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Comparison of different statistical downscaling methods for climate change rainfall projections over the Lake Victoria basin considering CMIP3 and CMIP5

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Abstract

In this study, outputs of three statistical downscaling (SD) methods including the change factor (Delta), simplified (simQP) and advanced (wetQP) quantile-perturbation-based approaches were compared based on daily rainfall series at 9 meteorological stations in the Lake Victoria basin (LVB) in Eastern Africa. The comparison was made considering phase 5 and phase 3 of the Coupled Model Inter-comparison Project, i.e. CMIP5 and CMIP3 respectively. For the CMIP5 (CMIP3) at each station, there were a total of 7 (14) GCMs, 18 (20) daily historical (control) simulations over the period 1961–2000, and 35 (49) daily future projection series of the periods 2050s and 2090s. The ensemble mean of the GCMs' *Bias* in reproducing rainfall extremes for return periods in the range of 1 to 40 years for the CMIP5 (CMIP3) varied from −19.05% to 3.11% (−65.85% to −4.86%). For the high greenhouse gas scenario rcp8.5 (A2) of the CMIP5 (CMIP3), the ensemble mean of the projected changes over the LVB in the 10-year rainfall intensity quantile obtained from the Delta, simQP, wetQP SD goes up to 5.8, 10 and 22.4% (11.7, 15.9 and 43.6%) in the 2050s and 8, 11.4, and 25.4% (14.2, 23.3 and 40.6%) in the 2090s. Rainfall totals of the main wet (dry) season are generally projected to increase (decrease) in both the 2050s and 2090s. Because the outputs from the three SD methods captured well the pattern of monthly rainfall totals, the difference between the projected changes of seasonal or annual rainfall totals from the Delta, simQP and wetQP was shown to be insignificant. However, the differences in the results from the Delta, simQP and wetQP methods with respect to the projections of rainfall quantiles indicate that the choice of the SD method can be made on a case by case basis in line with the objectives of the climate change impact study, e.g. the Delta does not capture well the changes in rainfall extremes, whereas the wetQP is suitable for both rainfall extremes and rainfall totals at both seasonal and annual time scales. The findings of this study also show the need to consider evaluations of the inter-GCM differences in the LVB as a data scarce region in assessing the discernible impact of climate change on rainfall extremes and/totals for decision making related to water resources management and engineering.

Keywords: Climate change; Statistical downscaling; GCMs; CMIP3 versus CMIP5; Rainfall; Lake Victoria basin

1. Introduction

Planning, design and operation of a number of water engineering applications including water supply projects (e.g. dikes, dams, irrigation systems) or urban drainage facilities such as sewer conduits, etc., require statistics of rainfall intensity quantiles and/or totals. The challenge that the contemporary water managers are faced with in their decision making is debatably the impact of climate change on the hydrometeorology. The hypothesized impact of global warming has seized an immense portion of the international attention directed toward investigating the effect of climate change on water resources. Examples of some recent climate change

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impact studies include Artlert et al. (2013), Fathelrahman et al. (2014), Lee et al. (2014), and Nkomozepi and Chung (2014). Changes in rainfall is a critical factor, among other hydro-climatological variables, to determine the influence of the climate system on hydrology in support of water resources management in a regional attempt to adapt to climate change impacts. Changes in climate extremes and their impacts on the natural physical environment were examined by the Intergovernmental Panel on Climate Change, IPCC (2012). The need to consider changes in climate conditions was also emphasized in the fifth Assessment Report (AR5) of the IPCC (2013).

A number of studies have shown that climate change will have a considerable impact on the water resources. This is also the case for the Nile basin (which has its key source of drainage from the Lake Victoria basin (LVB)) as shown by, among others, Beyene et al. (2010), Conway and Hulme (1996), Githui et al. (2009), Nyeko-Ogiramoi et al. (2010), Taye et al. (2011), and Tungaraz et al. (2012). Many of the above cited references show significant bias in the General Circulation Models (GCM) results of the Coupled Model Inter-comparison Project (CMIP), especially of the previous generation, i.e. phase 3 (CMIP3). However, due to improvements in the GCMs, a reduction in their bias was expected in the recently released phase 5 (CMIP5). The performance of the GCMs from the CMIP5 to reproduce the rainfall over the Lake Victoria was recently assessed by Akurut et al. (2014). Such study (with limited focus rather on the Lake Victoria than the entire basin, i.e. LVB) is, with respect to the lake outflow, important for hydropower operations and planning, e.g. for Owen Falls Dam, and abstraction, say, for irrigation. Considering the entire LVB as done in this study is vital for agricultural practices and risk-based water engineering management. Despite the need for climate change impact assessment in the study area, the issue of data quality as reflected in the uncertainty analyses (see e.g. Kizza et al., 2011; Onyutha and Willems, 2013; Onyutha and Willems, 2015a) cannot be ignored despite some remedial attempts to deal with it, for instance by Nyeko-Ogiramoi et al. (2012a), Kizza et al. (2013) and Onyutha and Willems (2015b). Questionable data quality is one reason for the bias in the GCMs to reproduce rainfall. This, with respect to rainfall intensity extremes and totals, highlights the need for an insight into amount by which the GCMs of the CMIP5 were improved compared with those of the CMIP3 to capture the typical conditions of data scarcity and/or questionable data quality of the LVB. Although comparison between the CMIP3 and CMIP5 for rainfall projections was recently made on a global scale by Kumar et al. (2014), by the time of this study, no such attempts at the level of catchment or basin especially for the study area could be found in literature.

Because significant bias in the GCM results may be valid as well for the future projections, it makes them inappropriate for direct use in climate change impact assessment at local scale. Eventually, downscaling and/or bias correction is first required before impact analysis of climate change is done. Despite the general assumption that the major sources of uncertainty are linked to the GCMs and Greenhouse Gases Emissions Scenarios (GGES) (Chen et al., 2011), other sources exist such as the statistical method applied to transfer the climate change signal obtained from the GCM results to the local, case-specific impacts. This transfer is commonly done using the statistical downscaling (SD). The influence of the SD methods on climate change impact analysis was investigated before by Chen et al. (2011), Ghosh and Katkar (2012), Khan et al. (2006), Prudhomme and Davies (2009), Quintana-Segui et al. (2010), etc. Some studies, e.g. Prudhomme and Davies (2009), demonstrated that uncertainties from GCMs are larger than those from the downscaling methods and GGES. In the impact assessment of climate change on rainfall extremes in the LVB, the uncertainties stemming from the inter-GCM differences, and those due to the choice of the SD method cannot be ignored. The main SD methods used to project climate changes on hydro-meteorological variables in the study area include the change factor (Delta) and quantile-based perturbation approaches. Just to mention some few examples for the LVB, the Delta method was used by Dessu and Melesse (2013), and the quantile-based SD was applied by Akurut et al. (2014), and Nyeko-Ogiramoi et al. (2012b). According to Melesse et al. (2011), one of the main causes of food insecurity and the most daunting challenge the entire Nile Basin (where LVB is located) faces is the subsistence and rain-fed agriculture, together with high rainfall variability. This problem in the LVB is exacerbated by severe damage to public life and property inflicted by extreme rainfalls and associated flooding events, for instance, downstream of Nzoia River and Nyando River, and around the Budalang'i and Kano plains. These problems altogether mean that for appropriate regional planning of adaptation measures for the climate change impacts with respect to agriculture and risk-based water management, it is important to consider both seasonal or annual rainfall volumes and the extreme events. It is known, as will also be shown in this study that, the Delta method is suitable for changes in the mean of rainfall, and the quantile-based perturbation approach is commendable for extreme events. However, in each of the previous climate change studies for the LVB, projections of rainfall were made either based on only the Delta method (Dessu and Melesse, 2013) or the quantile-based perturbation approach (Akurut et al., 2014; Nyeko-Ogiramoi et al., 2012b) but not using both methods. In this study, both SD methods were used to provide findings to incorporate impacts of climate change in both agricultural practices and risk-based water management. The difference, if any, among the SD methods indicate the need to assess influence due to the choice of the particular downscaling approach on the projections of the hydro-meteorological variables.

This study, therefore with respect to the insights into the uncertainty in the climate change projections of rainfalls across the LVB, was aimed at: 1) assessing the influence of the SD methods on the projections of rainfall extremes as well as annual and seasonal totals, and 2) comparatively performing consistency check of the CMIP3 and CMIP5 GCMs in reproducing historical conditions of rainfall extremes and totals.

2. Study area and data series

2.1. Study area

The LVB, which has a total catchment area of about 184,000 km^2, stretches 355 km in east–west direction (31°37′E