A Critical Discussion of Recent Studies Evaluating the Impacts of Climate Change on Water Resources in the Nile basin

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Abstract

This note provides a concise presentation of the state-of-the-art methods to assess climate change impacts on water systems with reference to the Nile basin. In particular, recent studies dealing with climate change in the Nile basin are summarized and guidelines for dealing with uncertainty in planning water resources in a changing climate are illustrated. The paper also includes potential strategy recommendations to policy and decision makers for planning adaptation measures in the water sector. In particular, the need to better recognize and characterize the uncertainty of climate change impacts on the hydrology of the Nile basin as well as the necessity to effectively support decision-makers and propose adaptation strategies and measures are discussed.

Key Words: Nile, Climate Change, Hydrology, Water Resources, Uncertainty, Decision Makers.

1. INTRODUCTION

In recent years, a large part of the scientific community has made efforts analyzing the impact of climate change on water resources and proposing adaptation strategies. The usual framework of this type of studies can be summarized as follow (Hadley Centre, 2001): a) choice of one or more scenarios of the IPCC (Intergovernmental Panel on Climate Change) special report on emission scenarios (Bates et al., 2008), which depend on the future economy and energy use policies; b) choice of one or more Global Circulation Models (GCM); c) downscaling of the GCM output to the specific river basin scale; d) use of the downscaled GCM outputs as inputs for a hydrological model; and e) analysis of hydrological model results by comparing them to the corresponding results related to the current climate or different possible future climates. This approach has become very popular as it potentially allows the quantification of changes in floods, flow duration curves, and whatever aspect of the hydrological cycle (e.g. Blöschl and Montanari, 2010).

In this context, a number of studies analyzed the impact of climate change on the hydrology of the River Nile Basin (RNB). In fact, the RNB could be vulnerable to water stress under climate change because of the limited water availability and the increasing demand for water from different sectors (Bates et al., 2008; Di Baldassarre et al., 2011). Regarding the Nile water resources, Conway (2005) found that there is no clear indication of how River Nile flow would be affected by climate change, because of the uncertainty in projected rainfall patterns in the basin and the influence of complex water management (and water governance structures). More recently, Githui et al. (2008) used a technique of adjustment of historical time series to project GCM impacts on flood risks in the Nzoia River, a tributary of the Lake Victoria. In addition, Elshamy et al. (2009a) analyzed climate change effects on the main Nile at Dongola and the Blue Nile at Diem, respectively, using a spatio-temporal statistical downscaling technique for various GCMs and showed varying trends depending on the GCM used. Elshamy et al. (2009b) used a statistical bias-correction technique to downscale outputs from a larger number of GCMs to assess the impacts of climate change on the upper Blue Nile at Diem with even larger varying trends.

This paper briefly summarizes the most recent findings coming out from research and capacity building activities dealing with the impact of global change on the water resources of the River Nile Basin (RNB) by referring to the lessons learned from the project ACCION (Adaptation to climate change impact on the Nile basin) funded by UPaRF (UNESCO-IHE Partnership Research Fund) and its links to other initiatives and projects in the Nile region, such as NBCBN (Nile Basin Capacity Building Network), NBI (Nile Basin Initiative), and the UNESCO FRIEND/Nile.

In particular, this paper: i) provides a concise, presentation of the state-of-the-art methods to evaluate climate impacts on water systems; ii) summarizes recent studies dealing with climate change in the RNB; iii) includes guidelines for dealing with uncertainty in planning water resources in a changing climate; and iv) indicates potential strategy recommendations to policy and decision makers for planning adaptation measures in the water sector. This note focuses on the need to better recognize and characterize the uncertainty of climate change impacts on the hydrology of the RNB as well as the necessity to effectively support decision-makers and propose adaptation strategies and measures.

2. CLIMATE CHANGE - POTENTIAL IMPACTS

This section illustrates two potential climate change impacts that are of serious concern. The first one is that sea-level rise might impact the Nile Delta and consequently affecting the livelihood of its inhabitants the people living in the delta and as well as other coastal areas. To illustrate the potential impact of sea level rise on the Nile Delta, Figure 1 shows the potential increase of exposure to coastal flooding related to sea level rise.

It should be noted that Figure 1 was derived by following a simplified approach, based on the use of SRTM (Shuttle Radar Topography Mission) topography with the only scope to illustrate the potential increase of exposure to coastal flooding related to sea level rise without considering associated impacts or existing protection. Thus, the map of Figure 1 should be taken with extreme caution because of the low accuracy of the SRTM topography and the fact that embankments were not considered.

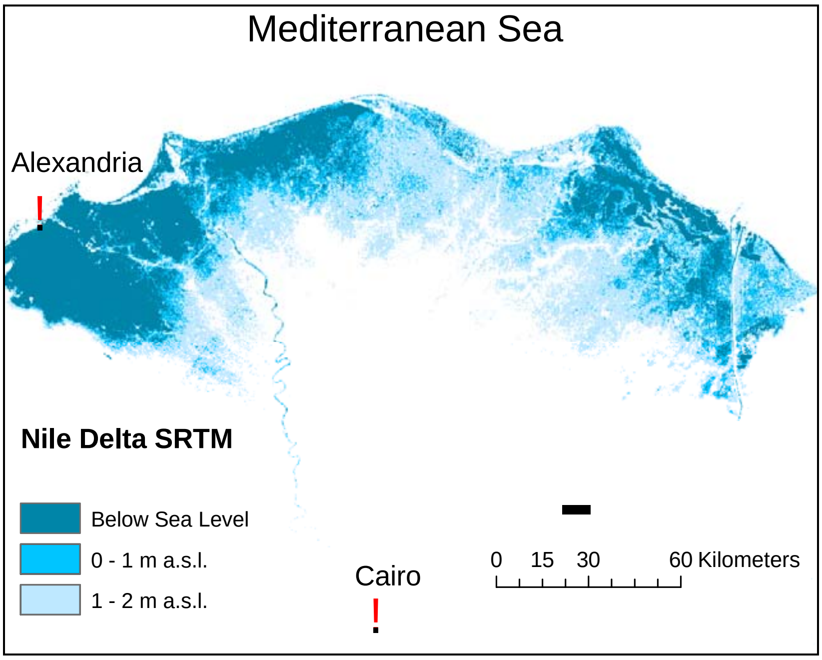

Figure 1. Potential impacts of sea level rise on the Nile Delta, Egypt. The SRTM topography is classified to show the regions that are currently below sea level rise, and the territories that might be potentially flooded by sea level rise.

Anyhow, Hereher (2010) investigated the vulnerability of the Nile Delta with more elaborated techniques and pointed out that sea level rise might seriously affect the Nile Delta as it would lead to shoreline erosion, contamination of lagoons, deterioration of water quality, and inundation of many valuable and productive agricultural lands. Also, sea level rise and current abstraction of groundwater might increase sea water intrusion. This might become a serious issue and pose very difficult situations for local agriculture who heavily depend on shallow groundwater.

Another concern on the Nile Delta is the change in winter precipitation that might increase the dependency on irrigation of the many productive agricultural lands. In this context, Sayed and Di Baldassarre (under review) investigated the interdependence between the NAO and winter precipitation and temperature in the Nile Delta. The outcomes of the study showed the presence of a slightly significant correlation between the NAO, winter rainfall (Figure 2) and temperature.

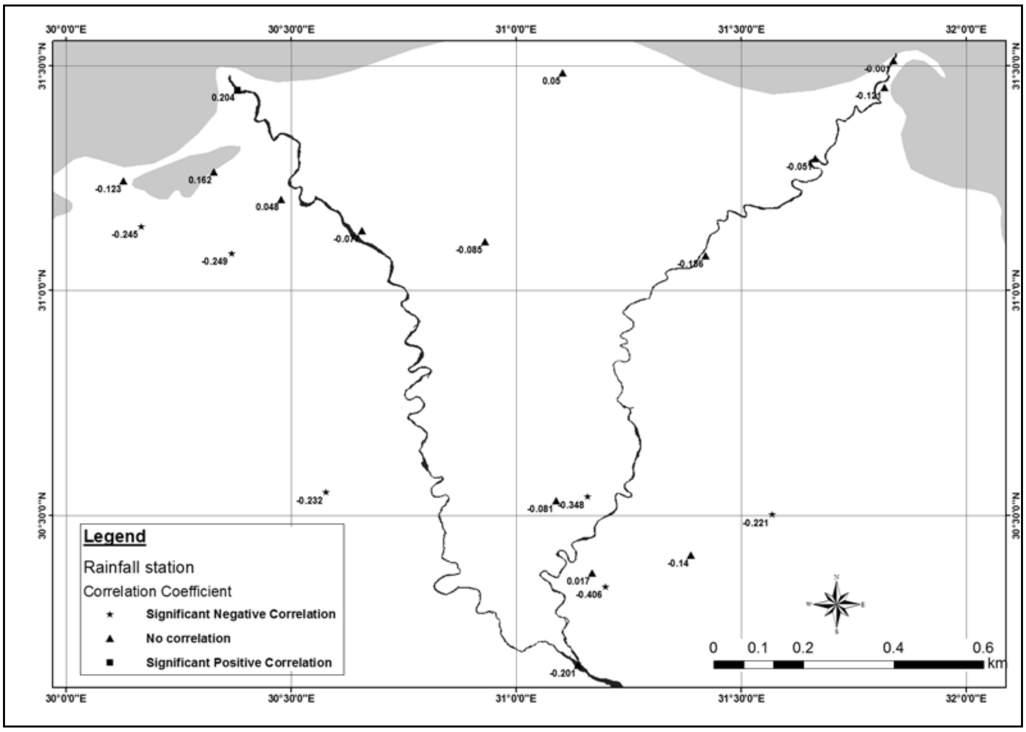

Figure 2. Correlation coefficients between NAO and winter precipitation (CRU data).

The Blue Nile is the most important sub-basins of the RNB in terms of water quantity; about 2/3 of the total Nile discharge originate from this sub-basin. One of the main concerns related to climate change is the highly sensitive response nature of this sub-basin to future climate change scenarios. Many authors investigated this non-linear behavior of Blue Nile flow (e.g. Conway and Hulme, 1993; Sayed, 2004; Elshamy et al, 2009) and it was found out that a 10% increase in rainfall over the upper Blue Nile sub-basin might cause increases of over 30% in flow, while a reduction of 10% in rainfall might result in reductions of outflows of the sub-basin by more than 20%. In particular, it was found that changes in precipitation produced larger changes in runoff than changes in potential evaporation while the runoff response was greater than the precipitation anomaly: a 10% increase in precipitation caused a 34% increase in runoff in the Blue Nile while a 4% decrease in potential evaporation causes an 8% increase in runoff (Sayed, 2004).

The second recognized concern over the Blue Nile is the significant uncertainty associated to the climate change projections and its impact on water availability (e.g. Soliman et al. 2008; Elshamy et al, 2009; Di Baldassarre et al., 2011: Moges et al., under review). Elshamy et al. (2009) indicated that there is no consensus among the GCMs on the direction of precipitation change for the upper Blue Nile basin. Changes in total annual precipitation range between -15% to +14%, but more models report reductions than those reporting increases. Several models report small changes within 5%. The ensemble mean of all models shows almost no change in the annual total rainfall and only a slight reduction in the wet season total. The numbers change only marginally if the two models with the greatest biases are excluded.

Furthermore, Soliman et al. (2008) investigated climate change effects on the Blue Nile catchment using the regional climate model RegCM3 to downscale the ECHAM5 General Circulation Model (Max Planck Institute, Hamburg) results. These studies demonstrate the large diversity in the use of IPCC scenarios, climate models and downscaling techniques (time series adjustments, statistical, and physically-based methods). These different techniques may lead to opposing trends and contradicting recommendations for policy makers (Di Baldassarre et al., 2011).

Recent uncertainty study by Moges et al. (under review) in five catchments of the Blue Nile based on RegCM3 regional climate model outputs showed divergent results and the level of uncertainty varies significantly from catchment to catchment. Figure 3 shows an example of this study, referring to one of the biggest catchments of Blue Nile basin, namely the Dedissa catchment.

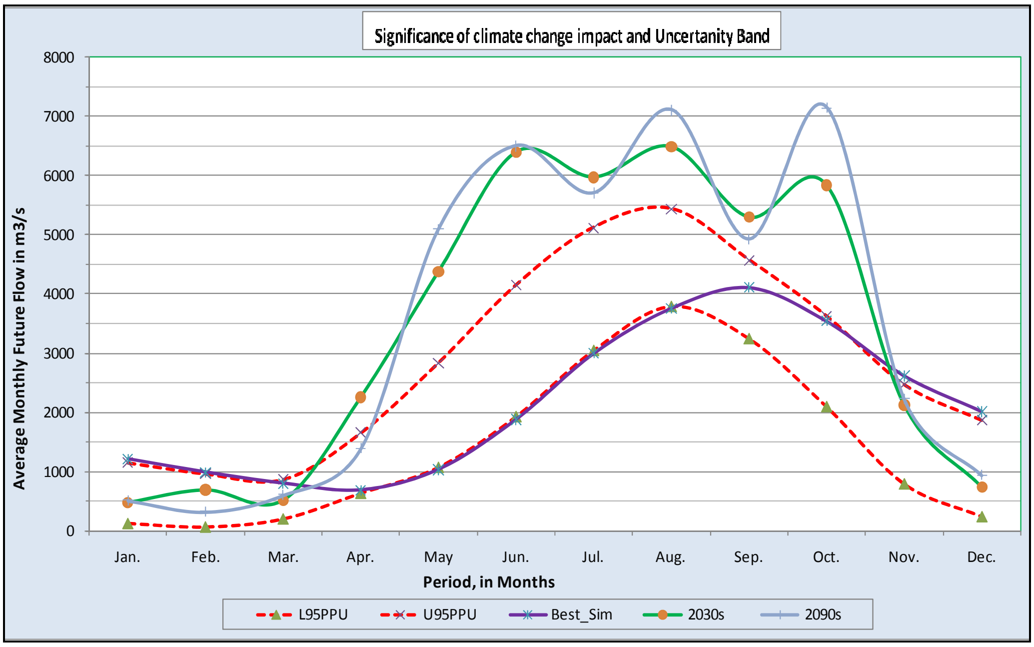

Figure 3: Impact of climate change on flow of Dedissa river under hydrological uncertainty (Moges et al., under review)

Given that the Blue Nile sub-basin is the largest flow contributor to the Nile, the high sensitivity of flow to slight changes in precipitation remains a concern for all Eastern Nile riparian countries.

3. CLIMATE CHANGE - UNCERTAINTY

It has been customary for water research communities to use climate model outputs as quantitative information for assessing climate change impacts on water resources management, flood risk management, and rain-fed agriculture, to name a few. However, caution is always needed in considering certain modelling aspects, such as: i) the choice of the particular model or set of global models to use; ii) domain configurations for regional models; iii) choosing appropriate model physics and parameterization especially those handling moisture convective processes related to reproducing observed climatology and inter-annual features of regional and local precipitation and evaporation fluxes. With respect to the coupling procedure with other models, it is sometimes necessary to choose plausible methods of statistical downscaling as well as finding a way of generating robust precipitation estimates from various models to be able to drive hydrological models at various scales, e.g., reproducing decadal and multi-decadal features as well as climate change projections. Recent studies that can help in addressing some of these modelling concerns include Kang and Hong (2008), Schoof et al. (2009), Mutemi et al. (2007), and Wilby et at. (2009).

As mentioned, analysis of climate change is complicated by the associated uncertainties, which are very significant (Koutsoyiannis et al., 2007). In fact, the entire modelling chain (climate modelling, spatial and temporal downscaling, hydrological modelling, and impact assessment) is affected by relevant uncertainty, which is important to take into account in decision making processes (e.g. Pappenberger et al., 2005).

Concerning the climate modelling, projections of future precipitation have been showed to be highly uncertain (e.g. Covey et al., 2003), with an increasing uncertainty as one goes down in scale and moves to more extreme events (Blöschl et al., 2007). In contrast, changes in temperatures projected by climate models are usually considered more reliable.

Kay et al. (2006) showed that the largest source of uncertainty is related to the structure of GCM models, as also pointed out by Elshamy et al. (2009b), followed by emission scenarios and hydrological modelling. Yet, it is worth noting that bias corrections, applicable for the known past, might fail for the unknown future as the behavior (in terms of the required corrections) might potentially be relatively different in the future. In addition, none of the discussed studies included the uncertainty of the hydrological models. Nevertheless, one should not underestimate the uncertainty of the models (e.g. Beven, 2006; Ndomba et al. 2008; Ndomba and Birhanu, 2008; Di Baldassarre et al., 2010) used to simulate the future hydrologic cycle. In fact, it is well known that hydrological models are difficult to calibrate and validate (e.g. Beven and Binley, 1992; Uhlenbrook et al., 1999; Di Baldassarre et al., 2009) and their prediction capability in a possibly warmer planet is impossible to evaluate, because of the lack of temporal and spatial data available to different climate conditions (Loaiciga et al., 1996).

It may be as well worth noting that the term of "projection" should be treated carefully in respect of its relation with other closely related terms such as prediction and forecast. This is especially important when communicating the GCM/RCM based climate change impact studies to stakeholders who may see the results as forecasts, but in fact they are derived from climate projections which are model simulation with certain predefined conditions (scenarios). These predefined (future) conditions are merely best estimates and far from accurate description as a real model can produce. Also in view of other sources of uncertainty, it is therefore necessary to pass the entire picture of uncertainty when applying the results form GCM-hydrological model chain to the field of building adaptation measures.

The ACCION research team performed a comprehensive review of several studies that were carried out to understand the possible impacts of climate change on the Nile system (Di Baldassarre et al., 2011). This review showed that a large number of studies have been carried out in the RNB using climatic model output as input of hydrologic models to project future hydrologic regimes. Much less systematic work has been done to estimate associated uncertainties (Koutsoyiannis et al., 2007). However, the acknowledgement of the uncertainties is fundamental to the decision making process (Elshamy et al., under review). Climate change projections based on a single simulation ignores the large uncertainties and will provide misleading information to decision makers or the public and may lead to wrong decisions. In this context, Elshamy et al. (under review) proposed a method to propagate and estimate the uncertainty of climate change impact studies (Figure 3) due to different climate models and emissions scenarios, within the GLUE framework (Beven and Binley, 1992). However, ensemble projections reflecting the uncertainties from scenarios, climate model, downscaling techniques and hydrological model tend to project nearly every potential change and consequently hamper fact-based decision support (Figure 3).

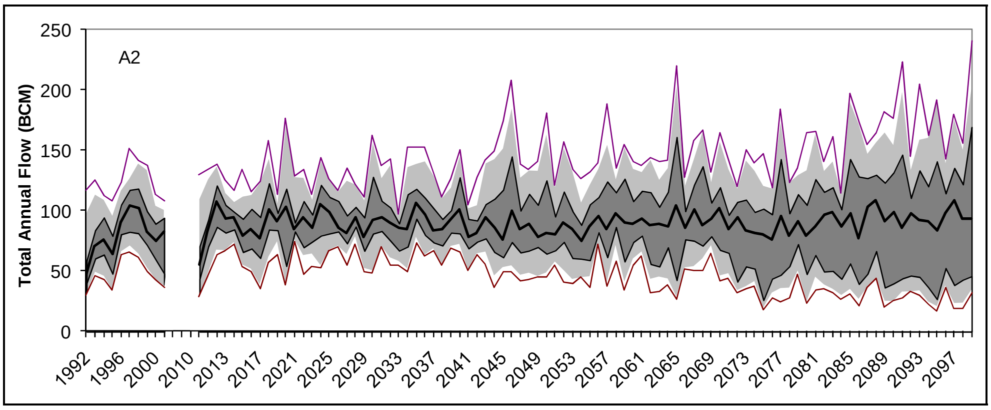

Figure 4. Nile at Dongola station: uncertainty bounds under A2 (for more details, see Elshamy et al., under review).

4. CLIMATE CHANGE - BEST PRACTICE

Di Baldassarre et al. (2011) pointed the need for best practices in climate change impact studies out, which go beyond the "IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations" (IPCC, 1994). According to Di Baldassarre et al. (2011), such a practice should include the following requirements: a) results should not be presented in a simplified way assuming a one-way cause-effect relationship, b) ensembles of several climate model projections should be used to reflect the large variability in climate model projections, c) the performance of the models applied to historical data should be provided, d) appropriate downscaling techniques should be used and the underlying assumptions should be reported, and e) appropriate uncertainty analysis techniques should be applied to the entire modelling chain.

Very recently, Blöschl and Montanari (2010) provided an inspiring idea that should be part of such a code of good practice: impact studies should not only present the assumptions, results and interpretation, but also provide a clear explanation of *why* certain changes are projected by the applied models. The idea is that one should not trust that the results are valid unless we understand why an impact study projects changes in a given hydrological variable.

Besides the large uncertainty, one of the lessons learned is that there is a wide recognition that other driving factors, such as population growth and consequent land-use changes and urbanization (e.g. Uhlenbrook, 2009) can play a more relevant role on the water resources of the RNB than climate change especially for short and medium planning horizons. Thus, when it comes to plan appropriate adaptation and mitigation measures, it is important to consider also non-climatic factors such as population growth, and changes in per capita and agricultural water demand (Conway et al., 1996; Vörösmarty et al., 2000). In fact, economically- and demographically-driven growth in demand generally leads to large changes in per capita water availability and often outweighs climatically-induced changes. For instance, fluctuations of the level of Lake Victoria in the Nile basin, such as the floods of 1997 and 1998 and the large decline in levels between 2005 and 2007, have impacted upon lake-shore communities in Kenya, Tanzania and Uganda (Conway et al., 2005; Pearce, 2006). Both climate variability and management of the lake outflow in Uganda for hydroelectric power are likely to have been responsible for the recent decline in lake levels (Pearce, 2006; Sutcliffe & Petersen, 2007). Moreover, Di Baldassarre et al. (2010) showed that the dramatic increase of flood fatalities in the African continent is mostly caused by the growth of urban population and, in particular, human settlements in flood prone areas.

Thus, given the deep uncertainties in climate projections and the fact that climate is often only one factor influencing adaptation decisions, an approach that avoids heavy reliance on climate projections and assesses the robustness of alternative adaptation decisions to a range of plausible futures is preferable (Dessai and Hulme, 2007; Goulden et al., 2009). Stakhiv (1998) recommends that a “no-regret” strategy could be provided by applying the adaptive management principle for water resource management.

5. ACKNOWLEDGMENTS

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