggests that the northern highlands of Ethiopia become even more susceptible to severe drought conditions as is already the case at present.

5. Acknowledgements

The study is carried under the collaboration project VLIR Institutional University Co-operation (IUC) Programme between the Universities of Flanders, Belgium, and Mekelle University, Ethiopia supported by the Flemish Interuniversity Council and the Belgian government. Authors would like to thank the Ministry of Water resources and Ethiopian Meteorological Agency for the data provided and used in this study. The authors also would like to thank the U.K. Meteorological Office, Hadley Center, and the Canadian climate research data distribution centre for providing data and software used in this study.

6. References

[1] M. Tavakoli and F. De Smedt. Impact of climate change on streamflow and soil moisture in the Vermilion basin, Illinois, USA, (ASCE), 2011. doi: 10.1061/(ASCE)HE.1943-5584.0000546

[2] S. G. Setegn, D. Rayner, A. M. Melesse, B. Dargahi, and R. Srinivasan . Impact of climate change on the hydroclimatology of Lake Tana Basin, Ethiopia, Water Resour. Res., 2011, 47, W04511, doi:10.1029/2010WR009248.

[3] F.H.S. Chiew, W.J. Young, W. Cai, and J. Teng. Current drought and future hydroclimate projections in southeast Australia and implications for water resources management. Stochastic Environmental Research and Risk Assessment, 2010, 25: 602-612

[4] D.L. Ficklin, Y. Luo, E. Luedeling, S.E. Gatzke, M. Zhang. Sensitivity of agricultural runoff to rising levels of

CO2 and climate change in the San Joaquin Valley watershed of California. Environmental Pollution 2009b, 158: 223–234.

[5] B.C. Bates, Z.W. Kundzewicz, S. Wu and J.P. Palutikof (Eds.). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 2008, pp 210.

[6] Y.N. Chen, K. Takeuchi, C.C. Xu, Y.P. Chen, Z.X. Xu. Regional climate change and its effects on river runoff in the Tarim Basin China.Hydrological Processes, 2006, 20: 2207–2216.

[7] FAO, ISRIC and ISSS. World reference base for soil resources; Food and Agricultural Organization of the United Nations. World soil resources report 84. Rome, Italy, 1998.

[8] A. Anandhi, V.V. Srinivas, R.S. Nanjundiah, and D.N. Kumar. Downscaling precipitation to river basin in India for IPCC SRES scenarios using support vector machine. International Journal of Climatology, 2008, 28: 401-420

[9] L.R. Wilby and C.W. Dawson. SDSM 4.2 — A decision support tool for the assessment of regional climate change impacts. Version 4.2 User Manual, UK, 2007, pp94.

[10] L.R. Wilby, E. Zorita, B. Timbal, P. Whetton, L.O. Mearns, S.P. Charles. "Guidelines for use of climate scenario developed from statistical downscaling methods." Environmental Agency of England and Wales, UK, 2004, pp27.

[11] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA, 2007.

[12] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (ed. by J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell & C.A. Johnson). Cambridge University Press, Cambridge, UK and New York, NY, USA, 2001, pp881.

[13] Y. Liu, F. De Smedt. WetSpa Extension, Documentation and User Manual. Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Belgium, 2004, pp108.

[14] Z.M. Wang, O. Batelaan & F. De Smedt. A distributed model for water and energy transfer between soil, plants and atmosphere (WetSpa), Phys. Chem. Earth, 1996, 21(3):189-193.

[15] P. M. Nyenje & O. Batelaan. Estimating the effects of climate change on groundwater recharge and baseflow in the upper Ssezibwa catchment, Uganda, Hydrological Sciences–Journal–des Sciences Hydrologiques, 2009, **54**(4): 713-726.

[16] R. Nurmohamed, S. Naipa, and F. De Smedt. Modeling hydrological response of the Upper Suriname river basin to climate change, Journal of Spatial Hydrology, 2007, **7**(1): 1-22

[17] G. Yilma, A. Jonoski, and A. Van Griensven. Hydrological Response to Climate change in the Upper Beles river Basin, Upper Blue Nile, Ethiopia. Nile Basin Water Engineering Scientific Magazine, 2009, Vol2: 49-59.

[18] D. Legesse, C. Vallet-Coulomb and F. Gasse. Hydrological response of a catchment to climate and land use changes in Tropical Africa: a case study South Central Ethiopia, Journal of Hydrology, 2003, **275**(2003): 67-85.